INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

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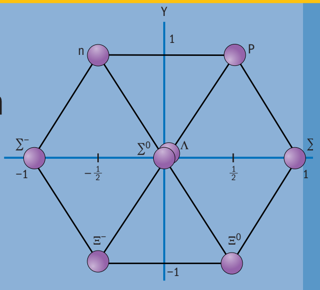

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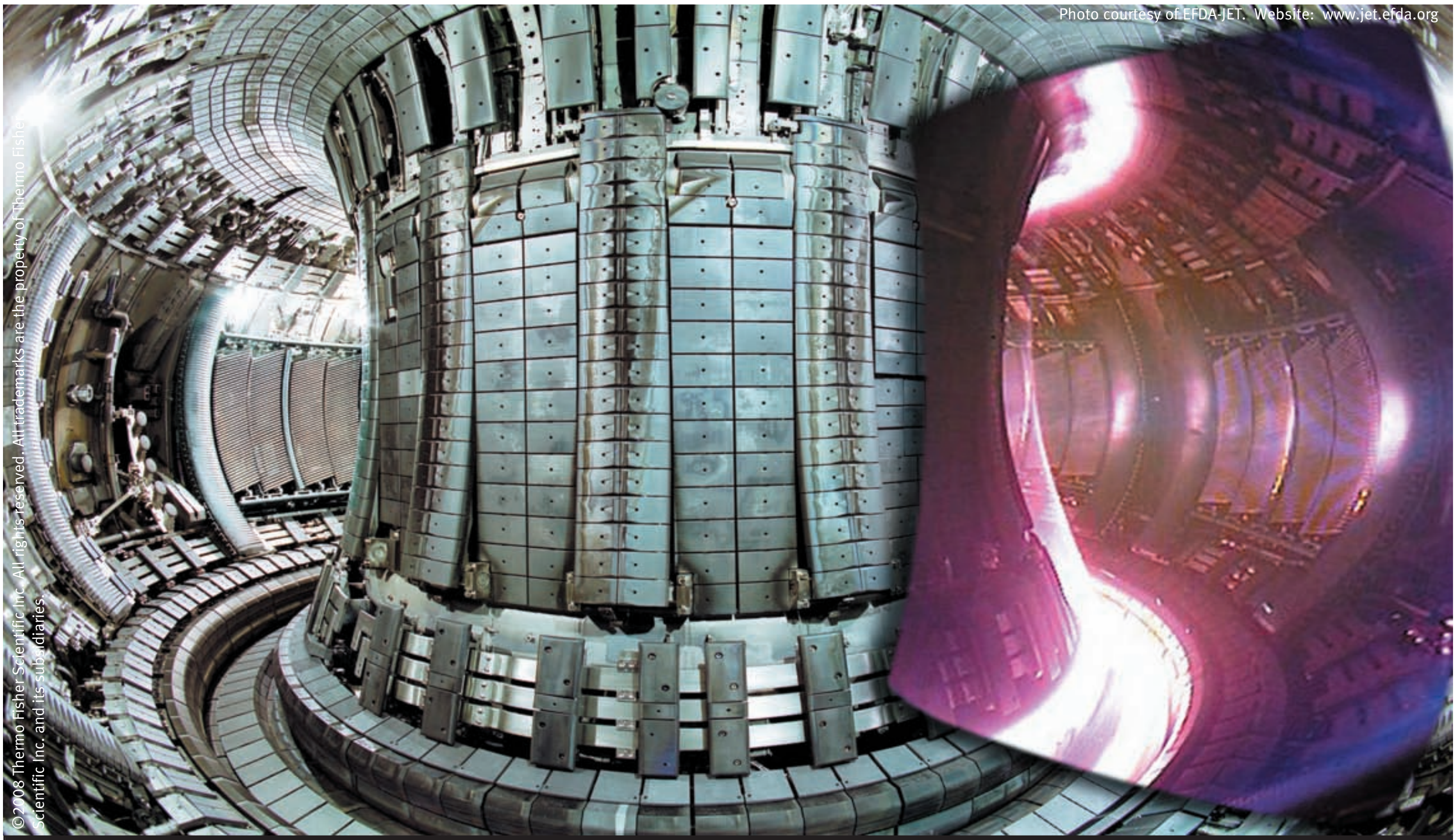

Photo courtesy of EFDA-JET. Website: www.jet.efda.org

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

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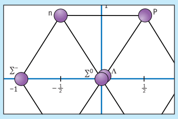

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On the cover: Stars rotate round the southern celestial pole during a night at ESO's La Silla Observatory in Chile. ESO's foundation saw many links with CERN, which went on to include work on the 3.6 m telescope, seen on the left, (p26). Now, the organization runs several world-leading facilities in Chile (p13 and p50). (Image credit: Iztok Bončina/ESO.)

STPiX455
Maglev Turbopump

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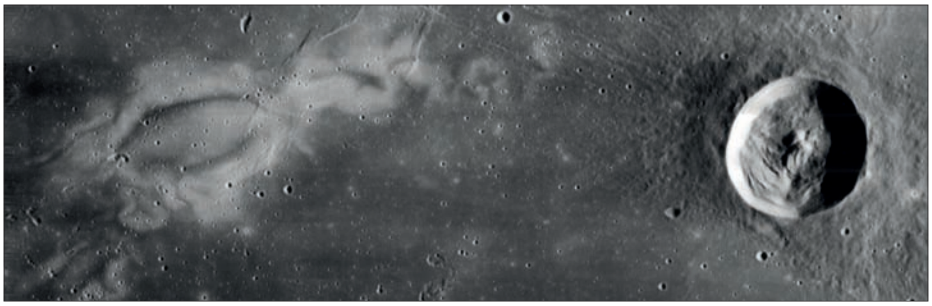
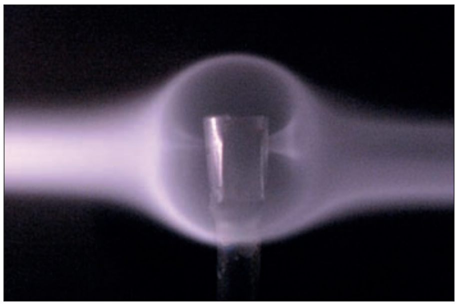
News

PLASMA PHYSICS

Deflector shields protect the lunar surface



The most striking "lunar swirl", left, known as Reiner Gamma, can be seen from the Earth using a good telescope. The swirl is some 100 km from the Reiner impact crater after which it is named. (Image credit: NASA.)



A "mini-magnetosphere" created in the laboratory. The glow is the stream of charged particles in the plasma wind tunnel. The experiment shows how a thin barrier is formed, creating a cavity in the "plasma wind" that in turn protects much of the surface of the target. (Image credit: Ruth Bamford.)

The origin of the enigmatic "lunar swirls" – patches of relatively pale lunar soil, some measuring several tens of kilometres across – has been an unresolved mystery since the mid-1960s, when NASA's *Lunar Orbiter* spacecraft mapped the surface of the Moon in preparation for the Apollo landings. Now, a team of physicists has used a combination of satellite data, plasma-physics theory and laboratory experiments to show how the features can arise when the hot plasma of the solar wind is deflected around "mini-magnetospheres" associated with magnetic anomalies at the surface of the Moon.

Initially thought to be smeared-out craters, close-range photographs from *Lunar Orbiter II* showed that at least one large swirl – named Reiner Gamma, after the nearby Reiner impact crater – could not be a crater. Studies from subsequent Apollo missions revealed that the swirls are associated with localized magnetic fields in the lunar crust. Because the Moon today has no overall magnetic field, these "magnetic anomalies" seem to be remnants of a field that has existed in the past.

In 1998–1999, the *Lunar Prospector* mission discovered that the magnetic anomalies create miniature magnetospheres above the Moon's surface, just as the Earth's planetary magnetic field does on a much larger scale when it deflects the charged particles of the solar wind around the planet. Could the mini-magnetospheres on the Moon, which are only a few hundred kilometres in size, somehow shield the crust from the solar wind and so prevent the surface from darkening as a result of constant bombardment by incoming particles?

One problem with this idea has been that the magnetic fields – in the order of nanotesla – seem to be too weak to affect the energetic particles of the solar wind on the scales observed. However, a team led by Ruth Bamford of the Rutherford Appleton Laboratory and York University has shown that it is the electric field associated with the shock formed when the solar wind interacts with the magnetic field that deflects the particles bombarding the Moon.

Data from various lunar-orbiting spacecraft suggested a picture in which the solar wind is deflected round a magnetic "bubble", creating the effect of a cavity within the plasma density that is enclosed by a "skin" that is only kilometres thick. This skin effectively reflects incoming protons, increasing their energy.

To explain these observations, Bamford and colleagues invoke a two-fluid model of the plasma, with unmagnetized ions and magnetized electrons. The electrons are slowed down and deflected by the magnetic barrier that forms when the magnetic field of the solar wind encounters the magnetic anomaly – but the much heavier ions do not respond so quickly. This leads to a separation in space-charge and hence an electric field.

The team confirmed the principle of their theoretical model by using a plasma wind tunnel with a supersonic stream of hydrogen plasma and the dipole field of a magnet. The experiment showed that the plasma particles were indeed "corralled" by a narrow electrostatic field to form a cavity in the plasma, so protecting areas of the surface towards which the particles were flowing. Translated to the more irregular magnetic fields on the lunar surface, with a range of overlapping cavities, this can provide the long-awaited explanation of the light and dark patterns – protected and unprotected regions, respectively – that make up the swirls.

● **Further reading**

Bamford *et al.* 2012 *Phys. Rev. Lett.* **109** 081101.

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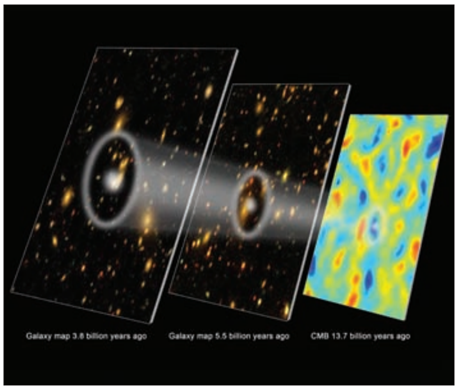
COSMOLOGY

Baryon oscillation spectra for all

By professional astronomy standards, the 2.5 m telescope at Apache Point Observatory is quite small. More than 50 research telescopes are larger and many are located at much better sites. Apache Point Observatory is also a little too close to city lights – the atmospheric turbulence that dominates the sharpness of focus is about two times worse than at the best sites on Earth – and summer monsoons shut down the observatory for two months each year.

Yet, the Sloan Digital Sky Survey (SDSS), using this telescope, has produced the most highly cited data set in the history of astronomy (Trimble and Ceja 2008; Madrid and Macchetto 2009). Its success is rooted in the combination of high-quality, multipurpose data and open access for everyone: SDSS has obtained 5-filter images of about a quarter of the sky, spectra of 2.4 million objects and has made them publicly available on a yearly basis, even as the survey continues.

SDSS-III launched its ninth data release (DR9) on 31 July. This is the first release to include data from the upgraded spectrographs of the Baryon Oscillation Spectroscopic Survey (BOSS) – the largest of the four subsurveys of SDSS-III. By measuring more distant galaxies, these spectra probe a larger volume of the universe than all previous surveys combined.



The record of baryon acoustic oscillations (white rings) in Galaxy maps. The BOSS measurements (centre) compared with the cosmic microwave background (right) and nearby Galaxy surveys (left) trace how the universe has expanded with time. (Image credit: E M Huff, the SDSS-III team and the South Pole Telescope team; graphic by Zosia Rostomian.)

BOSS has already published its flagship measurement of baryon acoustic oscillations (BAO) to constrain dark energy using these data (Anderson *et al.* 2012). BAO are the leftover imprint of primordial matter-density fluctuations that froze out as the universe expanded, leaving correlations in the distances between galaxies. The size scale of these correlations acts as a "standard ruler" to measure the expansion of the universe, complementing the "standard candles" of Type Ia supernovae that led to the discovery of the accelerating expansion of the universe.

Another major BOSS analysis using these data is still in progress. In principle, BAO can also be measured by using bright, distant quasars as backlights and measuring the "Lyman alpha forest" absorption in the spectra as intervening neutral hydrogen absorbs the quasars' light. The wavelength of the absorption traces the red shift of the hydrogen and the amount of absorption traces its density. Thus, this also measures the structure of matter – including BAO – but at much further distances than is possible with galaxies. BOSS has the first data set with enough quasars to make this measurement and the collaboration is nearing completion of this analysis. However, the final results are not yet published and now the data are public for anyone else to try this.

Are there any surprises in the results? Not yet. BOSS has the most accurate BAO measurements yet, with distances measured to 1.7%, but the results are consistent with the "ΛCDM" cosmological standard model, which includes a dark-energy cosmological constant (Λ) and cold dark matter (CDM). But DR9 contains only about a third of the full BOSS survey and BOSS has already finished observations for data release 10 (DR10), due to be released in July 2013. DR10 will also include the first data from APOGEE, another SDSS-III subsurvey that probes the dynamical structure and chemical history of the Milky Way.

● **Further reading**

Anderson *et al.* 2012, submitted to *MNRAS*, arXiv:1203.6594.
J P Madrid and D Macchetto 2009 arXiv:0901.4552v1.
V Trimble and J A Ceja 2008 *Astronomische Nachrichten* **329** 632.

CERN

Summer running at the LHC

The LHC has delivered more than twice as many collisions to the ATLAS and CMS experiments this year as it did in all of 2011. On 4 August, the integrated luminosity recorded by each of the experiments passed the 10 fb^{-1} mark. Last year, they each recorded data corresponding to around 5.6 fb^{-1}. On 22 August this year, the more specialized LHCb experiment passed 1.11 fb^{-1}, the same as its entire data sample for 2011.

The LHC's peak luminosity had been running 5–10% lower following June's technical stop. This was mainly owing to a slight degradation in beam quality from the injectors – an issue that was resolved at the beginning of August. The LHC had also been suffering from occasional beam instabilities, which have resulted in significant beam losses. A solution to this second problem lay in finding new optimum machine settings with the polarity of octupole magnets reversed relative to that of recent years. (The octupole magnets are used to correct beam instabilities.)

This reversal, accompanied by an adjustment of the settings in the sextupole magnets, was studied over several days in August. These changes paid off and the beams became more stable when brought into collision, so the bunch currents could be increased from 1.5×10^{11} to 1.6×10^{11} protons per bunch. With this increased bunch intensity, the peak luminosity in ATLAS and CMS reached more than 7.5×10^{33} $cm^{-2} s^{-1}$, compared with the maximum peak luminosity of 3.6×10^{33} $cm^{-2} s^{-1}$ in 2011.

In addition, successful commissioning of injection and RF-capture using new Super Proton Synchrotron optics (called Q20 optics) has opened the way for even higher bunch intensities. This new optics system has yet to be used operationally.

During the summer runs, the machine regularly enjoyed long fills in the 12- to 15-hour range. This showed the benefits of the extensive consolidation work to mitigate the effects of radiation to electronics in the LHC tunnel and the continuing efforts to improve overall reliability. The LHC is well on its way towards its goal of delivering in the order of 15 fb^{-1} in 2012. Indeed, at the beginning of September, CMS and ATLAS had already recorded more than 13 fb^{-1}.

LHC PHYSICS

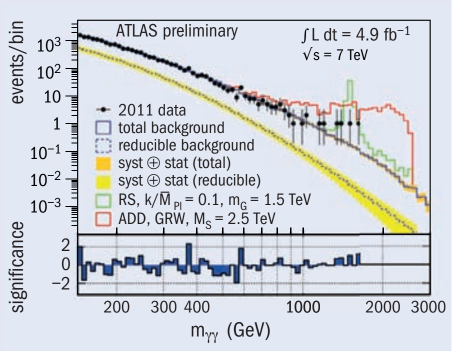
Illuminating extra dimensions with photons

Photons are a critical tool at the LHC, and the ATLAS detector has been carefully designed to measure photons precisely. In addition to playing a central role in the recent discovery of a new particle resembling the Higgs boson, final states with photons are used both to make sensitive tests of the Standard Model and to search for physics beyond it.

Recent results from the ATLAS experiment using the full 2011 data set are shining new light – in more than one sense – on theoretical models that propose the existence of extra dimensions. In these models, which were originally inspired by string theory, the extra dimensions are "compactified" – finite in extent, they are curled up on themselves and so small that they have not yet been observed. Such models could answer a major mystery in particle physics, namely the weakness of gravity as compared with the other forces. The basic idea is that gravity's influence could be diluted by the presence of the extra dimensions. Different variants of these models exist, with corresponding differences in how they could be detected experimentally.

Events with two energetic photons provide a good place to search. In the Randall-Sundrum (RS) models of extra dimensions, a new heavy particle could decay to a pair of photons. A plot of the diphoton mass should then reveal a narrow peak above the smooth background expected from Standard Model backgrounds. In Arkani-Hamed-Dimopoulos-Dvali (ADD) models, on the other hand, the influence of extra dimensions should lead to a broad excess of events with large diphoton masses.

The figure shows the diphoton mass spectrum measured by ATLAS. The Standard Model background expectation has been superimposed, as have contributions expected for examples of RS or ADD signals. The data agree well with the background expectation and provide stringent constraints on the extra-dimension models. For instance, the mass of the RS graviton must be larger than 1–2 TeV, depending on the strength of the graviton's couplings to Standard Model particles.



The diphoton mass distribution, compared with the sum of all expected Standard Model backgrounds, with examples of RS and ADD signals overlaid. The lower part demonstrates the good agreement between the data and the background expectation.

ADD models can also be probed via the single-photon final state. The ATLAS collaboration has searched for single photons accompanied by a large apparent imbalance in the energy measured in the event, which would result from a particle escaping into the extra dimensions and taking its energy with it. The ATLAS analysis found a total number of such events in agreement with the expectation for the small Standard Model backgrounds. The final result, therefore, was used to establish new constraints on the fundamental scale parameter M_D of the so-called ADD Large Extra Dimension (LED) model. The lower limits set on the scale, which improve on previous limits, lie in the range 1.74–1.87 TeV, depending upon the number of extra dimensions.

As expected, photons are proving to be an extremely useful probe for new physics at the LHC, providing important tests of many models. With the higher LHC energy in 2012 and the larger data set being accumulated, photon analyses will continue to provide an ever greater potential for discovery.

● Further reading

ATLAS collaboration 2012, ATLAS-CONF-2012-087.

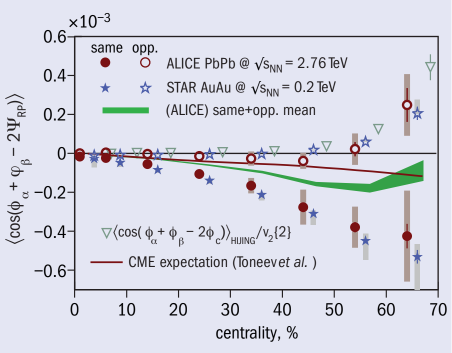
ATLAS collaboration 2012, ATLAS-CONF-2012-085.

Can heavy-ion collisions cast light on strong CP?

The symmetries of parity (P) and its combination with charge conjugation (C) are known to be broken in the weak interaction. However, in the strong interaction the P and CP invariances are respected – although QCD provides no reason for their conservation. This is the "strong CP problem", one of the remaining puzzles of the Standard Model.

The possibility of observing parity violation in the hot and dense hadronic matter formed in relativistic heavy-ion collisions has been discussed for many years. Various theoretical approaches suggest that in the vicinity of the deconfinement phase transition, the QCD vacuum could create domains – local in space and time – that could lead to CP-violating effects. These could manifest themselves via a separation of charge along the direction of the system's angular momentum – or, equivalently, along the direction of the strong, approximately 10^{14} T, magnetic field that is created in non-central heavy-ion collisions and perpendicular to the reaction plane (i.e. the plane of symmetry of a collision, defined by the impact-parameter vector and the beam direction). This phenomenon is called the chiral magnetic effect (CME). Fluctuations in the sign of the topological charge of these domains cause the resulting charge separation to be zero when averaged over many events. This makes the observation of the CME possible only via P-even observables, expressed in terms of two- and multi-particle correlations.

The ALICE collaboration has studied the charge-dependent azimuthal particle correlations at mid-rapidity in lead–lead collisions at the centre-of-mass energy per nucleon pair, $\sqrt{s_{NN}} = 2.76$ TeV. The analysis was performed over the entire event sample recorded with a minimum-bias trigger in 2010 (about 13 million events). A multi-particle correlator was used to probe the magnitude of the potential signal while at the same time suppressing any background correlations unrelated to the reaction plane. This correlator has the form $\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle$, where ϕ is the azimuthal angle of the particles and the subscript indicates the charge or the particle type. The orientation of the reaction plane angle is represented by Ψ_{RP}; it is not known experimentally but is instead estimated by constructing the event plane using azimuthal particle distributions.



The centrality dependence of the correlator $\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle$ measured by ALICE and compared with model calculations (CME) and results from the STAR experiment at RHIC. A more detailed description is given in the text.

The figure shows the correlator as a function of the collision centrality compared with model calculations, together with results from the Relativistic Heavy-Ion Collider (RHIC). The points from ALICE, shown as full and open red markers for pairs with the same and opposite charge, respectively, indicate a significant difference not only in the magnitude but also in the sign of the correlations for different charge combinations, which is consistent with the qualitative expectations for the CME. The effect becomes more pronounced moving from central to peripheral collisions, i.e. moving from left to right along the x-axis. The previous measurement of charge separation by the STAR collaboration at RHIC in gold–gold collisions at $\sqrt{s_{NN}} = 0.2$ TeV, also shown in the figure (blue stars), is in both qualitative and quantitative agreement with the measurement at the LHC.

The thick solid line in the figure shows a prediction for the same-sign correlations caused by the CME at LHC energies, based on a model that makes certain assumptions about the duration and time-evolution of the magnetic field. This model underestimates the observed magnitude of the same-sign correlations seen at the LHC. However, parallel calculations based on arguments related to the initial time at which the magnetic field develops, as well as the same value of the magnetic flux for both energies, suggest that the CME might have the same magnitude at the energies of both colliders. Conventional event-generators, such as HIJING, which do not include P-violating effects, do not exhibit any significant difference between correlations of pairs with the same and opposite charge (green triangles). They were averaged in the figure.

An alternative explanation to the CME assumption was recently provided by a hydrodynamical calculation, suggesting that the correlator being studied may have a negative (i.e. out-of-plane), charge-independent, dipole-flow contribution that originates from fluctuations in the initial conditions of a heavy-ion collision. This could lead to a shift of the baseline, which when coupled to the well known effect in which the local charge conservation induced in a medium exhibits strong azimuthal (i.e. elliptic) modulations, could potentially give a quantitative description of the centrality-dependence observed by both ALICE and STAR. The results from ALICE for the charge-independent correlations are indicated by the blue band in the figure.

The measurements are supplemented by a differential analysis and will be extended with a study of higher harmonics, which will also investigate the correlations of identified particles. These studies are expected to shed light on one of the remaining fundamental questions of the Standard Model.

● Further reading

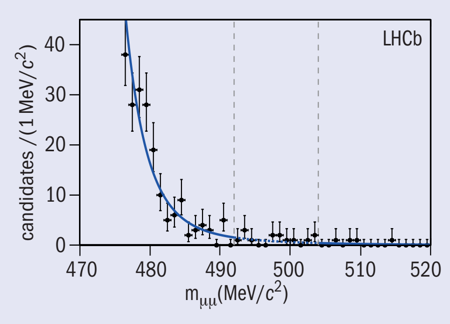
B I Abelev *et al.* ALICE collaboration 2012 arXiv: 1207.0900 [nucl-ex], submitted to *Phys. Rev. Lett.*, P Christakoglou (for the ALICE collaboration) 2011 *J. Phys. G* **G38** 124165.

Searching for new physics in rare kaon-decays

The LHCb experiment was originally conceived of to study particles containing the beauty-flavoured b quark. However, there are many other possibilities for interesting measurements that exploit the unique forward acceptance of the detector. For example, the physics programme has already been extended to include the study of particles containing charm quarks, as well as electroweak physics (*CERN Courier* January/February 2012 p7 and April 2012 p34). Now, a new result from LHCb on a search for a rare kaon-decay has further increased the breadth of the experiment's physics goals.

This search is for the decay $K^0_S \to \mu^+\mu^-$, which is predicted to be greatly suppressed in the Standard Model. The branching ratio is expected to be 5×10^{-12}, while the current experimental upper limit (dating from 1973) is 3.2×10^{-7} at 90% confidence level (CL). Although the dimuon decay of the K^0_L has been observed, with a branching fraction of the order of 10^{-8}, searches for the counterpart decay of the K^0_S meson are well motivated because such decays can be mediated in independent ways to the K^0_L decay.

The analysis is based on the 1.0 fb^{-1} of data collected by LHCb in 2011. To suppress the background most efficiently, it involves several techniques that were originally developed for the search for $B^0_S \to \mu^+\mu^-$, for which LHCb has set the best limit in the world. The analysis also benefits from knowledge of K^0_S production and reconstruction that has been developed in several previous measurements (including LHCb's first published paper, on the production of K^0_S mesons in 900 GeV proton–proton collisions).



Invariant mass distribution of selected $\mu^+\mu^-$ pairs, for the case where the muons were responsible for triggering the experiment. The dashed lines indicate the signal region for the K^0_S, where no significant signal is seen.

To extract an upper limit on the branching fraction, the yield is normalized relative to that in the copious $K^0_S \to \pi^+\pi^-$ decay mode. The 90% CL upper limit on the branching ratio $B(K^0_S \to \mu^+\mu^-)$ is determined to be less than 9×10^{-9}, a factor of 30 improvement over the previous most restrictive limit. As the figure shows, no significant evidence of the decay is seen.

Although the new limit is still three orders of magnitude above the Standard Model prediction, it starts to approach the level where new physics effects might begin to appear. Moreover, the data collected by LHCb in 2012 already exceed the sample from 2011 and by the end of the year the total data set should have more than trebled. The collaboration is continuing to search for ways to broaden its physics reach further to make the best use of this unprecedented amount of data and to tune the trigger algorithms for future data-taking and for the LHCb upgrade.

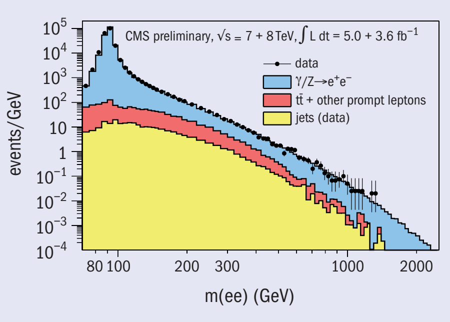
Further reading

LHCb-PAPER-2012–023, submitted to *JHEP*.

The search for 'big news' continues

The big news this summer was on the new Higgs-like boson and how the hint of an excess in last year's 7 TeV data from the LHC became an observation with this year's 8 TeV data. Yet there were many other search results, first presented at the International Conference on High-Energy Physics (ICHEP) in Melbourne (*CERN Courier* September 2012 p53), which benefited greatly from the new higher-energy data. The search for hypothetical heavy partners of the Standard Model W and Z bosons – the W' and Z' – were the CMS collaboration's priorities for analysis with the 8 TeV data, both because the 7 TeV data included a hint of a high-mass excess and because the 8 TeV data provide a large boost in sensitivity at high mass. Searches for other heavy particles, such as the supersymmetric partners of the gluon and quarks (the gluino and squarks) were similarly priorities that benefited from the increased LHC energy.

Building on last year's interesting results, the collaboration searched for narrow high-mass Z' resonances decaying to pairs of electrons or muons in the 8 TeV data collected between April and June this year.



The dielectron mass spectrum in 2011 and 2012 data samples amounting to an integrated luminosity of 8.6 fb^{-1}, together with the expectation from Standard Model backgrounds.

At the same time, a search was conducted for a W', which should decay to a neutrino and a single lepton (electron or muon). Because the Z' and W' can be massive, the searches require the identification of highly energetic leptons and a detailed understanding of their behaviour in the detector. The figure shows the spectra for the decay of the Z' to electron pairs, for the 7 TeV and 8 TeV data combined. It illustrates the importance of understanding the high masses – just a few events appearing there may indicate a discovery.

The search for supersymmetric particles also relies on the production of a few events with massive particles, e.g. gluinos or squarks. These typically undergo cascading decays culminating in multi-jet final states with apparent momentum nonconservation in the detector, owing to the production of two neutral, weakly interacting particles at the end of the cascades that escape detection. (These particles would serve as excellent dark-matter candidates). Decays involving multiple b quarks, photons or same-sign dileptons were all priority search modes with the 8 TeV data. Each benefited from last year's methods to measure backgrounds from control samples in the data. They also benefited from the rarity of Standard Model processes with such high-mass and complex final states. One particularly interesting background that affects the same-sign dilepton search is the production of a W or Z boson in association with top quarks, which leads to spectacular final states. A first measurement of these processes – obtained with the 8 TeV data – was also presented at ICHEP.

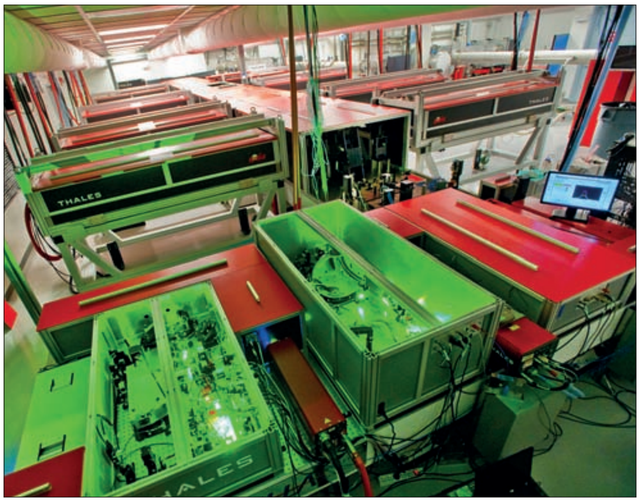
These high-mass searches have found the data to be consistent with Standard Model processes and have significantly improved limits on the range of possible masses for these hypothetical particles. The W' and Z' searches set 95% CL limits at 2.85 TeV and 2.59 TeV, respectively, and the gluino/squark searches excluded their masses up to 1.0 TeV. These results correspond to large increases in sensitivity, thanks to the LHC's energy increase and improved analysis of the new data. At CMS, the search for more "big news" continues.

Further reading

Z': CMS-PAS-EXO-12-015.
W': CMS-PAS-EXO-12-010.
SUSY searches: CMS-PAS-SUS-12-016; CMS-PAS-SUS-12-017; CMS-PAS-SUS-12-018.
ttW and ttZ: CMS-PAS-TOP-12-014.

BERKELEY

BELLA laser achieves 1 PW at 1 pulse a second



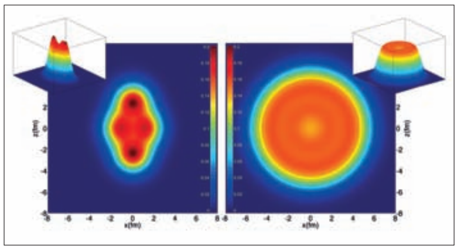
The BELLA laser during construction. After initial amplification in the front end (foreground), laser pulses for BELLA are amplified by titanium sapphire crystals boosted by 12 pump lasers on either side of the long central chamber. The pulses are then compressed before being directed to BELLA's electron-beam accelerator. (Image credit: Roy Kaltschmidt/LBNL.)

The laser system of the Berkeley Lab Laser Accelerator (BELLA) has achieved a world record for laser performance by delivering 1 PW of power in a 1 Hz pulse only 40 fs long. No other laser system has achieved this peak power at such a rapid pulse rate. Although the laser's average power is only 42.4 W, it achieves the enormous peak power in part through compression into an extremely short pulse. This laser system will drive the acceleration of electron beams in a metre-long plasma channel, with the aim of reaching 10 GeV for the first time with a laser-driven plasma accelerator.

BELLA, conceived of in 2006 by Wim Leemans, head of the Lasers and Optical Accelerator Systems Integrated Studies programme (LOASIS), is nearing completion at the Lawrence Berkeley National Laboratory (LBNL). The facility builds on previous experiments on laser-driven plasma acceleration by the LOASIS programme (*CERN Courier* January/February 2010 p8). It promises to pave the way for developing compact particle accelerators for high-energy physics, as well as table-top free-electron lasers for investigating materials and biological systems. Experiments to demonstrate the production of 10-GeV electron beams are now beginning.

NUCLEAR PHYSICS

The atomic nucleus: fissile liquid or molecule of life?



Probability density for the presence of neutrons and protons predicted for the nuclei of ^{20}Ne (left) and ^{120}Sn using the density-functional theory. ^{20}Ne is not homogeneous: the neutrons and protons are distributed in clusters, whereas ^{120}Sn displays a homogenous quantum liquid density.

The atomic nucleus is generally described as a drop of quantum liquid. In particular, such liquid-like behaviour explains nuclear fission and applies especially to heavy nuclei such as uranium. The so-called liquid drop mass formula is a typical textbook model in nuclear physics. On the other hand, light nuclei can behave like tiny molecules – or clusters – made up of neutrons and protons within the nucleus. This molecular aspect at the femtometre scale makes it possible to understand the stellar nucleosynthesis of ^{12}C and consequently of heavier elements such as oxygen.

So far, both the "molecular nucleus" and the "liquid nucleus" views have co-existed. Now, a team from the Institut de Physique Nucléaire d'Orsay (Université Paris-Sud/CNRS) and the French Atomic Energy Commission (CEA), in collaboration with the University of Zagreb, has proposed a unified view of these two aspects. By using relativistic-energy density functionals, the researchers have demonstrated that, although a light nucleus can show molecule-like behaviour (tending towards the crystalline state), heavier nuclei take on a more liquid-like behaviour.

The team took inspiration from neutron stars – remnants of core-collapse supernovae that are composed mainly of neutrons with a few protons. Inside the crust of neutron star, matter passes from being a nucleonic crystalline medium to becoming a nuclear-liquid medium. Thanks to this analogy, the team identified a mechanism of transition from the liquid to the crystalline state in the nucleus.

When the interactions between neutrons and protons – through the depth of the confining nuclear potential – are not strong enough to fix them within the nucleus, the latter is in a quantum-liquid-like state where protons and neutrons are delocalized. Conversely, in a crystalline state, neutrons and protons would be fixed at regular intervals within the nucleus. The nuclear molecule is interpreted as being an intermediate state between a quantum liquid and a crystal. In the long term, the aim is to attain a unified understanding of these various states of the nucleus.

- **Further reading**

J-P Ebran, E Khan, T Nikšić and D Vretenar 2012 *Nature* **487** 341.

***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

Masers come in from the cold

Solid-state masers, the analogues of lasers but working with microwaves instead of light, have been limited in their applications owing to their need for cooling and strong magnetic fields. This is set to change with work by Max Oxborrow of the UK's National Physical Laboratory and colleagues, who have built the first maser that works at room temperature. Operating at around 1.45 GHz, it uses a molecular crystal, p-terphenyl, doped with pentacene.

The pentacene is photoexcited by yellow light; exploiting a spin-selective molecular intersystem-crossing into a triplet state, it then decays via microwave emission. Operating in air and in the normal terrestrial magnetic field, in oscillator mode the maser puts out about 100 million times the power of an atomic hydrogen maser, at a similar frequency. As an amplifier, the new maser can provide gain with a noise-temperature far below room temperature. So far, the device runs only in pulsed mode but it nevertheless represents an amazing breakthrough.


This maser core was developed at the National Physical Laboratory in the UK. (Image credit: Andrew Brookes/NPL.)

● Further reading
M Oxborrow *et al.* 2012 *Nature* **488** 353.

One photon at a time

Photons, as all particle physicists know, can interact with each other via charged particles so that some nonlinearity appears that is not present for the free electromagnetic field. This nonlinearity can be increased in the presence of condensed matter but is usually extremely small at intensities corresponding to one or two photons. Now, Thibault Peyronel of Massachusetts Institute of Technology and colleagues have demonstrated a medium that is so nonlinear that while individual photons can pass through, pairs are strongly absorbed.

The idea is to couple slowly-propagating photons coherently to strongly interacting Rydberg states in a cold, dense atomic gas of rubidium atoms. In addition to being essentially an optical switch controlled by a single photon, the device also constitutes a single-photon source that can operate in the megahertz range. It could lead to high quantum-efficiency photodetectors and quantum-switching devices for quantum computing and communications.

● Further reading
T Peyronel *et al.* 2012 *Nature* **488** 57.

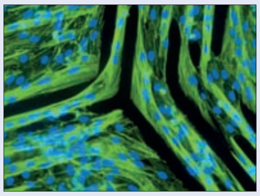
Fractal archeology

Fractal geometry has found a new application, namely figuring out where ancient civilizations built structures that have since disappeared from sight. Arne Ramisch of the Freie Universität in Berlin and colleagues noted that rivers carve out fractal patterns in landscapes and, by using computers, they found an area some 6 km^2 near the Dahshur royal necropolis in Egypt where the fractal pattern had broken down. This was enough to suggest that extensive human activity had taken place there, even though the signs are difficult to see with the untrained eye. Their work suggests a general approach to finding sites of archeological interest that can be used even when the elements have worn away obviously visible structures.

● Further reading
A Ramisch *et al.* 2012 *Quaternary Internat.* **266** 34.

Building a jellyfish

The fictional Dr Frankenstein tried to create a living human from bits and pieces. While that seems to be a far-off prospect in real life, Kevin Kit Parker of Harvard University, John Dabiri of Caltech and colleagues have done something similar at the level of jellyfish.


Close-up of engineered cardiac muscle used to power the tissue-engineered jellyfish. (Image credit: Janna Nawroth /Caltech.)

After characterizing the muscular structure of jellyfish, which make quick contractions and slow recoils to feed and move, the researchers made a mould to represent it. Seeding the mould with heart cells from a rat and coating it with a silicone polymer, they could the peel off a part silicone, part rat heart "medusoid" that, when placed in water through which a current was pulsed, swims like a real jellyfish. Their work opens the door to all sorts of synthetic muscular pumps and "organisms" that could be used to test drugs or even perform robotic tasks.

● Further reading
J C Nawroth *et al.* 2012 *Nature Biotech.* **30** 792.

The origin of Indo-European languages

Of all of the world's families of languages, Indo-European is the most global. It comprises more than 400 languages as diverse as English, French, Persian and Hindi, which together are spoken by about 3 billion people. Its origin, however, has remained obscure. Enter Quentin Atkinson of the University of Auckland and colleagues, who decided to apply to languages models originally designed to trace the genetic origins of pathogens. In effect, the idea is that languages might evolve over time in a similar way to the evolution of species.

The results come out clearly in favour of an origin with neolithic farmers in Anatolia (mainly in what is now Turkey) and against the other popular hypothesis that the Indo-European languages came from Bronze Age horse-masters from the Eurasian steppes. Not everyone agrees with the conclusions yet, but it demonstrates a fascinating extension of concepts from biology to linguistics.

● Further reading
R Bouckaert *et al.* 2012 *Science* **337** 957.

Astrowatch

COMPILED BY MARC TÜRLER, ISDC AND OBSERVATORY OF THE UNIVERSITY OF GENEVA

ALMA tastes sugar around a Sun-like star

A team of astronomers using the Atacama Large Millimetre/submillimetre Array (ALMA) has identified sugar molecules in the gas surrounding a young Sun-like star. This is the first time that sugar has been found in space around such a star and the discovery suggests that the building blocks of life are available when planets form.

A long list of molecules has already been detected in the interstellar medium. They range from simple diatomic compounds such as O_2 or CO to complex molecules, including alcohol or even fullerenes (C_{60} or "buckyballs"). The simple form of sugar found by ALMA is glycolaldehyde, $H_2COHCHO$, a molecule that was first detected in 2000 in a big molecular cloud, Sagittarius B2, near the centre of the Galaxy. It has now been detected in a planet-forming disc around IRAS 16293-2422, a young binary star of about the same mass as the Sun. The star is located some 400 light-years away in the relatively nearby Rho Ophiuchi star-forming region.

Finding molecules in space requires an extremely precise spectrometer in the microwave range of the electromagnetic spectrum. The vibration and rotation of a molecule is quantized and so can take only certain fixed values. As in atomic de-excitation, the transition from one vibrational or rotational level to another with less energy results in the emission of a photon of the corresponding energy. This leads to an excess of photons at given energies resulting in characteristic emission-lines in the spectrum of a source.

This picture of the ALMA antennae on the Chajnantor Plateau, 5000 m above sea level, was taken a few days before the start of ALMA Early Science. (Image credit: ALMA (ESO/NAOJ/NRAO)/W Garnier (ALMA).)

The ALMA observatory – which saw "first light" a year ago – offers the high sensitivity and spectral resolution needed for such studies (*CERN Courier* November 2011 p13). The project is a partnership between Europe, North America and East Asia in co-operation with the Republic of Chile. Led by the European Southern Observatory (ESO) on behalf of Europe, it is the largest astronomical project in existence. When completed in 2013, ALMA will be a giant array of 66 antennae that can be moved in different configurations with a maximum extension of 16 km. Located in the harsh environment of the Chajnantor plateau in northern Chile, at 5000 m above sea level, it benefits from a dry and thin high-altitude atmosphere.

The emission lines corresponding to glycolaldehyde were discovered by a team of astronomers led by Jes Jørgensen of the Niels Bohr Institute, University of Copenhagen. The importance of the discovery lies in glycolaldehyde being one of the ingredients in the formation of ribonucleic acid (RNA) – a macromolecule similar to DNA – which is essential for life on Earth. Finding such complex molecules around a star at distances similar to the distance between Uranus and the Sun means that the building blocks of life exist around new-born stars at the time of planet formation.

There are two open issues linked to the finding. First, how do these complex molecules form? Second, can they survive planet formation? Random interactions of atoms floating in space would not be sufficient to explain the amount and complexity of molecules that have been found there. Dust grains are thought to be a favoured place where atoms could be ionized by cosmic rays and then combined with nearby atoms or molecules by electrostatic attraction. If these space-born molecules are to be considered as the seeds for life, then a means of protecting them from excessive heat and the ionizing ultraviolet radiation from the star during the chaotic process of planet formation needs to be understood. What is much more certain, is that ALMA is keeping its promises and will bring new clues to the origin of life on Earth and possibly elsewhere.

● Further reading

J K Jørgensen *et al.* 2012 *ApJL* in press; arXiv:1208.5498 [astro-ph.SR].

Picture of the month

This postcard from Mars attests that NASA's *Curiosity* rover landed safely on the "Red Planet" and is ready to start scientific exploration. Launched on 26 November 2011, *Curiosity* landed on 6 August 2012, in the Gale crater near Mount Sharp. The rover has the task of searching for signs of martian life or at least of favourable conditions for the development of life in the past. *Curiosity* is equipped with hi-tech instruments to surpass the capabilities of *Spirit* and *Opportunity*, two smaller rovers that have been exploring Mars since January 2004. Despite being better equipped, it might be difficult for *Curiosity* to surpass the longevity of *Opportunity*, which is still in operation. This colour-enhanced image shows the base of Mount Sharp, which is the rover's eventual science destination. The triangular mound in the centre of the image is about 100 m high. (Image credit: NASA/JPL-Caltech/MSSS.)

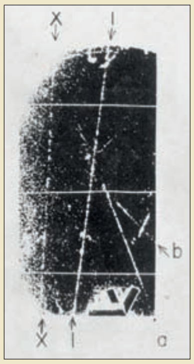
CERN Courier Archive: 1969

A look back to CERN Courier vol. 8, October 1969, compiled by Peggie Rimmer

AROUND THE LABS

Quark candidates in Sydney

A report, by a team from the Cornell-Sydney University Astronomy Centre, Australia, on a high-energy cosmic-ray search which seems to have evidence for quarks, appeared in *Physical Review Letters* on 22 September. A preliminary announcement was made at the 11th International Conference on Cosmic Ray Physics in Budapest, 25 August to 4 September, and on 8 September L S Peak, who participated in the experiment with L Cairns, R L S Woolcott and team leader C B A McCusker, spoke at CERN about their intriguing findings.



A photograph of a "quark candidate" in high-energy cosmic-ray showers, taken in a Wilson cloud chamber by the University of Sydney team. The track (X–X) contains fewer droplets than its neighbours, suggesting the passage of a particle producing lower ionization.

The postulate that the many strongly interacting particles are built from quarks, coming together in different ways, has been the most successful of the theoretical models which attempt to explain observations. However, all previous searches, both at particle accelerators and in low-energy cosmic rays, have failed to reveal a quark as a physical object. This does not necessarily mean that quarks do not exist – their mass may be too high for them to be produced at existing accelerator energies. They may, however, occur in much higher-energy cosmic rays.

One of their unusual properties would be that they would carry a charge of 1/3 or 2/3 the unit charge of the electron. Once above a certain energy, the ionization that a particle produces as it passes through matter is proportional to the square of its charge, independent of its mass. This provides a rather clean handle to get hold of the quark.

Beginning in July 1968, the Sydney team looked at cosmic-ray air-shower cores with a detector consisting of lead-shielded scintillation counters triggering four Wilson cloud chambers at an energy above 10^{15} eV [10^3 TeV]. In a little over a year they recorded about 60,000 high-energy particle tracks and found five with ionization about half that of a normal particle.

Other possible sources of low ionization – such as a statistical fluctuation in ion production, the Chudakoff effect, poor illumination, clearing field present – have been eliminated, leaving the most likely source as the passage of particles carrying less than unit charge, possibly quarks of charge 2/3.

The results have been greeted with guarded optimism. The Sydney group, obviously keen to provide more evidence, is constructing a larger detection system with high-pressure cloud chambers and streamer chambers, both sensitive to particle charge.

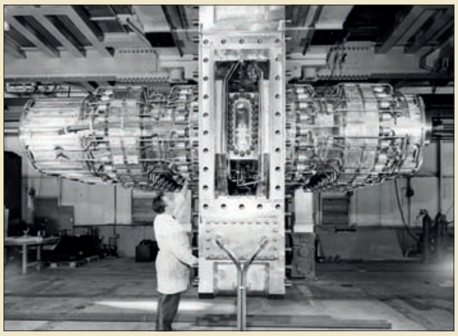
● Compiled from texts on pp307–308.

CERN NEWS

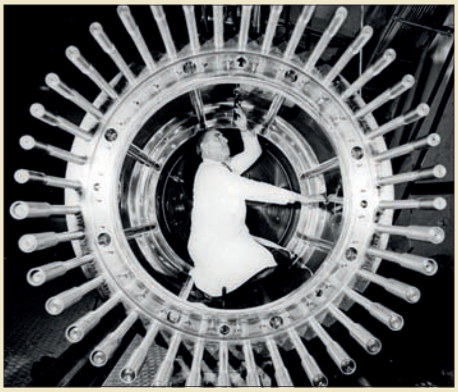
PS shutdown: the bubble chambers

The annual shutdown of the PS, 13 October until 26 November, allows work on the three bubble chambers in service at CERN. The 2 m hydrogen chamber has taken more than 3.8 million photographs between November 1968 and October 1969. On 6 September it reached the total of 10 million photographs since it came into operation less than five years ago. The 81 cm hydrogen chamber took 1.9 million photographs in the same period, bringing its total close to 13 million since 1961. The 1.2 m propane chamber had taken 1.6 million, bringing its total to 7.5 million since 1960.

● Compiled from texts on pp301–304.

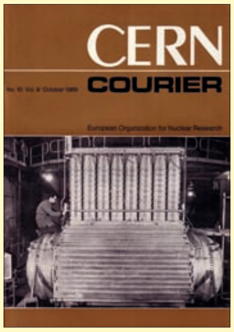


The 2 m hydrogen bubble chamber is undergoing modifications during the annual PS shutdown. For this, the two halves of the magnet, which normally hide the chamber, safety tanks, cooling pipes etc, are rolled back.



An unusual view into the 1.2 m heavy-liquid bubble chamber, which is also having a wash and brush up while out of action during the PS shutdown.

Compiler's Note



CERN
COURIER

In the 1960s, bubble chambers were in their heyday at labs such as CERN, although cloud chambers still found some use. The quarks that were 'discovered' in the device in Sydney were soon being 'undiscovered', as *CERN Courier* reported in January 1970. Other groups should have seen similar events but did not. The events in Sydney were probably low-energy muons or tracks through a poorly illuminated part of the chamber.

Currently, we are enjoying a period of unguarded optimism concerning the appearance at the LHC of something resembling a Higgs boson, with an energy around 125 GeV. The full LHC collision energy of 14 TeV, not yet achieved, corresponds to a 10^5 TeV fixed-target proton beam or cosmic ray. Yet, cosmic rays can still trump that, reaching energies as high as 10^8 TeV.

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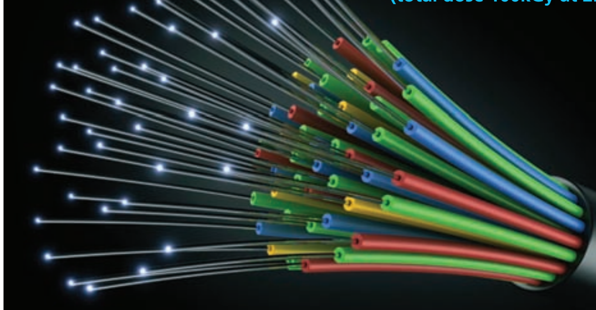

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3D cooling for uranium collisions at RHIC

For the world's first uranium–uranium collisions, stochastic cooling in the longitudinal, vertical and horizontal planes was used to shrink the beam size and increase the collision rate.

In May this year, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) finished its first run with beams of uranium ions – the heaviest ions ever used in a collider. Heavy ions contain large numbers of protons and neutrons and, when colliding at high energies, they create quark–gluon plasma, the state of matter that probably existed at the dawn of the universe. Not only was this the first time that uranium ions have been used in a particle collider, it was also the first time that the complete bunched-beam stochastic cooling system was used at RHIC, allowing cooling in the longitudinal, vertical and horizontal planes in both of the collider's interlaced magnet rings.

Uranium ions are now available at RHIC courtesy of the recently commissioned electron-beam ion source (EBIS). Physicists at the STAR and PHENIX experiments are particularly interested in uranium nuclei because of their prolate shape, more like a rugby ball than a sphere. Some of these nuclei will collide along their long axes, creating a quark–gluon plasma denser than the plasma discovered and now routinely created at RHIC in collisions of gold nuclei, which are more spherical. Some nuclei will collide with their long axes parallel, although perpendicular to their directions of motion. This arrangement creates a quark–gluon plasma with an oblong cross-section but without the strong magnetic field generated by grazing incidence collisions of spherical nuclei. Both of these possibilities make uranium–uranium collisions a new tool for studying quark–gluon plasma, adding to the toolbox that is currently available at both RHIC and the LHC.

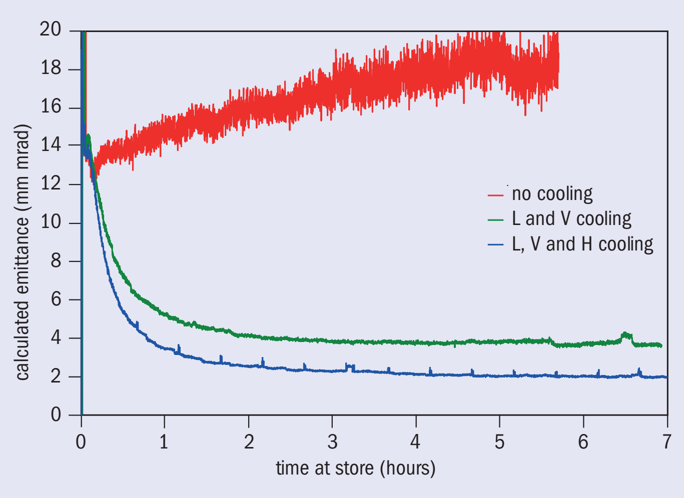

Fig. 1. Transverse emittances in stores without cooling; with longitudinal and vertical cooling; and with longitudinal, vertical and horizontal cooling. (Emittance is proportional to the square of the beam size.)

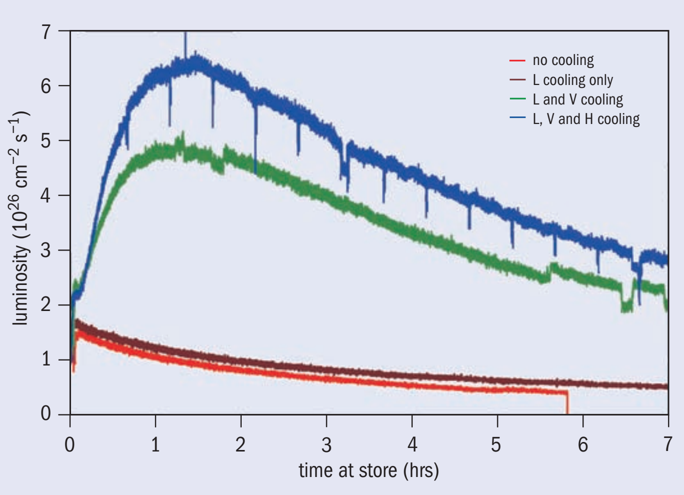

Fig. 2. Luminosity (collision rate) for stores without cooling; with longitudinal cooling only; with longitudinal and vertical cooling; and with cooling in all planes.

A hadron-collider 'first'

The amount of data delivered to the STAR and PHENIX experiments in the three-week exploratory run was increased five-fold by stochastic cooling, a feedback technique that shrinks the ion beams while they are colliding. This technique was developed at RHIC by a team that included Mike Blaskiewicz, Mike Brennan and Kevin Mernick (Blaskiewicz *et al.* 2010). The cooling is so strong that the beam size is reduced by half after an hour of storage time (figure 1) and the peak luminosity – or collision rate – rises to three times its initial value (figure 2). This has never been achieved in a hadron collider before. With a re-optimized lattice and stochastic ▷

cooling, no ions were lost by any mechanism other than through the uranium–uranium collisions themselves, which is also a first for a hadron collider.

In stochastic cooling, invented by Simon van der Meer and first demonstrated at CERN's Intersecting Storage Rings in 1975, random fluctuations of particle distributions are detected and corrected for. The result is smaller and smaller distributions (*CERN Courier* June 2011 p17). The technique involves sending a signal from a pickup at one location to activate a kicker to correct the same bunch at a point further round the ring. While stochastic cooling was and is used in a number of low-energy storage rings, RHIC is the first collider with operational stochastic cooling. The procedure was first demonstrated in 2006 using a low-intensity proton bunch with 10^9 particles. Operational longitudinal cooling of gold ions in one of RHIC's two rings was demonstrated the following year. Since then, both the Blue ring (clockwise) and the Yellow ring (anticlockwise) have been fitted with horizontal, vertical and longitudinal cooling, with full 3D cooling now available.

From pickup to kicker

The detection of fluctuations of distributions with high numbers of particles requires bandwidths in the gigahertz range. At RHIC, the ion beams at storage energy are composed of bunches of 5 ns full-width, separated by 107 ns. Cooling times of about 1 hour are obtained with a system bandwidth of 3 GHz and optimal kicker voltages of typically 3 kV. To reduce the microwave power required, a set of kicker cavities with a bandwidth of only 10 MHz has been adopted to take advantage of the bunch spacing. Each kicker consists of 16 cavities. Therefore, with three cooling planes there are 96 cavities in all for the two rings. The systems in the two rings are quite similar, so the following describes only the set-up for the Blue ring.

The longitudinal pickup is located in the 2 o'clock straight section (figure 3). Before the pickup signal is transmitted, it is first put through a traversal filter that repeats the signal 16 times to stretch it, with output $S_1(t)=S_0(t)+S_0(t-\tau)+\dots+S_0(t-15\tau)$ and $\tau=5.000$ ns. The effect of the filter, which is a key feature of the system at RHIC, is to maintain all of the information in the 5-ns-long bunch core while reducing the peak signal. This, in turn, lightens the load on the specially adapted commercial microwave link that is used to send the signal to the longitudinal kicker in the 4 o'clock straight section of the Blue ring. There, a one-turn filter is applied, where $S_2(t)=S_1(t)-S_1(t-T_{rev})$ with the revolution period T_{rev} accurate to better than 1 ps. This filter ensures that the kick to the beam is proportional to the rate at which the beam is changing, similar to a viscous damping force being proportional to the velocity of a particle, not its position. The traversal filter causes the spectrum of the signal to have peaks of width 10 MHz separated by 200 MHz.

The 16 kicker cavities in the longitudinal system operate at frequencies of 6.0 GHz, 6.2 GHz, …, 9.0 GHz. To drive them, the pickup signal is split into 16 channels, corresponding to the individual cavities. Each channel goes through a band-pass filter with a width of 100 MHz centred at its cavity frequency so that a given cavity is driven by a sinusoidal signal whose phase and amplitude change from one bunch to the next. The individual signals are put through analogue linear modulators that adjust the phase and amplitude to obtain optimal cooling. The amplifiers are located in the tunnel close to the kickers and have a peak power of 40 W.

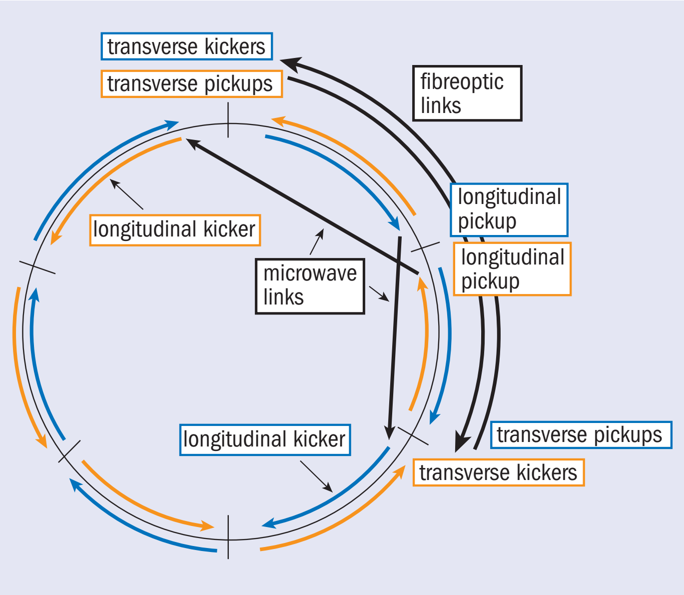

Fig. 3. Schematic of stochastic cooling in RHIC (above). Longitudinal signals are sent via microwave links (right) and transverse signals by fibreoptics in the tunnel. (Image credit: BNL.)

To set up the system, open-loop beam transfer-functions are measured at each cavity frequency. The phase and amplitude are optimized using the signal suppression observed in the pickup spectrum. Signal suppression occurs because the observed signal from the beam is the sum of the Schottky signal and the coherent beam response of the cooling system. When things are tuned correctly the observed signal has 1/4 the power of the signal without cooling. During operation the full aperture of the kicker is only 2 cm, so the cavities are open during injection and acceleration and close only after storage energy is reached.

The vertical and horizontal stochastic cooling systems employ fibre-optic links between the pickups and the kickers, with a net delay of about 2/3 of a turn. The use of fibres, with their reduced signal velocities, is possible because these transverse systems can tolerate the extra delay without compromising performance. Here the Blue cavities operate at frequencies of 4.7 GHz, 4.9 GHz, … 7.7 GHz, the Yellow cavities at 4.8 GHz, 5.0 GHz, …, 7.8 GHz. The offset in frequency between the rings is needed to avoid ring-to-ring interference via microwaves propagating from one ring to the other through the common straight sections. The Blue low-level system employs the antisym-

The cooling reduced the beam size to such an extent that the integrated luminosity was increased by a factor of 5.

metrical filter with $S_1(t) = S_0(t) - S_0(t-\tau) + S_0(t-2\tau) \ldots - S_0(t-15\tau)$ with $\tau = 5.000$ ns to get the peaks in the signal spectrum at the cavity frequencies. Like their longitudinal counterparts, the transverse cavities are open during injection and acceleration and close once storage energy is reached.

As the beam distribution evolves and components warm up, the optimal loop parameters change. The gain and phase of the system-transfer functions are therefore automatically optimized, approximately every 5 to 15 minutes. This is done one cavity at a time so that cooling is not compromised. The open-loop system-transfer function for each cavity is measured using a network analyser. The measured transfer function is compared with a stored reference function and the phase and amplitude of the low-level gain are adjusted to minimize the mean-square difference between the measured and stored transfer functions. The one-turn delay filters of the longitudinal systems are also corrected automatically by adjusting a piezoelectric delay module in the fibreoptic cable that supplies the delay.

The stochastic cooling system has significantly improved the integrated luminosity. During 2011 vertical and longitudinal cooling was used in both rings with gold ions, while horizontal cooling was achieved using betatron coupling. With all of the other parameters held constant, the cooling system doubled the integrated luminosity per store. After the installation of horizontal cooling systems, RHIC ran with uranium–uranium collisions in 2012. Figure 2 shows collision rates in the STAR and PHENIX detectors. The cooling reduced the beam size to such an extent that the collision rates were increased by almost a factor of 3 and, when compared with no cooling, the integrated luminosity was increased by a factor of 5.

● Further reading

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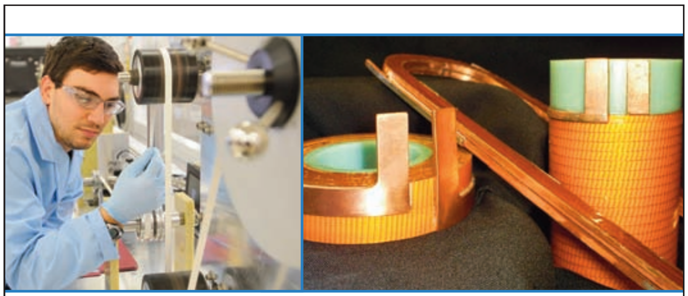
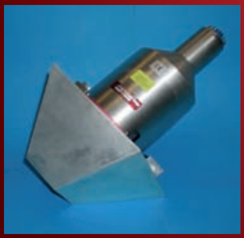
Résumé

Refroidissement 3D pour les faisceaux d'uranium à RHIC

En mai, le collisionneur d'ions lourds relativistes RHIC du laboratoire national de Brookhaven a terminé sa première campagne avec faisceaux d'ions uranium, soit les ions les plus lourds jamais utilisés dans un collisionneur. C'était aussi la première fois que le système de refroidissement stochastique complet était utilisé au RHIC. Ce système permet le refroidissement sur le plan longitudinal, vertical et horizontal dans les deux anneaux d'aimants entrelacés de la machine. Le refroidissement a permis de réduire la taille du faisceau dans de telles proportions que le taux de collision a presque triplé (par rapport au taux sans refroidissement), la luminosité intégrée augmentant d'un facteur 5.

Mike Blaskiewicz and **Wolfram Fischer**, Brookhaven National Laboratory.



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The history of QCD

Harald Fritzsch, one of the pioneers of quantum chromodynamics, recalls some of the background to the development of the theory 40 years ago.

About 60 years ago, many new particles were discovered, in particular the four Δ resonances, the six hyperons and the four K mesons. The Δ resonances, with a mass of about 1230 MeV, were observed in pion–nucleon collisions at what was then the Radiation Laboratory in Berkeley. The hyperons and K mesons were discovered in cosmic-ray experiments.

Murray Gell-Mann and Yuval Ne'eman succeeded in describing the new particles in a symmetry scheme based on the group SU(3), the group of unitary 3×3 matrices with determinant 1 (Gell-Mann 1962, Ne'eman 1961). SU(3)-symmetry is an extension of isospin symmetry, which was introduced in 1932 by Werner Heisenberg and is described by the group SU(2).

The observed hadrons are members of specific representations of SU(3). The baryons are octets and decuplets, the mesons are octets and singlets. The baryon octet contains the two nucleons, the three Σ hyperons, the Λ hyperon and the two Ξ hyperons (see figure 1). The members of the meson octet are the three pions, the η meson, the two K mesons and the two $\bar{K}$ mesons.

In 1961, nine baryon resonances were known, including the four Δ resonances. These resonances could not be members of an octet. Gell-Mann and Ne'eman suggested that they should be described by an SU(3)-decuplet but one particle was missing. They predicted that this particle, the Ω^-, should soon be discovered with a mass of around 1680 MeV. It was observed in 1964 at the Brookhaven National Laboratory by Nicholas Samios and his group. Thus the baryon resonances were members of an SU(3) decuplet.

It was not clear at the time why the members of the simplest SU(3) representation, the triplet representation, were not observed in experiments. These particles would have non-integral electric charges: 2/3 or –1/3.

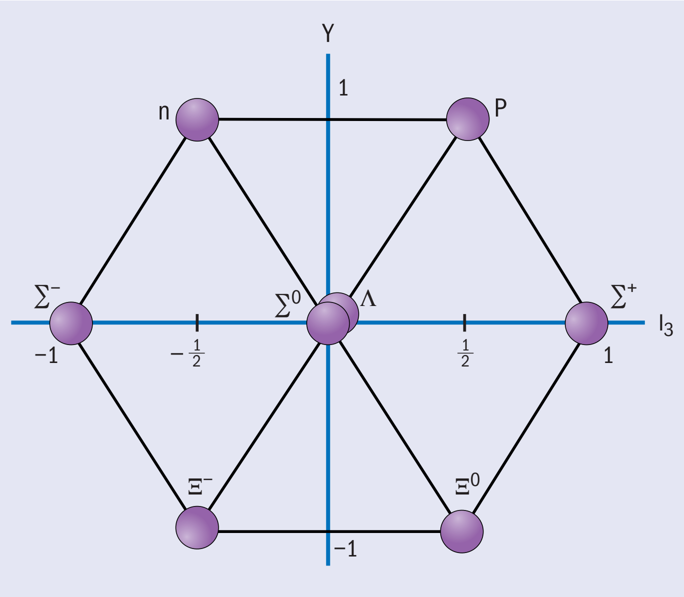

Fig. 1. SU(3) octet of the ground-state baryons.

Murray Gell-Mann (right) and Harald Fritzsch. (Image credit: courtesy H Fritzsch.)

The quark model

In 1964, Gell-Mann and his PhD student George Zweig, who was working at CERN, proposed that the baryons and mesons are bound states of the hypothetical triplet particles (Gell-Mann 1964, Zweig 1964). Gell-Mann called the triplet particles "quarks", using a word that had been introduced by James Joyce in his novel *Finnegans Wake*.

Since the quarks form an SU(3) triplet, there must be three quarks: a u quark (charge 2/3), a d quark (charge –1/3) and an s quark (charge –1/3). The proton is a bound state of two u quarks and one d quark (uud). Inside the neutron are two d quarks and one u quark (ddu). The Λ hyperon has the internal structure uds. The three Σ hyperons contain one s quark and two u or two d quarks (uus or dds). The Ξ hyperons are the bound states uss and dss. The Ω^- is a bound state of three s quarks: sss. The eight mesons are bound states of a quark and an antiquark. ▷

In the quark model, the breaking of the SU(3)-symmetry can be arranged by the mass term for the quarks. The mass of the strange quark is larger than the masses of the two non-strange quarks. This explains the mass differences inside the baryon octet, the baryon decuplet and the meson octet.

Introducing colour

In the summer of 1970, I spent some time at the Aspen Center of Physics, where I met Gell-Mann and we started working together. In the autumn we studied the results from SLAC on the deep-inelastic scattering of electrons and atomic nuclei. The cross-sections depend on the mass of the virtual photon and the energy transfer. However, the experiments at SLAC found that the cross-sections at large energies depend only on the ratio of the photon mass and the energy transfer – they showed a scaling behaviour, which had been predicted by James Bjorken.

In the SLAC experiments, the nucleon matrix-element of the commutator of two electromagnetic currents is measured at nearly light-like distances. Gell-Mann and I assumed that this commutator can be abstracted from the free-quark model and we formulated the light-cone algebra of the currents (Fritzsch and Gell-Mann 1971). Using this algebra, we could understand the scaling behaviour. We obtained the same results as Richard Feynman in his parton model, if the partons are identified with the quarks. It later turned out that the results of the light-cone current algebra are nearly correct in the theory of QCD, owing to the asymptotic freedom of the theory.

The Ω^- is a bound state of three strange quarks. Since this is the ground state, the space wave-function should be symmetrical. The three spins of the quarks are aligned to give the spin of the omega minus. Thus the wave function of the Ω^- does not change if two quarks are interchanged. However, the wave function must be antisymmetric according to the Pauli principle. This was a great problem for the quark model.

In 1964, Oscar Greenberg discussed the possibility that the quarks do not obey the Pauli statistics but rather a "parastatistics of rank three". In this case, there is no problem with the Pauli statistics but it was unclear whether parastatistics makes any sense in a field theory of the quarks.

Two years later, Moo-Young Han and Yoichiro Nambu considered nine quarks instead of three. The electric charges of these quarks were integral. In this model there were three u quarks: two of them had electric charge of 1, while the third one had charge 0 – so on average the charge was 2/3. The symmetry group was SU(3) × SU(3), which was assumed to be strongly broken. The associated gauge bosons would be massive and would have integral electric charges.

In 1971, Gell-Mann and I found a different solution of the statistics problem (Fritzsch and Gell-Mann 1971). We considered nine quarks, as Han and Nambu had done, but we assumed that the three quarks of the same type had a new conserved quantum number, which we called "colour". The colour symmetry SU(3) was an exact symmetry. The wave functions of the hadrons were assumed to be singlets of the colour group. The baryon wave-functions are antisymmetric in the colour indices, denoted by red (r), green (g) and blue (b):

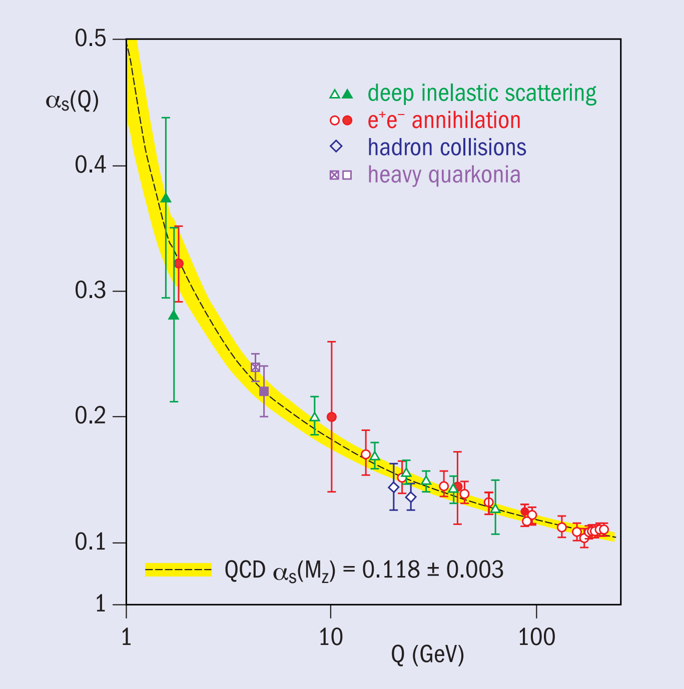

Fig. 2. The strong coupling-constant as a function of energy.

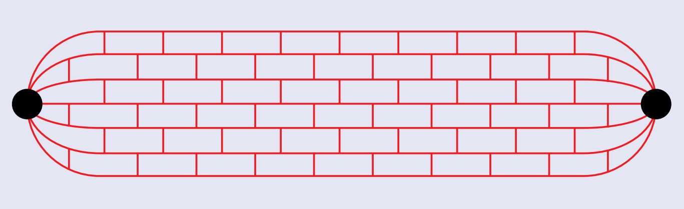

Fig. 3. Two heavy quarks, connected by a gluonic string.

$$(qqq) \rightarrow (q_r q_g q_b - q_g q_r q_b + q_b q_r q_g - q_r q_b q_g + q_g q_b q_r - q_b q_g q_r)$$

Thus the wave function of a baryon changes sign if two quarks are exchanged, as required by the Pauli principle. Likewise, the wave functions of the mesons are colour singlets:

$$(\bar{q}q) \rightarrow (\bar{q}_r q_r + \bar{q}_g q_g + \bar{q}_b q_b)$$

The cross-section for electron–positron annihilation into hadrons at high energies depends on the squares of the electric charges of the quarks and on the number of colours. For three colours this leads to:

$$\frac{\sigma(e^+ + e^- \rightarrow \text{hadrons})}{\sigma(e^+ + e^- \rightarrow \mu^+ + \mu^-)} \rightarrow 3\left[\left(\frac{2}{3}\right)^2 + \left(-\frac{1}{3}\right)^2 + \left(-\frac{1}{3}\right)^2\right] = 2$$

Without colours this ratio would be 2/3. The experimental data, however, were in agreement with a ratio of 2.

In 1971–1972, Gell-Mann and I worked at CERN. Together with William Bardeen we investigated the electromagnetic decay of the neutral pion into two photons. It was known that in the quark model the decay rate is about a factor nine less than the measured

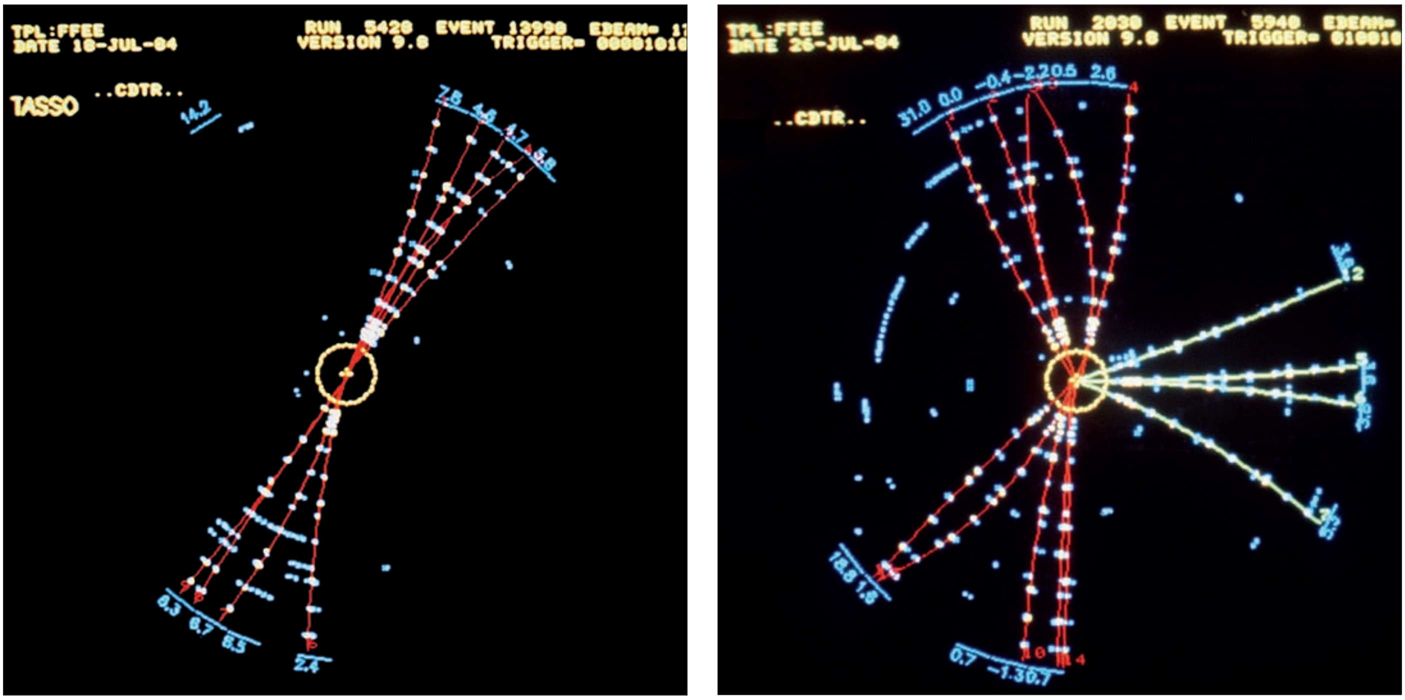

Fig. 4. An event with quark jets, left, and a three-jet event, right, observed at DESY. (Image credit: Oxford University PPU.)

decay rate – another problem for the quark model.

The decay amplitude is given by a triangle diagram, in which a quark–antiquark pair is created virtually and subsequently annihilates into two photons. We found that after the introduction of colour, the decay amplitude increases by a factor three – each colour contributes to the amplitude with the same strength. For three colours, the result agrees with the experimental value.

In the spring of 1972, we started to interpret the colour group as a gauge group. The resulting gauge theory is similar to quantum electrodynamics (QED). The interaction of the quarks is generated by an octet of massless colour gauge bosons, which we called gluons (Fritzsch and Gell-Mann 1972). We later introduced the name "quantum chromodynamics", or QCD. We published details of this theory one year later together with Heinrich Leutwyler (Fritzsch *et al.* 1972).

In QCD, the gluons interact not only with the quarks but also with themselves. This direct gluon–gluon interaction is important – it leads to the reduction of the coupling constant at increasing energy, i.e. the theory is asymptotically free, as discovered in 1972 by Gerard 't Hooft (unpublished) and in 1973 by David Gross, David Politzer and Frank Wilczek. Thus at high energies the quarks and gluons behave almost as free particles. This leads to the approximate "scaling behaviour" of the cross-sections in the deep-inelastic lepton–hadron scattering. The quarks behave almost as free particles at high energies.

The logarithmic decrease of the coupling constant depends on the QCD energy-scale parameter, Λ, which is a free parameter and has to be measured in the experiments. The current experimental value is:

$$\Lambda = 213^{+38}_{-35}\ \text{MeV}$$

Experiments at SLAC, DESY, CERN's Large Electron–Positron (LEP) collider and Fermilab's Tevatron have measured the decrease of the QCD coupling-constant (figure 2). With LEP, it was also possible to determine the QCD coupling-constant at the mass of the Z boson rather precisely:

$$\alpha_s\,(M_Z) = 0.1184 \pm 0.0007$$

It is useful to consider the theory of QCD with just one heavy quark Q. The ground-state meson in this hypothetical case would be a quark–antiquark bound state. The effective potential between the quark and its antiquark at small distances would be a Coulomb potential proportional to 1/r, where r is the distance between the quark and the antiquark. However, at large distances the self-interaction of the gluons becomes important. The gluonic field lines at large distances do not spread out as in electrodynamics. Instead, they attract each other. Thus the quark and the antiquark are connected by a string of gluonic field lines (figure 3). The force between the quark and the antiquark is constant, i.e. it does not decrease as in electrodynamics. The quarks are confined. It is still an open question whether this applies also to the light quarks.

In electron–positron annihilation, the virtual photon creates a quark and an antiquark, which move away from each other with high speed. Because of the confinement property, mesons – mostly pions – are created, moving roughly in the same direction. The quark and the antiquark "fragment" to produce two jets of particles. The sum of the energies and momenta of the particles in each jet should be equal to the energy of the original quark, which is equal to the energy of each colliding lepton. These quark jets were observed for the first time in 1978 at DESY (figure 4). They had already been predicted in 1975 by Feynman.

If a quark pair is produced in electron–positron annihilation, ▷

then QCD predicts that sometimes a high-energy gluon should be emitted from one of the quarks. The gluon would also fragment and produce a jet. So, sometimes three jets should be produced. Such events were observed at DESY in 1979 (figure 4).

The basic quanta of QCD are the quarks and the gluons. Two colour-octet gluons can form a colour singlet. Such a state would be a neutral gluonium meson. The ground state of the gluonium mesons has a mass of about 1.4 GeV. In QCD with only heavy quarks, this state would be stable but in the real world it would mix with neutral quark–antiquark mesons and would decay quickly into pions. Thus far, gluonium mesons have not been identified clearly in experiments.

The simplest colour-singlet hadrons in QCD are the baryons – consisting of three quarks – and the mesons, made of a quark and an antiquark. However, there are other ways to form a colour singlet. Two quarks can be in an antitriplet – they can form a colour singlet together with two antiquarks. The result would be a meson consisting of two quarks and two antiquarks. Such a meson is called a tetraquark. Three quarks can be in a colour octet, as well as a quark and an antiquark. They can form a colour-singlet hadron, consisting of four quarks and an antiquark. Such a baryon is called a pentaquark. So far, tetraquark mesons and pentaquark baryons have not been clearly observed in experiments.

The three quark flavours were introduced to describe the symmetry given by the flavour group SU(3). However, we now know that in reality there are six quarks: the three light quarks u, d, s and the three heavy quarks c (charm), b (bottom) and t (top). These six quarks form three doublets of the electroweak symmetry group SU(2):

$$\begin{pmatrix} u \\ c \end{pmatrix} \leftrightarrow \begin{pmatrix} c \\ s \end{pmatrix} \leftrightarrow \begin{pmatrix} t \\ b \end{pmatrix}$$

The masses of the quarks are arbitrary parameters in QCD, just as the lepton masses are in QED. Since the quarks do not exist as free particles, their masses cannot be measured directly. They can, however, be estimated using the observed hadron masses. In QCD they depend on the energy scale under consideration. Typical values of the quark masses at the energy of 2 GeV are:

$$m_u = 0.004\,\text{GeV},\ m_c = 1.2\,\text{GeV},\ m_t = 174\,\text{GeV},$$
$$m_d = 0.006\,\text{GeV},\ m_s = 0.1\,\text{GeV},\ m_b = 4.4\,\text{GeV}.$$

The mass of the t quark is large, similar to the mass of a gold atom. Owing to this large mass, the t quark decays by the weak interaction with a lifetime that is less than the time needed to form a meson. Thus there are no hadrons containing a t quark.

Richard Feynman. (Image credit: Fermilab.)

The theory of QCD is the correct field theory of the strong interactions and of the nuclear forces. Both hadrons and atomic nuclei are bound states of quarks, antiquarks and gluons. It is remarkable that a simple gauge theory can describe the complicated phenomena of the strong interactions.

● Further reading

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Résumé

L'histoire de la QCD

Au cours des soixante dernières années, la recherche a révélé que les hadrons comme les noyaux atomiques sont des états liés de quarks, d'antiquarks et de gluons. Il est remarquable qu'une simple théorie de jauge, la chromodynamique quantique, soit à même de décrire les phénomènes compliqués que sont les interactions fortes et les forces nucléaires à l'œuvre dans ces systèmes. Dans cet article, Harald Fritzsch, l'un des pionniers de la chromodynamique quantique, évoque le développement de la théorie, dont les fondements ont été posés dans les travaux qu'il a réalisés avec Murray Gell-Mann en 1972.

Harald Fritzsch, Ludwig-Maximilians-Universität, Munich.


NHS 6 260p
6 x +6kV / 1mA
MENU
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CHANNELS VI-SET
PUSH TO SELECT
ON/OFF
OK HV ON


LakeShore
Model 350 Temperature Controller
SETPOINT
ALL OFF
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Unpacking the blank of the 3.6 m mirror at the REOSC workshops, near Paris, in 1967. (All image credits: ESO.)

Signing the ESO–CERN agreement for collaboration in the construction of the ESO 3.6 m telescope at CERN, 1970; Jan Bannier, president of ESO Council, left, and Bernard Gregory, director-general of CERN.

Location of ESO's Telescope Project (TP) D
Sky Atlas Laboratory (SA) at CERN in the 19

ESO and CERN: a tale

The early days of ESO, founded in October 1962, saw many links with CERN, including work on the 3.6 m telescope.

On 5 October 1962, five nations signed the convention that founded the European Southern Observatory (ESO). Belgium, France, the Federal Republic of Germany, the Netherlands and Sweden where soon followed by Denmark. They were later joined by Switzerland, Italy, Portugal, the UK, Finland, Spain, the Czech Republic and, most recently, Austria in 2009. Brazil, whose membership is pending ratification, will be the 15th member state and the first from outside Europe. The organization's main mission, laid down in the convention signed in 1962, is to provide state-of-the-art research facilities to astronomers and astrophysicists, allowing them to conduct front-line science in the best conditions. With headquarters in Garching near Munich, ESO operates three observing sites high in the Atacama Desert region of Chile, which are home to a world-leading collection of observing facilities (p50).

ESO's ruling body is its council, which delegates day-to-day responsibility to the executive under the director-general, while other governing bodies of ESO include the Finance Committee and the Committee of Council. If this sounds familiar, it is probably because the origins of ESO bear more than a passing resemblance to those of CERN. The founding of ESO has its roots in a statement signed on 26 January 1954 by leading astronomers from six countries – the five nations that would later sign the ESO convention, plus the UK (which was to go in a different direction and join ESO only in 2002). The statement pointed to the lack of coverage of the skies of the southern hemisphere – which include interesting regions such as the Magellanic Clouds – by powerful telescopes at that time. It went on to put the case that although no one country had sufficient resources for such a project, it could be possible through international collaboration. Finally, it recommended the establishment of a joint observatory in South Africa that would house a 3 m telescope and a 1.2 m Schmidt telescope with a wide field of view, which would be valuable for surveys. These instruments would complement the 5 m Hale Telescope and the 1.2 m Schmidt that had been observing the skies of the northern hemisphere from the Palomar Observatory in California since 1948.

The idea for a joint European effort had originated the previous spring, when the pioneering Dutch astronomer, Jan Oort, invited Walter Baade, a renowned German working at the Mt Wilson and Palomar Observatories, to stay at Leiden for a couple of months. Oort mobilized a group of leading European astronomers for a meeting with the influential visitor on 21 June 1953, where Baade proposed capitalizing on existing designs for a 3 m telescope being built for the Lick Observatory in California and for the Schmidt telescope at Palomar. Also present at the meeting was Jan Bannier, director of the Dutch national science foundation and president of the provisional CERN Council.

The ESO convention

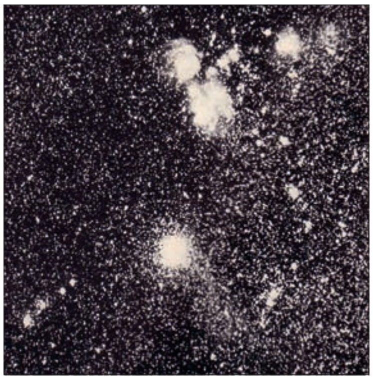
In November 1954, Bannier and Gösta Funke, director of the Swedish National Research Council and a member of the newly established formal CERN Council, drew up the first draft of a convention for ESO, with key similarities to the CERN convention. ESO would have a council with two delegates (at least one an astronomer) from each member state; each country would have an equal vote; financial contributions would be in proportion to national income up to a fixed limit.

Further progress was slow because the project's supporters grappled with financial and political difficulties in their countries. Important impetus came with Oort's successful application in 1959

Division and
1970s.

An early scanner for photographic plates, located at CERN, used for one of the first digitized surveys by the Sky Atlas Lab.

Main structure of the ESO 3.6 m telescope during assembly in France before shipping to La Silla, in Chile.



Part of one of the first images from the 3.6 m telescope. Taken on 17 November 1976 it shows an area of the Large Magellanic Cloud.

# of two organizations

for a grant from the Ford Foundation in the US for a $1 million – a fifth of the estimated cost at the time – on condition that at least four of the five potential members sign the convention. It took another three years for further issues to be resolved and for the convention to be signed on 5 October 1962, in the Ministry of Foreign Affairs in Paris. Even then, it was only in early 1964 that real work could begin (and the grant from the Ford Foundation released) when France became the fourth country to ratify the convention, after the Netherlands, Sweden and the German Federal Republic.

The original idea had been to locate the observatory in South Africa and over the period 1953–1963 searches for suitable places were followed by systematic tests at three sites in the Karoo region. However, in 1959 astronomers in the US began to explore the possibilities in the Chilean Andes, through the Association of Universities for Research in Astronomy (AURA). It soon became clear that the Andes might offer better climatic conditions than South Africa for astronomy and in November 1962 two members of ESO's site-testing team went to Chile. Their findings indicated a general superiority, in particular longer spells of clear weather and smaller temperature differences during the night (owing, in fact, to the higher altitude).

So, in June 1963 Otto Heckmann, the embryonic organization's provisional director-general, and others including Oort went to Chile to meet members of AURA and see the mountains chosen by the Americans. Although the ESO convention had still to be ratified by the requisite four countries, in November the ESO Committee opted unanimously for the Andes, a decision that the formal ESO Council approved at its first meeting in 1964. Later that year, ESO decided on a site that was independent of the Americans – a mountaintop at 2400 m that Heckmann proposed naming La Silla (the saddle).

La Silla Observatory in the late 1970s. In the background, the 3.6 m telescope stands on the highest point of the observatory. (Image credit: Seggewiss/ESO.)

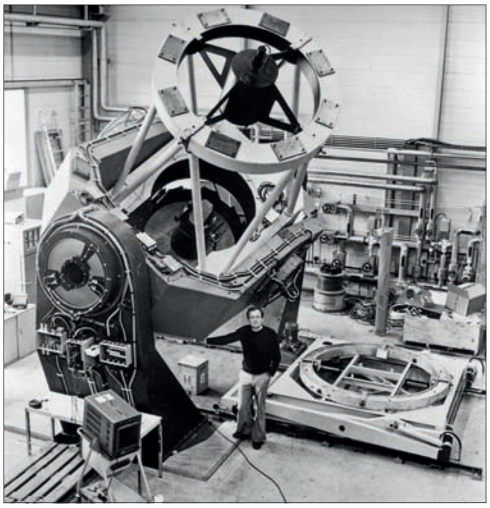
ESO went on to develop La Silla, first installing a number of intermediate-size telescopes that had been foreseen in the convention, as well as some smaller national telescopes. The official inauguration, by the president of the Republic of Chile, Eduardo Frei Montalva, took place on 25 March 1969.

In the meantime, there was mounting concern about the slow progress on the larger telescopes described in the ESO convention and in March 1969 a working group was set up to advise the ESO Council on this and various administrative matters. In particular, it was to look into budget procedures and the project for the 3.6 m telescope. (The proposed size had grown after experience in the US had shown that the observer's cage for a 3 m instrument raised problems for larger astronomers.) The working group was chaired by Funke and both he and Augustin Alline, the French government ESO Council delegate, were members of CERN Council. Their recommendations led to the introduction at ESO of the "Bannier process", which had been established at CERN for budgetary matters; and at Alline's suggestion, ESO also followed CERN's example in setting up a Committee of Council, whose informal meetings of fewer people could iron out potential difficulties between meetings of Council.

It was at the meeting of CERN's Committee of Council in November 1969 that CERN's director-general, Bernard Gregory, reported on discussions with his counterpart at ESO about a possible collaboration between the two ▷

organizations – in essence, a rescue plan for the 3.6 m telescope. The project was similar in size and complexity to that of a large bubble chamber and there was also a strong feeling that particle physicists and astronomers could benefit from closer contact. The committee gave Gregory the go-ahead to report to the meeting of CERN Council in December, which in turn authorized him to continue the discussions with ESO. At the meeting, Bannier, who was currently president of the ESO Council, pointed out that with its greater experience in building large-scale apparatus and in dealing with industry CERN would bring valuable expertise to advance the 3.6 m project.

By June 1970, a draft co-operation agreement had been drawn up that foresaw the setting up of ESO's Telescope Project Division at CERN. CERN would provide administrative, technical and professional services – the latter covering the project management as well as technical and scientific advice. This would be at no cost to CERN because all would be financed by ESO and no additional staff at CERN would be required. The June council meetings at ESO and CERN consented to collaboration between the two organizations and on 16 September the agreement was signed by Gregory and Adriaan Blaauw, ESO's director-general. Within six months, the nucleus of the Telescope Project (TP) Division had formed at CERN. Led by ESO's Svend Laustsen, it included his small technical group. The division then grew to comprise some 40 astronomers, engineers and technicians, all involved in the final design, construction and testing of the 3.6 m telescope, while benefiting from CERN's experience in engineering and the administrative aspects of implementing a large project.



The Coudé Auxiliary Telescope (CAT) assembled at CERN circa 1980, before the telescope was installed on La Silla. (Image credit: ESO.)

The members of TP interacted mainly with CERN's Proton Synchrotron Department (particularly Wolfgang Richter and the department head, Kees Zilverschoon), the Technical Services and Building Division (Henri Laporte and E Leroy) and the Data Handling Division (Detmar Wiskott), while the placing of contracts involved working with the Finance Division. The first two years focused on completing the design of the telescope and the building

The ESO 3.6 m telescope was completely upgraded in 1999. It is equipped with HARPS, the most precise spectrograph in the world. (Image credit: H H Heyer/ ESO.)

The star Eta Carinae and the Keyhole Nebula, part of the larger Carina Nebula, imaged with the ESO 3.6 m telescope on La Silla.

to house it, with a first design report issued in February 1971. A year later, the group was awarding contracts related to the construction of the telescope, the building and a computer system, both to steer the telescope and for data-acquisition and some online analysis.

Further developments

November 1972 saw another development at CERN, with the inauguration of the ESO Sky Atlas Laboratory. To match the atlas of the northern sky made by the 1.2 m Schmidt telescope at Mt Palomar, ESO and the UK were pooling the resources of ESO's 1 m Schmidt in Chile and the UK's 1.2 Schmidt in Australia. A copy of each of the glass plates recorded in Chile was sent to the lab at CERN for further copying onto film. After a first rapid survey, ESO's Schmidt telescope went on to cover red wavelengths in detail, the UK's instrument covering blue. The Sky Atlas Lab was involved in producing 200 copies of the complete atlas, the full view totalling 200 m^2 of film. One highlight of this work was the discovery of a new comet on 5 November 1975, named after its discoverer, the lab's head, Danish astronomer Richard West.

In April 1975, the 3.6 m telescope was ready for testing in Europe. One innovation concerned the use of a fully automated control system, which involved some 120 individual computer-controlled motors for steering. The 18 m tall structure was assembled in a hall with a specially constructed pit to accommodate it at the Société Creusot-Loire at St Chamond. There, a van from CERN packed with electronic control-circuitry tested out the control system, determining the optimum configuration for driving the telescope's two orientation axes. With testing complete, the telescope was dismantled and packed up for its journey to Chile, where it would be fitted with its giant mirror. The mirror blank had been ordered from Corning in the US as early as 1965 but a number of problems meant that its final processing to achieve a surface accuracy of 0.06 μm was not completed by the Recherches et études d'optique et de sciences connexes (REOSC), near Paris, until early 1972.

A year after it arrived in Chile, the telescope finally saw its "first light" on the night of 7–8 November 1976. The links with CERN were not quite over, however. A smaller 1.4 m instrument – the Coudé Auxiliary telescope (CAT) – was later designed by the TP team at CERN. Manufactured mainly by industry, it was assembled in CERN in early 1979 before going to Chile, where it fed the 3.6 m Coudé Echelle Spectrometer through a light tunnel. Fully computer controlled, the CAT was used for many different astronomical observations, including measuring the ages of ancient stars. The 3.6 m itself has since gone on to be highly productive, most recently with the High Accuracy Radial velocity Planet Searcher (HARPS), the world's foremost hunter of planets beyond the solar system.

Writing in ESO's journal, *The Messenger*, in 1981, Charles Fehrenbach, the director of the Haute Provence Observatory, who was involved with ESO for many of the early years, stated: "There is no doubt in my mind that it was the installation in Geneva which saved our organization." The strong links with CERN certainly helped to set ESO on its way and the older organization can now look on with pleasure at its younger sibling's many achievements.

● Further reading

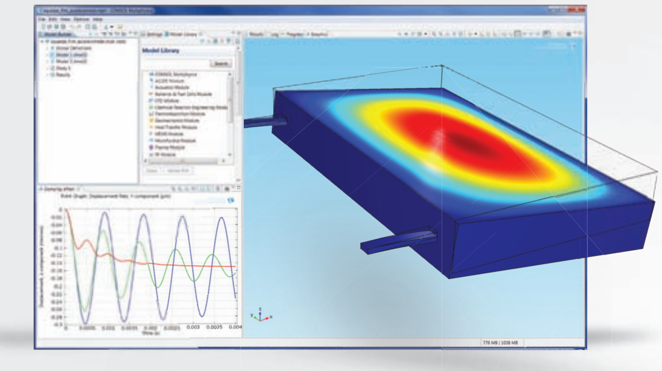
This article is based on articles on "ESO's early history, 1953–1975" by Adriaan Blaauw (ESO's director-general 1970–1974), published first in *The Messenger* in the 1980s, and later as the book *ESO's Early History*, as well as on documents from CERN Council and past articles in *CERN Courier*.

Résumé

ESO et CERN : deux organisations très liées

Cette année, l'Observatoire européen austral (ESO) célèbre son 50^e anniversaire. Comptant 14 États membres européens, l'Organisation propose ses infrastructures aux astronomes, un peu comme le CERN met ses installations à la disposition des spécialistes de physique des particules. Il existe de fait des liens historiques entre les deux organisations. La Convention ESO, signée par cinq États le 5 octobre 1962, est inspirée de la Convention CERN. Par la suite, au cours de années 1970, le savoir-faire du CERN concernant les grands projets technologiques a été mis à contribution pour la conception et la construction de l'instrument vedette de l'ESO, le télescope de 3,6 m, dont l'équipe de projet était d'ailleurs basée sur le site de Meyrin.

Christine Sutton, CERN.



Development and design of complex systems
Waveguide structures
UHV compatible joining of Ceramic to Stainless Steel
Low and high temperature technologies
Vacuum brazing of Diamond to Copper
Clean room assembly and particle-free cleaning

Particle and nuclear physics intersect in Florida

The 11th Conference on the Intersections of Particle and Nuclear Physics covered a range of topics where different fields overlap.

The Conferences on the Intersections of Particle and Nuclear Physics (CIPANP) form a triennial series that focuses on topics of interest to particle physicists, nuclear physicists, astrophysicists, cosmologists and accelerator physicists. Since the first conference took place in Steamboat Springs, Colorado, in 1984, the overlap in the interests of these areas has increased markedly. For example, the LHC is exploring both elementary-particle physics and heavy-ion physics, with the ALICE detector designed in particular for studies of lead-ion collisions. Explorations of the neutrino sector have attracted traditional nuclear physicists as well as particle physicists to measurements of solar neutrinos, reactor neutrinos, cosmic neutrinos, long-baseline neutrinos and neutrinoless double-beta decay. Facilities with rare-isotope beams have opened possibilities for innovative studies of questions in fundamental physics. The searches for physics beyond the Standard Model cover the whole range, from table-top experiments to those at the large collider facilities.

CIPANP 2012, the 11th conference in the series, took place at the Renaissance Vinoy Resort and Golf Club in St Petersburg, Florida, on 28 May – 3 June, the venue and dates being chosen according to well established CIPANP criteria. Plenary and parallel sessions were organized following the 14 topics selected for the conference: the high-energy frontier; the low-energy precision frontier; neutrino masses and neutrino mixing; electroweak tests of the Standard Model; the cosmic frontier; dark matter and dark energy; particle and nuclear astrophysics; heavy flavour and the CKM matrix; QCD, hadron spectroscopy and exotics; hadron physics and spin; nucleon structure; nuclear structure; quark matter and high-energy heavy-ion collisions; new facilities and their instrumentation. Each parallel session was organized with on average five two-hour sessions under two convenors. There were 29 invited plenary talks and a concluding “vision statement”. This report covers some of the highlights from the many excellent presentations at the meeting.

The waterfront at the Vinoy Resort, where CIPANP 2012 took place. (Image credit: Renaissance Vinoy.)

The ATLAS and CMS collaborations reported on results of the first two years of operation of the LHC, giving tantalizing hints at 2.5 σ and 2.8 σ, respectively, at a mass of about 125 GeV for the much searched-for Higgs boson. Within the Standard Model, the Higgs-boson searches plus electroweak precision data give the combined hints for the Higgs from the LHC and the Tevatron a 3.4 σ significance. (These results have been superseded by those reported at CERN on 4 July, see *CERN Courier* September 2012 p43, p46 and p50.) The CDF collaboration presented a more precise value for the mass of the W boson with an uncertainty of ± 19 MeV, giving the world average an error of ± 16 MeV.

Elsewhere, the Alpha Magnetic Spectrometer experiment mounted on board the International Space Station may yield information on ultrarelativistic cosmic particles and their interactions. The MuLan and MuCap collaborations at PSI reported their final determinations of the Fermi constant and the nucleon’s weak induced pseudoscalar coupling-constant, respectively. Current and future heavy-flavour experiments will search for evidence of physics beyond the Standard Model and, if found, characterize its make-up. Understanding hadron properties from lattice QCD calculations is making considerable progress.

Sessions on neutrino physics at CIPANP 2012 addressed a variety of questions. What is the hierarchy of the neutrino masses? Are the neutrinos their own antiparticles? What is their mass scale? Are there more than three neutrino species? The talks also covered CP violation in the neutrino sector related to the preponderance of matter over antimatter and the limits on neutrinoless double-beta decay. The highlight in this area was the electron-antineutrino oscillation results from the Daya Bay, RENO and Chooz experiments, with Daya Bay measuring $\sin^2(2\theta_{13}) = 0.092 \pm 0.016$, significantly different from zero (*CERN Courier* May 2012 p6).

In the sessions on electroweak tests, emphasis was placed on the two-boson corrections in parity-violating electron scattering, ▷

which are important for the Qweak experiment at Jefferson Laboratory and the Olympus experiment at DESY. Consensus is slowly emerging on the corrections that need to be applied in the determination of the Weinberg angle by the NuTeV experiment at Fermilab. The size of the proton is a question that remains, with newer electron-scattering experiments in agreement with the earlier ones. However, the discrepant atomic-spectroscopy result from PSI still stands.

This was the first time that CIPANP included prominently such topics as the cosmic frontier and the related fields of dark matter and dark energy. Cosmological observations indicate that only 4.5% of the mass/energy of the universe is baryonic matter, with the remaining 95% still unknown. Of the latter, 22% is dark matter, which interacts via gravity like ordinary matter. The evidence for this physics beyond the Standard Model is entirely based on cosmological observations, since many laboratory experiments undertaken so far have not presented any compelling evidence. Searches for dark matter (as well as neutrinoless double-beta decay) rely on the ultraquiet environment afforded by current and planned deep-underground laboratories with the depth and volume of the detectors being the most important parameters.

The sensitivity of gravitational-wave detectors is steadily improving with the laser interferometer experiments, Advanced LIGO and Advanced VIRGO. It is possible that at the next Intersections Conference the first results from gravitational-wave astronomy may be presented.

With the baryon-to-photon ratio well determined by the Wilkinson Microwave Anisotropy Probe, standard Big Bang nucleosynthesis no longer has any free parameters. The theoretical predictions for the abundances of ^{2}H, ^{4}He and ^{7}Li can be compared with the observed abundances, indicating an over-prediction of ^{7}Li by a factor of four. Rare isotopes with unusual proton-to-neutron ratios are the stepping-stones to nuclear element synthesis and the generation of nuclear energy in stellar explosions. The ultimate configuration in this context is a neutron star wrapped with a layer of rare isotopes. It is the rare-isotope beam facilities that elucidate the intricacies of these processes.

The structure of the nucleon is as complex an object as can be imagined. After a fair measure of scrutiny the electric and magnetic form factors are now well established. There is however a plethora of required descriptions of the quark and gluon distributions, especially if the longitudinal and transverse spins of the nucleon are included (Boer-Mulders, Collins, Sivers functions). The overriding question is: where is the spin of the nucleon hidden?

Understanding nuclear structure and nuclear reactions from first principles with input from QCD, and employing Hamiltonians constructed within chiral effective field theory, have come far. The nuclear interaction comprises two-nucleon, three-nucleon, and even four-nucleon components. Questions remain however about incorporating relativistic effects.

The quest for super-heavy elements continues. With the recent acceptance of the evidence for elements with $Z = 114$ and 116, further investigations are focusing on the elements with $Z = 118$, 113 and 115. The formation of doubly magic nuclei with neutron number $N = 184$ and the (possibly) matching proton numbers of $Z = 120$ or 126 may not be too far off in the future.

The utilization of high-energy heavy-ion collisions has allowed the detailed study of the quark–gluon plasma in the laboratory under conditions like those that existed in the first instances of the universe. The recent studies performed at the LHC with the ALICE detector and at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven have enabled a mapping out of the phase diagram of nuclear matter.

For the future

Upgrades for the LHC and the LHCb experiment at CERN were presented at the conference, as well as for RHIC and the PHENIX experiment, and for the 12 GeV Continuous Electron Beam Accelerator Facility at Jefferson Laboratory. An illuminating talk discussed the science and prospects for an electron–ion collider, with proposals from Brookhaven (e-RHIC) and Jefferson Laboratory (EIC) – soon to be amalgamated to become a priority item as part of the US Nuclear Science Advisory Committee's Long Range Plan for Nuclear Physics – and from CERN (LHeC). The status of the Facility for Antiproton and Ion Research at GSI with its all-encompassing PANDA detector was another topic presented. Also discussed were the planned Facility for Rare Isotope Beams at Michigan State University and TRIUMF's rare-isotope beam programme with the Isotope Separator and Accelerator facility and the Advanced Rare Isotope Laboratory, as well as Project-X at Fermilab, which has an important future high-intensity frontier research programme.

Ernest J Moniz, from Massachusetts Institute of Technology (MIT) and its Energy Initiative Institute gave the traditional public lecture, entitled "Energy and the Future (a Worldwide Perspective)". The banquet speech was an exposé on the life and art of Salvador Dali given by Peter Tush of the Dali Museum in St Petersburg. CIPANP 2012 ended with a vision statement presented by Richard G Milner, director of the Laboratory for Nuclear Science at MIT.

- CIPANP 2012 was organized with the help of TRIUMF and Jefferson Laboratory. For further information, see http://cipanp2012.triumf.ca.

Résumé

Intersections entre physique des particules et physique nucléaire en Floride

La 11^{e} édition de la Conférence sur les intersections entre physique des particules et physique nucléaire (CIPANP) a eu lieu cette année en Floride. Depuis la première édition, en 1984, le chevauchement entre les deux disciplines s'est fortement accru. Cette année, la réunion a couvert différents sujets de la physique des particules, de la physique nucléaire, de l'astrophysique, de la cosmologie et de la physique des accélérateurs. Parmi les thèmes abordés, l'exploration des hautes énergies et la confrontation du Modèle standard aux limites des connaissances cosmiques, la matière noire et l'énergie noire. Il a également été question des perspectives concernant de nouvelles installations ainsi que d'améliorations pour les installations existantes.

Willem T H van Oers, TRIUMF.

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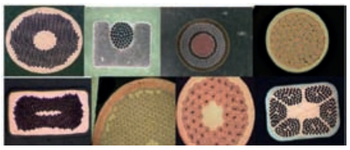

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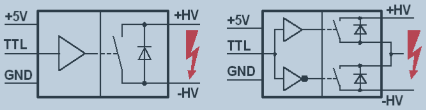

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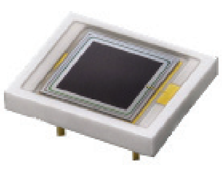

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Boosting sensitivity to new physics

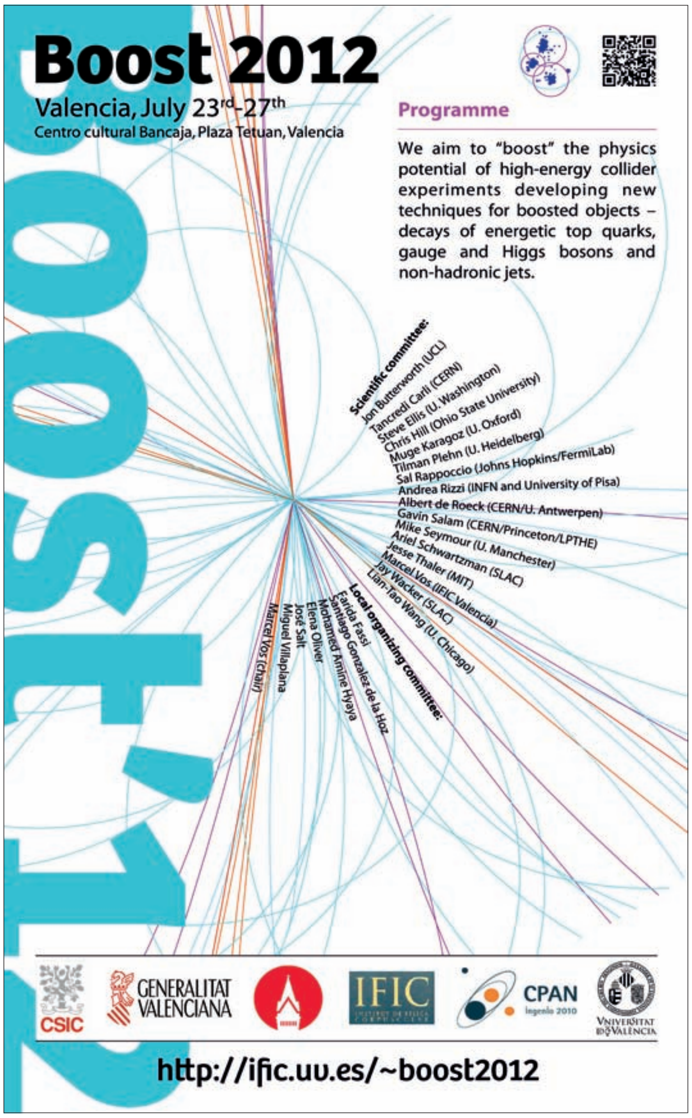
Techniques specifically developed for "boosted objects" – the highly boosted hadronic decays of the top quark and W and Z bosons – are taking over from more classical algorithms in searches for massive new particles at the LHC.

The LHC is a tremendously powerful tool built to explore physics at the tera-electron-volt scale. This year it is being operated with a centre-of-mass energy of 8 TeV, which is a little over half of the full design energy. This beats by a factor of four the previous world record held by Fermilab's Tevatron, which shut down a year ago. For the study of ultrahigh-energy collisions, a second figure of merit of the machine – luminosity – is also of crucial importance. Here, the LHC is living up to its promise. In the first 8 months of proton–proton operations in 2012, the ATLAS and CMS experiments have registered close to 10 fb^{-1} at 8 TeV, a data set similar to that collected during the entire 10-year Run II at the Tevatron.

In this uncharted territory at the energy frontier, known particles behave in unfamiliar ways. For the first time, the heaviest known particles – the W and Z bosons, the top quark and the recently discovered new boson – do not seem quite so heavy. Their rest masses (of the order 100 GeV) are small compared with the energy unleashed in the most energetic collisions, which can be up to several tera-electron-volts. Therefore, every so often these massive particles are produced with an enormous surplus of kinetic energy such that they fly through the laboratory at enormous speed.

A serious challenge

The velocity of these massive particles has implications for the way that they are observed in experiments. For particles produced with a large boost, the decay products (leptons or jets of hadrons) are emitted at small angles to the original direction of their parent. The full energy of the massive particle is deposited in a tiny area of the detector. Reconstructing and selecting these highly collimated topologies represents a serious challenge. For a sufficiently large boost, the two jets of particles that appear in hadronic two-body decays (W, Z, $H \rightarrow q\bar{q}$) cannot be resolved by standard reconstruction algorithms.



Boost 2012

Valencia, July 23rd-27th

Centro cultural Bancaja, Plaza Tetuan, Valencia

Programme

We aim to "boost" the physics potential of high-energy collider experiments developing new techniques for boosted objects – decays of energetic top quarks, gauge and Higgs bosons and non-hadronic jets.

Scientific committee:
Jon Butterworth (UCL)
Tancredi Carli (CERN)
Steve Ellis (U. Washington)
Chris Hill (Ohio State University)
Muge Karagoz (U. Oxford)
Tilman Plehn (U. Heidelberg)
Sal Rappoccio (Johns Hopkins/FermiLab)
Andrea Rizzi (INFN and University of Pisa)
Albert de Roeck (CERN/U. Antwerpen)
Gavin Salam (CERN/Princeton/LPTHE)
Mike Seymour (U. Manchester)
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Local organizing committee:
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Santiago Gonzalez de la Hoz
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Elena Oliver
José Salt
Miguel Villaplana
Marcel Vos (chair)

http://ific.uv.es/~boost2012

The poster for BOOST2012, showing a candidate event for a boosted top-quark.

An approach pioneered by Michael Seymour, now at Manchester University, provides an interesting alternative by simply turning the problem round (Seymour 1994). Instead of trying to resolve two jets and adding up their momenta to reconstruct the parent particle, the technique is to reconstruct a single jet that contains the full energy of the decay. The fat jet containing the decay of a boosted object must then be distinguished from ordinary jets that are ▷

Expected number of events	Tevatron run II 10 fb^{-1} @ 1.96 TeV	LHC 2012 20 fb^{-1} @ 8 TeV	LHC design 300 fb^{-1} @ 13 TeV	High-energy LHC 300 fb^{-1} @ 33 TeV
Inclusive $t\bar{t}$ production	60,000	4,000,000	200,000,000	1,400,000,000
Boosted production $m_{t\bar{t}} > 1$ TeV	23	60,000	5,200,000	71,000,000
Highly boosted $m_{t\bar{t}} > 2$ TeV	0	480	110,000	3,900,000

Expected number of events at past, present and future colliders. Inclusive production is dominated by top quarks produced approximately at rest. The boosted and highly boosted kinematic regimes are defined on the basis of the invariant mass of the top-quark pair. Numbers are obtained with a next-to-leading order calculation implemented in the MCFM code and MSTW2008NLO parton distribution functions for proton and antiproton.

produced by the million at the LHC. This is achieved through an analysis of the jet's internal structure. This alternative appears to be the most promising approach whenever the energy of the massive particle exceeds its rest mass by a factor of three or more. The boosted regime thus starts at an energy a little over 200 GeV for a W boson and at roughly 500 GeV for a top quark.

Dawn of the boosted era

The LHC is the first machine where boosted objects are a crucial part of the physics programme. A more quantitative grasp of exactly how the LHC crosses the threshold of the boosted regime is obtained by comparing the expectation in the Standard Model for the production rate of top quarks – the heaviest known particle – at past, present and future colliders.

Since the discovery of the top quark in 1995, the Tevatron has produced tens of thousands of these particles. A large majority of these were produced approximately at rest; only two dozen or so top quark pairs had a mass exceeding 1 TeV. By contrast, the LHC is a real top factory. In 2012 alone, it has already produced more than 20 times as many top-quark pairs as the Tevatron had in its lifetime. At the LHC, most top-quark pairs are still produced close to threshold but production in the boosted regime increases by several orders of magnitude. Several tens of thousands of top-quark pairs will be produced this year with $m_{t\bar{t}} > 1$ TeV.

Impressive as these numbers may be, these first years mark just the start of a long programme. After a shutdown in 2013–2014, the LHC should emerge in its full glory, with protons colliding close to the design energy of 14 TeV and the experiments collecting tens of inverse femtobarns of data each year. Boosted top quarks will be produced by the millions in the next phase of the LHC and a sizeable sample of top quarks with tera-electron-volt energies is expected.

Over the past few years, much work has been done to address the experimental challenges inherent in the new approach for boosted objects. Using the substructure of jets requires a precise understanding of how they are formed. Sophisticated new algorithms to identify boosted objects – W-taggers, top-taggers, Higgs-taggers – have been put forward and developed further by the LHC experiments.

The potential of these new methods to improve the sensitivity of LHC analyses has been estimated by using Monte Carlo simulations. One obvious area where tools tailored to boosted topologies might make a difference is in searches for signals of physics beyond the Standard Model in the most energetic collisions. Several such cases have been studied in detail. A significant pay-off in physics return is expected in resonance searches in the $t\bar{t}$ mass spectrum and studies of diboson production at high energy. Boosted techniques may also be applied to the high-energy tails of continuum production in the Standard Model. In what has become a seminal paper, the seemingly hopeless Higgs search in the WH, $H \rightarrow b\bar{b}$ channel was resurrected by requiring that the Higgs boson is produced with moderate boost (Butterworth *et al.* 2008).

BOOST2012

By bringing together key theorists and experimentalists every year, a series of workshops known as BOOST offers a forum for discussion of the progress in this fast-moving field. The first of these at SLAC (2009) and in Oxford (2010) focused on Monte Carlo studies that laid the foundations for what was to come. At Princeton in 2011, the first measurements on LHC data of jet substructure were shown, as well as candidate events for the world's first boosted top quarks. The display of one of these was chosen as the logo for the latest workshop, BOOST2012, organized by the Instituto de Física Corpuscular (IFIC) in Valencia. Held near the Mediterranean in late July – soon after the historic announcement at CERN of the discovery of a Higgs-like boson – this latest workshop definitely held the promise of becoming the "hottest" BOOST event so far. The 80 or so participants definitely did not let the organizers down.

A lively debate arose in the session centred on attempts to predict the invariant mass of energetic jets, comparing them with the more sophisticated measurements that have become available this year. Experimentalists and theorists joined efforts to develop new techniques to deal with the impact of the 30 overlapping collisions that occur every time that the LHC bunches cross. The recent discovery at CERN fuelled the discussion on the potential of these techniques to help isolate a Higgs signal in the crucial $b\bar{b}$ decay channel. However, perhaps the most exciting results were presented in the session on applications of these new ideas to searches for new physics with top quarks at the LHC.

Speakers from the ATLAS and CMS collaborations reviewed their experiments' searches for top-quark pair production through processes not present in the Standard Model. Some of these use the classical scheme to reconstruct top quarks, where the hadronic top-quark decay ($t \rightarrow Wb \rightarrow b\,q\bar{q}$)) is reconstructed by looking for three jets and then combining their four-vectors. Other searches adopt the "boosted" approach and reconstruct highly boosted top quarks as a single jet. While all searches have yielded negative results – reconstructed $t\bar{t}$ mass spectra following the Standard Model template to a frustrating precision – an evaluation of their relative sensitivity yields an encouraging conclusion. In both experiments, searches employing novel techniques specifically designed for boosted top-quark decay topologies are found to be considerably more sensitive than their classical counterparts in the high-mass region. This was expected from Monte Carlo studies, but these analyses show that the systematic uncertainties in the description of jet substructure, as well as the impact of pile-up on the experiments' performance, are under control. In that sense, seeing these excellent results so early in the LHC programme constitutes a real proof of principle for this new approach.

The LHC produces – for the first time in the laboratory – large numbers of highly boosted heavy Standard Model particles. Results presented at BOOST2012 show that the development of new tools is on track to extract the maximum knowledge from the most energetic collisions. After careful commissioning and with conservative estimates of the uncertainties that affect this new approach, the first analyses employing boosted techniques to search for $t\bar{t}$ resonances clearly outperform their classical counterparts. These results are a milestone for the people in the field. The boosted paradigm is clearly ready to take on a major role in the LHC physics programme.

● *The author would like to thank Gavin Salam for his useful comments in the preparation of this document*

● Further reading

J Butterworth *et al.* 2008 *Phys. Rev. Lett.* **100** 242001.
M Seymour 1994 *Z. Phys.* **C62** 127.

For more information about the challenges and potential of boosted objects, see the reports from BOOST2010 (2011 *Eur. Phys. J.* **C71** 1661) and BOOST2011 (2012 *J. Phys.* **G39** 063001), as well the BOOST2012 website, http://ific.uv.es/boost2012/.

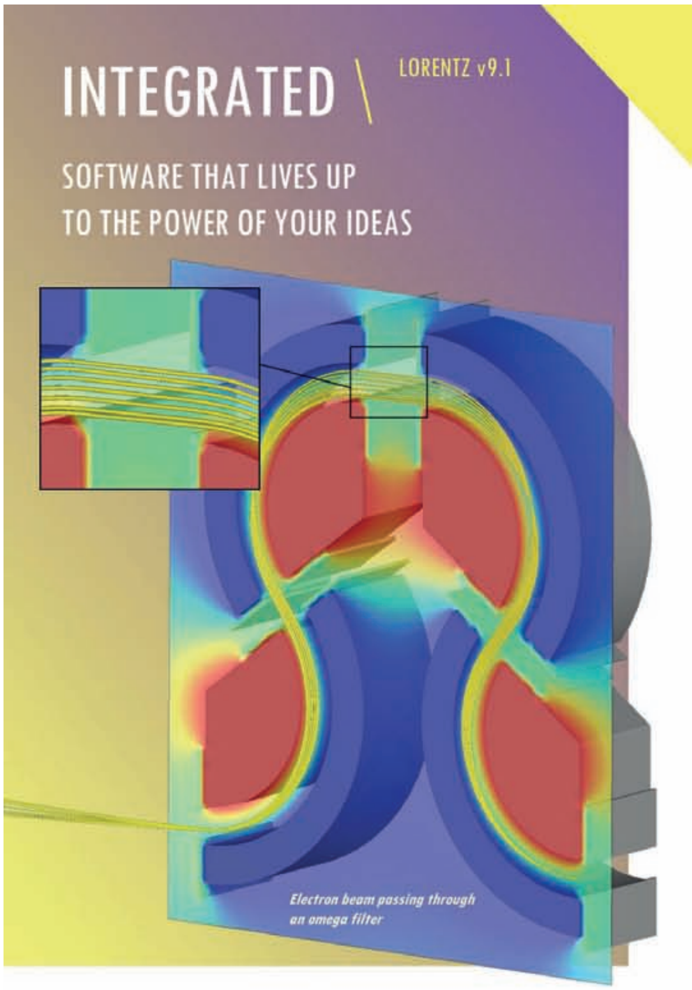
Relevant results from ATLAS and CMS can be found at: ATLAS collaboration 2012 *Eur. Phys. J.* **C72** 2038; ATLAS collaboration 2012 arXiv:1207.2409v1 [hep-ex], accepted by JHEP; and results shown at BOOST2012: ATLAS-CONF-2012-102, CMS-EXO-11-093-PAS, CMS-PAS-TOP-11-010 and CMS-PAS-EXO-11-053.

Résumé

Boosté pour la nouvelle physique

Du fait des hautes énergies atteintes au LHC, pour la première fois, les particules les plus lourdes connues ne semblent plus si lourdes ; leur masse au repos (de l'ordre de 100 GeV) est faible si on la compare à l'énergie des collisions. Ces particules massives peuvent être produites avec de grandes énergies cinétiques – elles sont « boostées » en quelque sorte – ce qui entraîne des conséquences sur la façon dont elles sont observées dans les expériences. Les techniques d'analyse mises au point pour ces « objets boostés » prennent maintenant le relais par rapport aux algorithmes plus classiques utilisés pour la recherche de nouvelles particules au LHC. Les ateliers BOOST rassemblent des théoriciens et des expérimentateurs pour discuter de ces évolutions.

Marcel Vos, IFIC Valencia (U Valencia/CSIC) and ATLAS, chair of the local organizing committee for BOOST2012.



Faces & Places

ASTROPARTICLE PHYSICS

Largest Cherenkov telescope sees first light

The largest Cherenkov telescope ever built has come into operation at the High Energy Stereoscopic System (HESS) in Namibia. HESS II joins the four smaller (12 m) telescopes that have been operating at the HESS observatory since 2004, a site dedicated to observing the most violent and extreme phenomena of the universe in very high-energy gamma-rays.

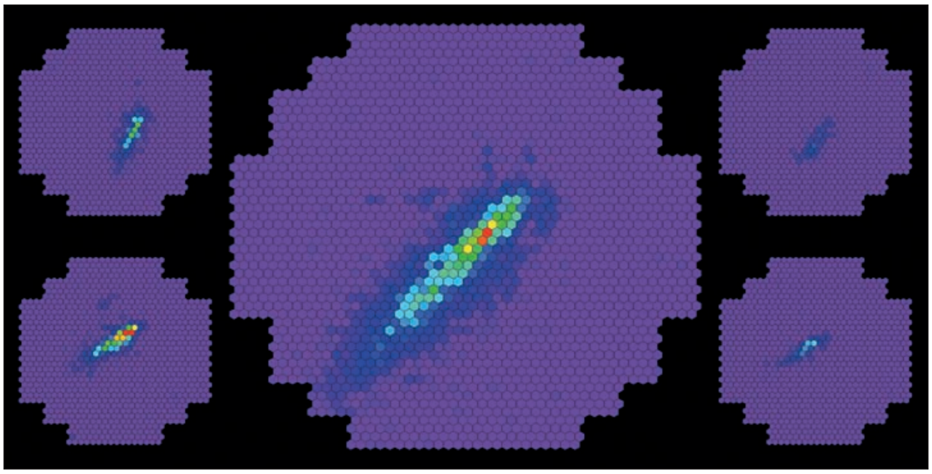
The new telescope has a mirror 28 m in diameter – equal in area to two tennis courts – and weighs almost 600 tonnes. It saw its first light in the early morning of 26 July, producing images of the particle cascades that are generated in the atmosphere by cosmic gamma rays and cosmic rays. With four times as many pixels for an area of sky compared with the smaller HESS I telescopes, HESS II can resolve unprecedented detail in the cascade images. It will explore the gamma-ray sky at energies in the range of tens of giga-electron-volts in the poorly explored transition region between current space-based instruments and ground-based telescopes.

When gamma rays interact high in the atmosphere, they generate a cascade of secondary particles that emit faint blue Cherenkov light as they traverse the atmosphere. This light can be recorded by ultrafast photodetectors, forming a "camera" at the focal planes of telescopes on the ground. The HESS II camera – weighing almost 3 tonnes – is 36 m above the primary mirror in the focal plane. Despite its size, the new telescope will slew twice as quickly as the smaller telescopes to respond immediately to fast and transient phenomena anywhere in the sky, such as gamma-ray bursts.

The most extreme gamma-ray emitters – active galactic nuclei – shine in gamma rays with an apparent energy output equivalent to 100 times the luminosity of the entire Milky Way, yet the radiation appears to emerge from a volume much smaller than that of the Solar System. It also turns on and off in a matter of minutes – a strong signature of supermassive black holes. Some of the objects seen with the four HESS I telescopes have no known counterpart at other wavelengths; they may represent a new type of celestial object that HESS II will help to characterize.

The HESS observatory has been in operation for a decade by a collaboration of more than 170 scientists from 32 scientific institutions in Namibia and South Africa, Armenia, Australia, Austria, the Czech Republic, France, Germany, Ireland, the UK, Poland and Sweden. The telescope structure and drive system for HESS II were designed by engineers in Germany and South Africa and produced in Namibia and Germany. The 875 hexagonal mirror facets that make up the huge reflector were manufactured in Armenia and individually characterized in Germany. The mirror-alignment system is the result of co-operation by German and Polish institutes. The camera, with its integrated electronics, was designed and built in France. The construction of the new HESS II telescope was driven and financed largely by German and French institutions, with significant contributions from Austria, Poland, South Africa and Sweden.

The HESS II telescope. (Image credit: HESS collaboration/Frikkie van Greunen.)



Images of particle cascades viewed simultaneously by the HESS II telescope (centre) and by the four HESS I telescopes (shown at a reduced size). Colour encodes light intensity. The images illustrate the dramatically improved intensity and resolution with which HESS II views the particle cascades. (Image credit: HESS collaboration.)

CONFERENCE

Munich welcomes Strings 2012

The poster for Strings 2012 shows Kämpfende Formen *("Fighting Forms") by Franz Marc (1914), an important German expressionist artist. The picture can be seen at Pinakothek der Moderne, the museum of modern art in Munich. (Image credit: layout design by Marco Baumgartl.)*

Edward Witten introduced string theory and its fundamental concepts in his public lecture to an audience of 750. (Image credit: A Grisch/Max-Planck Institute for Physics.)

The world's largest and most important annual conference on string theory, Strings, took place this year on 23–28 July at the Ludwig Maximilians University in Munich. Around 400 physicists from more than 35 countries gathered at Strings 2012 in Bavaria's capital to discuss recent developments, results and the future of string theory. The scientific programme was divided between seven research areas and lecture series. The sessions on each scientific field started with a plenary talk as an overview, with several technical lectures completing the programme for each scientific area.

In string theory, matter and fundamental forces arise from the vibrational modes of one-dimensional strings. String theorists seek to unite all physical forces in a universal theory, which includes the unification of the five different versions of string theory as proposed by Edward Witten. Following this successful unification, a theory of everything seems closer than ever. However, all string theories predict the existence of extra dimensions of space, which do not impinge directly on the everyday world but could have repercussions for the physics of the universe. If string theories are unable to define uniquely the exact nature of the hidden dimensions, then the question arises whether a "multiverse" exists (*CERN Courier* December 2007 p13).

Following the latest results of the Higgs search at the LHC, the conference saw much discussion about possible impacts on physics beyond the Standard Model. Will there be more to reveal at the LHC, such as the supersymmetric particles that have been postulated? Supersymmetry predicts that each of the known elementary particles has an as yet undiscovered partner. If supersymmetric particles can be detected by the LHC, then their properties could help pin down which concept of the hidden dimensions in string theory best describes the universe. Nobel laureate David Gross highlighted the importance of possible discoveries at the LHC during his excellent outlook talk, in which he presented his vision for string theory.

Another significant and much discussed topic was the progress in formulating a holographic description of the laws of quantum physics. This scientific endeavour generalizes the basic holographic principle, which allows the generation of a 3D image or hologram from a 2D surface. Juan Maldacena, founder of the holographic description in the context of string theory and a plenary speaker at Strings 2012, has invoked this principle to link Albert Einstein's theory of gravity with quantum physics. These ideas have led not only to deeper insights into the nature of quantum gravity, they are also being applied fruitfully in other fields, such as solid-state physics. Indeed, it turns out that gravitational solutions that describe black holes can also account for the properties of certain metals and superconductors. In his talk, Hermann Nicolai of the Max Planck Institute for Gravitational Physics in Potsdam presented alternative formulations of quantum gravity and discussed related open issues.

Other fervent discussion topics on the scientific schedule included the use of higher-spin theories as a refined test for anti-deSitter/conformal field theory correspondence by relating higher spin theories in the bulk to infinite dimensional W-algebras on the boundary. Black-hole complementarity versus firewalls, as well as subjects on quantum gravity in de Sitter space were also talking points.

String theory has become one of the most active and exciting research areas in modern theoretical physics and has aroused much interest not only among scientists but also with the media and the public. All of the speakers mentioned above attended the exclusive Strings 2012 press conference on 24 July. A high number of print and broadcast media representatives attended and took the opportunity to ask the scientists many questions.

Two public lectures were presented in association with the conference in the Main Aula at Ludwig Maximilians University. Rolf Heuer, CERN's director-general, gave an impressive lecture about particle physics, the LHC and the status of the Higgs search. The audience was also privileged to hear from Witten himself, who gave a remarkable talk about string theory and its fundamental concepts.

"German precision collides with Bavarian hospitality, an obvious success," is how Lars Brink of Chalmers University and the international advisory committee described Strings 2012 at the conference dinner, in appreciation of the well organized meeting. Dieter Lüst, chair of the local organizing committee, was for his part pleased to welcome so many outstanding scientists to Munich

● Strings 2012 was organized jointly by the Ludwig Maximilians University Munich, the Max-Planck Institute for Physics, the Arnold Sommerfeld Centre for Theoretical Physics and the Excellence Cluster Universe at the Technical University Munich.

MEETING

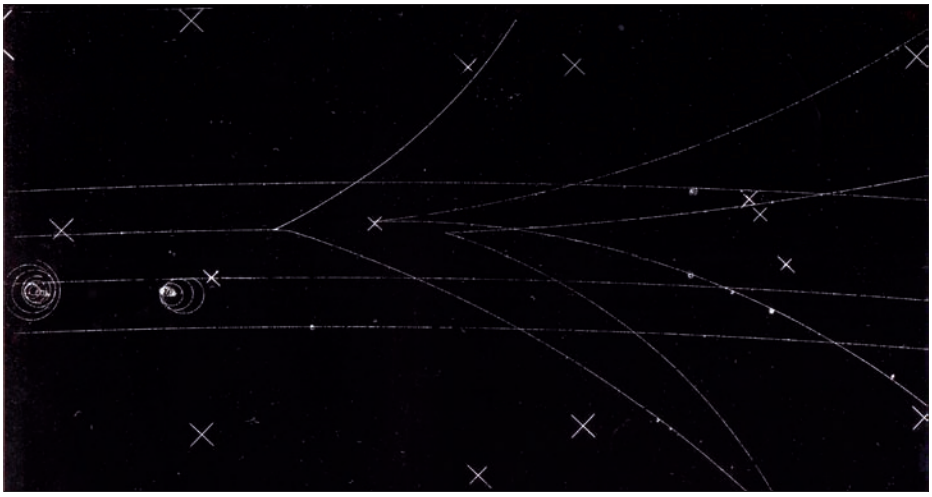
The **9th Vienna Central European Seminar on Particle Physics and Quantum Field Theory** is to be held at the University of Vienna on 30 November – 2 December. This year's subject is "Dark matter, dark energy, black holes and quantum aspects of the universe". Speakers include Sir Roger Penrose, who will also give a public lecture. For details, see www.univie.ac.at/vienna.seminar/2012.

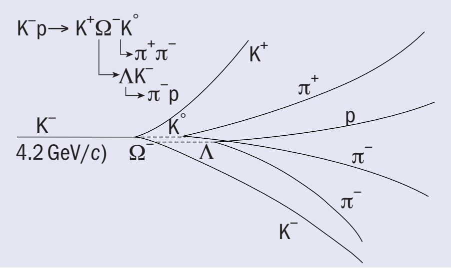
PAST EVENTS

A look back at a beautiful Ω^-

In July 1962, at the 11th "Rochester" Conference (now better known as the International Conference on High-Energy Physics), Murray Gell-Mann presented the scheme based on SU(3) symmetry that he and Yuval Ne'eman had developed to describe the proliferation of new particles. This needed one particle, the Ω^-, to complete an SU(3) decuplet of baryon resonances. The famous first example was discovered at Brookhaven National Laboratory in 1964, followed a year later by a few at CERN (*CERN Courier* November 2008 p12). Almost a decade later, fewer than 30 Ω^- events had been seen from only a handful of experiments.

Early in the 1970s, the Amsterdam-CERN-Nijmegen-Oxford collaboration proposed the first large-scale exposure of the CERN 2 m hydrogen bubble chamber to a 4.2 GeV/*c* K^- beam. With 3 million pictures, the goal was to measure all events with visible strange-particle decay to improve significantly on existing data. The production of the Ω^- was just possible kinematically, so Richard Hemingway, a member of the CERN team, encouraged the scanning team to look out for its characteristic signature in film taken in 1973. Some time in 1974, one of them succeeded, finding the event shown here – possibly the best ever taken of the Ω^-, with all of the produced particles clearly visible and identified by their bubble density. The experiment ultimately found 40 examples and provided good measurements of the mass and lifetime.





An Ω^- decay in CERN's 2 m hydrogen bubble chamber, found in 1974 in the experiment by the Amsterdam-CERN-Nijmegen-Oxford collaboration.

Further reading

R J Hemingway *et al.* 1978 *Nuclear Physics* **B142** 205.

VISIT

The French prime minister, **Jean-Marc Ayrault**, left, and French minister of higher education and research, **Geneviève Fioraso**, centre, were welcomed to CERN on 30 July and accompanied in the LHC tunnel by CERN's director-general, **Rolf Heuer**. During their visit they toured the CMS underground experimental area and viewed the *Universe of Particles* exhibition in the Globe of Science and Innovation before participating in a round-table discussion with members of the French and international scientific communities working at CERN.

Dinesh Kumar Srivastava, an eminent nuclear physicist, took over as director of the Variable Energy Cyclotron Centre (VECC) in Kolkata on 1 July, succeeding Rakesh Kumar Bhandari. VECC has a long association with CERN and is a collaborating institute of the ALICE experiment at the LHC. The centre carries out frontier research and development both in accelerator science and technology and in theoretical and experimental nuclear science, as well as in other areas such as material science, and computer science. (Image credit: VECC.)

Faces & Places

NEW PRODUCTS

Highland Technology Inc has announced the T240 single-channel externally triggered complementary-output pulse generator for driving electrical/optical modulators. The T240 features delay/pulse width in two ranges, from 100 ps FWHM up to 25 ns, and a programmable trigger threshold. It is controlled via USB, RS232 or trimpots and is powered by USB or standard 5 V micro-USB power supply. The T240 is also useful for RF applications including fast-pulse modulation and harmonic generation. For further details, tel +1 415 551 1700, fax +1 415 551 5129, e-mail info@highlandtechnology.com or see www.highlandtechnology.com.

ID Quantique has launched a new time-to-digital converter, the id800-TDC, with eight channels. This system is used to transfer the time-tags of events to a PC with picosecond precision and at high rates. It can also count single and multiple channel-coincident events at higher rates internally and convey those to a PC. A graphical user interface is supplied for Windows and Linux, with software examples are available for C/C++ and Labview. For more information, contact Michaël Désert, tel +41 22 301 8371, fax +41 22 301 8379, e-mail info@idquantique.com or visit www.idquantique.com.

Micromech has introduced the Parker Hannifin NX1, a robust brushless servomotor for applications including machine tools, X-Y tables and a variety of special-purpose machinery. This development extends torque output down to 0.45 Nm. The NX1 series is now the smallest product in Parker's existing range of brushless permanent-magnet synchronous servomotors, which offer a choice of torque outputs from 0.45 to 64 Nm, with power ratings from 0.2 to 13.7 kW at operating speeds of up to 7500 rpm. For further details, contact Alan Spinks, tel +44 1376 333 333 or e-mail alan@micromech.co.uk.

Photonic Science has announced the new high-sensitivity full HDTV low-noise cooled sCMOS camera, which delivers read-out noise as low as 1.2 electrons at 100 MHz overall scanning frequency. It is targeted at users with low light-level requirements, seeking real-time acquisition with high dynamic range > 20,000:1. The camera actively compensates for fixed-pattern noise, non-uniform response and gain balance on a parallel bus read-out architecture. For more information, contact Diane Brau, tel +33 476 935 720, fax +33 476 935 722, e-mail Diane@photonic-science.com or see www.photonic-science.com.

Telonic Instruments has launched a new low-cost, high-quality digital-spectrum analyser, the DSA815, manufactured by Rigol. The latest in a range of fast compact and lightweight spectrum analysers, the DSA815 can distinguish small signals to a frequency difference of only 100 Hz. The IF filter also enables smaller bandwidth settings. The DSA815 is available in a 9 kHz to 1.5 GHz frequency range, with a typical 135 dBm displayed average noise level for accurate measurements. For further details, contact Bob or Doug Lovell, tel +44 118 978 6911 or visit www.rigol-uk.co.uk.

Wavelength Electronics has redesigned the PLD10000 laser diode driver with a new compact heat sink and fan shroud, and improved internal heat-dissipation capability. This technology has also been leveraged into a high-current driver, the PLD12500, that can drive up to 12.5 A. Mounted on printed circuit boards, both can drive lasers with compliance voltage as high as 27.5 V and both include laser-safety features designed to enhance system reliability. For more information, tel +1 406 587 4910, fax +1 406 587 4911, e-mail sales@teamwavelength.com or see www.teamwavelength.com.

*Jan Hladký, an experimental physicist at the Institute of Physics of the Czech Academy of Sciences, has made many sculptures over the years based on recycled materials from particle-physics labs (*CERN Courier *June 2011 p46). His latest work is a celebration of the new boson discovered at CERN (*CERN Courier *September 2012 p46). The lower black glass plate (80 cm × 50 cm) represents the black mass of the universe. It is covered by a semi-black glass plate with a decoration (circles) that represents a field (the Higgs field?). An excited field particle appears as crystal glass, its decay through various channels symbolized by the ring with metal fingers. This includes two-gamma decay (the two fingers on the left), lepton decays (the few disordered fingers) and channels that are so far undiscovered (the undisturbed fingers). The large copper ring indicates zero spin – which, of course, is still to be confirmed. (Image credit: Renata Louvarova.)*

Bryan Webber, emeritus professor at the University of Cambridge, was awarded the degree of Doctor Honoris Causa at Lund University on 25 May. Webber has made a number of seminal contributions to particle-physics phenomenology. Among other honours, he received the 2008 Dirac Medal from the UK Institute of Physics and the 2012 J J Sakurai Prize from the American Physical Society. (Image credit: Lund University.)

SCHOOL

CAS course in Slovakia focuses on ion sources

Each spring, the CERN Accelerator School (CAS) offers a course on a speciality of accelerator physics. This year it was the turn of ion sources to feature in a course that was organized jointly by CAS and the Slovak University of Technology and held in Senec, Slovakia, on 29 May – 8 June.

Following some lectures that recapitulated background accelerator physics and the fundamental processes of atomic and plasma physics, the course went on to cover a range of topics related to ion sources and highlighted the latest developments in the field. Realistic case studies and topical seminars completed the programme. In addition, the participants were able to enjoy a one-day excursion that included a guided tour of Bratislava.

The school attracted 69 participants representing 25 nationalities. Their feedback was extremely positive, reflecting the high standard of the lectures. The case studies were pursued with great enthusiasm and produced some excellent results.

Marta Cimbáková, left, representing the ministry of education, science, research and sport of the Slovak Republic, with Marius Pavlovic of the Slovak University of Technology, the local organizer of the school. (Image credit: Peter Janata.)

A welcome event at the Hotel Senec included speeches by CERN's Roger Bailey, head of CAS, Marta Cimbáková, representing the ministry of education, science, research and sport of the Slovak Republic, Peter Ballo, a vice-dean of the faculty of electrical engineering and information technology of the Slovak University of Technology in Bratislava, Michal Petráš, director-general of the Hotel Senec, and Vladivoj Řezník, representing Slovenské Elektrárne As.

The next specialized CAS course will be on "Superconductivity for Accelerators" and will take place in Erice, Italy, on 24 April – 4 May 2013 (see www.cern.ch/schools/CAS).

● The CERN Accelerator School is grateful to the following sponsors: the City of Senec, EBG MedAustron Wiener Neustadt, GSI Helmolzzentrum Darmstadt, ministry of education, science, research and sport of the Slovak Republic via project KEGA 019STU-4/2012, Nadačný fond Slovenských Elektrární v Nadácii Pontis, ZŤS VVÚ KOŠICE As.

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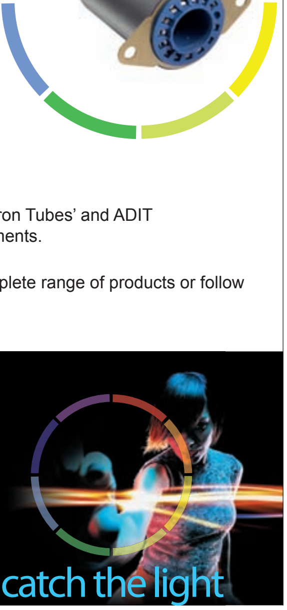

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LIGO

Postdoctoral Research Positions
LIGO Laboratory

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 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. The initial LIGO detectors have exceeded their design sensitivity and data sets spanning almost two years of coincidence operation have been collected. Analysis is ongoing, with extensive participation by the LIGO Scientific Collaboration (LSC). A major upgrade (Advanced LIGO) is now underway which will increase the sensitivity of the detectors by tenfold. In addition, a vigorous R&D program supports the development of enhancements to the detectors as well as future capabilities.

The LIGO Laboratory may have one or possibly more postdoctoral research positions at Caltech, MIT and at the two LIGO observatory sites beginning in Fall 2013, pending availability of funds. Hires will be made based on the availability of funding. Successful applicants will be involved in the operation of LIGO itself, analysis of data, both for diagnostic purposes and astrophysics searches, as well as the R&D program for future detector improvements. Expertise related to astrophysics, modeling, data analysis, electronics, laser 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).

Applications should include curriculum vitae, list of publications (with referred 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 January 1, 2013 and will continue until all positions have been filled.

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These positions are available on September 1, 2013. Interested applicant should email his/her application with curriculum vitae, research statement, publication list and three letters of recommendation before December 1, 2012 to
Ms. Yen-Ling Lee **ntulecospa@ntu.edu.tw**
For more information about LeCosPA, please visit its website at
http://lecospa.ntu.edu.tw/

Three letters of recommendation should be addressed to
Prof. Pisin Chen, Director
Leung Center for Cosmology and Particle Astrophysics
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Human Resources Department | Code: EM100/2012
Notkestraße 85 | 22607 Hamburg | Germany | Phone: +49 40 8998-3392 |
E-Mail: personal.abteilung@desy.de
Deadline for applications: 30 September 2012
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The **Heidelberg Graduate School of Fundamental Physics (HGSFP)** at the Department of Physics and Astronomy at Heidelberg University, a school funded by the German Excellence Initiative, invites applications for

Doctoral Fellowships

in the following areas of modern fundamental physics: (a) Astronomy and Cosmic Physics, (b) Quantum Dynamics and Complex Quantum Systems, (c) Fundamental Interactions and Cosmology, (d) Complex Classical Systems, (e) Mathematical Physics, and (f) Environmental Physics. Thesis research topics cover areas such as experimental and theoretical astrophysics, cosmology, accelerator based particle physics, precision measurements in physics, study of quantum systems – many body as well as small systems, low as well as high temperature physics, atomic, molecular and optical physics, mathematical physics and string theory. In addition, fundamental problems in biophysics, e.g. in material science aspects of cell biology, and in environmental physics are studied. The HGSFP combines doctoral projects at the forefront of international research in the areas mentioned above with a rich and thorough teaching programme. Further information can be found on the School's web site: **http://www.fundamental-physics.uni-hd.de**.

The branch Astronomy & Cosmic Physics is the International Max Planck Research School (IMPRS) for Astronomy and Cosmic Physics at the University of Heidelberg **(http://www.mpia.de/imprs-hd)**. Students accepted into the Graduate School will automatically be members of the IMPRS-HD and conversely. Admission in the IMPRS for Precision Tests of Fundamental Symmetries **(www.mpi-hd.mpg.de/imprs-ptfs)**, or the IMPRS for Quantum Dynamics in Physics, Chemistry and Biology **(http://www.mpi-hd.mpg.de/imprs-qd)**, is also possible. The IMPRS offer doctoral positions and fellowships as well, and are combined efforts of Heidelberg University with the Max Planck Institutes for Astronomy and Nuclear Physics, which form an integral part of the exciting and broad research environment in Heidelberg.

Highly qualified and motivated national and international students are invited to apply. Applicants should preferably hold a Master of Science or equivalent degree in physics. Excellent candidates holding a four year bachelor degree and proof of research experience may also be considered. At equal level of qualification, preference will be given to disabled candidates. Female students are particularly encouraged to apply.

Applicants have to initiate their application registering via a web form available at **http://www.fundamental-physics.uni-hd.de/fellowships**. Applications should reach us by December 1, 2012.

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At the **Faculty of Science** in the **Institute for Nuclear and Particle Physics** we have an opening for a

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on a fixed-term position for an initial period until 31.12.2014. The contract may be extended by a second period until 31.12.2017. The period of employment is governed by the Fixed Term Research Contracts Act (Wissenschaftszeitvertragsgesetz - WissZeitVG). The ATLAS group at the TU Dresden is involved in the upgrade of the readout electronics of the ATLAS Liquid Argon Calorimeters and is developing high-bandwidth, parallel-processing modules for new readout and trigger concepts in the High Luminosity phase of the Large Hadron Collider. Core activities are FPGA-based solutions for signal filtering, signal extraction, fast data processing and transfer, and interfaces based on standardized, fast networks. Furthermore, their impact on future physics analyses is investigated and interplay with the Dresden physics activities in the fields of heavy Higgs boson searches in Tau-Lepton final states or Vector Boson Scattering is possible. The successful candidate is expected to play an important role in these activities and to strengthen our existing upgrade efforts. The position also involves teaching in physics related subjects at the University level. In particular, in the summer terms, the selected candidate will be responsible for the lecture series on Modern Physics for engineering students (in English language) and the organization of the corresponding laboratory course as part of the Boston University International Program. The candidates should have a Ph.D. in Experimental High Energy Physics or equivalent experience. Further details available online at: http://www.verw.tu-dresden.de/StellAus/einzelstelle.asp?id=2177&lang=en

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6 Junior Research Positions in Experimental, Theoretical and Astrophysics

The Department of Physics and Astronomy at Heidelberg University invites applications for 6 junior research group leaders in experimental or theoretical physics or astrophysics. The positions are open in the context of the **Heidelberg Graduate School of Fundamental Physics**, granted in the framework of the “Excellence Initiative” of the German Federal and State Governments. The areas of research in fundamental physics at Heidelberg University encompass particle physics and cosmology, astronomy and cosmic physics, quantum dynamics and complex quantum systems, complex classical systems, mathematical physics and environmental physics.

Applicants must hold a Ph.D. and have a strong international research record in one of the six research directions of the school, to complement existing expertise. Successful candidates will be supported in building up independent research groups including associated doctoral positions and significant startup funding for experimental groups. They are expected to supervise doctoral projects in their field and contribute to the Graduate School’s teaching programme.

Heidelberg University is an equal opportunity, affirmative action employer and encourages applications from female scientists.

The positions are limited to 5 years. Applications including the usual professional documentation should be sent until **15th October 2012** to the Spokesperson of the Graduate School, **Prof. Dr. Markus Oberthaler, Heidelberg Graduate School of Fundamental Physics, Central Office, INF 226, 69120 Heidelberg, Germany.**

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KIT
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KSETA has open positions for doctoral researchers in elementary particle physics, astroparticle physics and advanced technologies

The KIT-Center Elementary Particle and Astroparticle Physics KCETA is a major institution in elementary particle and astroparticle physics and technological developments. Our topics include cosmic rays, Dark Matter, quantum field theory, collider physics, flavour physics, neutrino physics and computational physics. We combine fundamental research – in theory and experiment – with the development of related modern technologies like superconducting detectors with terahertz bandwidth, analog and digital electronics, optical data transmission technology and parallel signal processing on FPGAs and GPUs. KCETA is a major contributor to leading-edge large-scale research projects such as AMS, Auger, Belle, CMS, EDELWEISS, JEM-EUSO and KATRIN; we host the German Tier-1 center GridKa and coordinate the Helmholtz Alliance for Astroparticle Physics.

The Graduate School KSETA has been established in the framework of the German Excellence Initiative; it will be in full operation from November 2012. We offer an inspiring interdisciplinary environment, international networking with research visits abroad, tailor-made course programs and career promotion.

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- Fermilab and LBNL (USA)
- KEK (Japan)
- UNSAM and ITeDA (Argentina)

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KIT – University of the State of Baden-Württemberg and
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www.kit.edu

Chief Scientist to lead a new laboratory in Nuclear Physics, RIKEN, JAPAN

RIKEN invites applications for the position of Chief Scientist (Laboratory Director) to lead a new laboratory in experimental nuclear physics using the RI Beam Factory (RIBF) of RIKEN Nishina Center for Accelerator-Based Science.

The present position is a permanent appointment, subject to RIKEN's mandatory retirement age of 60. RIKEN expects that the successful applicant will be able to take up this position on April 1st, 2013.

Applicants should send a full curriculum vitae and photograph; list of publications; one copy each of five key publications; a statement (about five pages A4 sized paper) explaining former research experience, and proposals for research at RIKEN; and the names and addresses of three referees.

All applications should reach RIKEN by September 24th, 2012.

Applicants should address all correspondence to: Dr. Hiroyoshi Sakurai, Chair of the Chief Scientist Search Committee, RIKEN Nishina Center for Accelerator-Based Science, 2-1 Hirosawa, Wako, Saitama 351-0198, JAPAN (E-mail address: sakurai@ribf.riken.jp)

For more information, please visit:
http://www.riken.jp/engn/r-world/info/recruit/k120924_e_rnc.html

RIKEN

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The **Department of Physics and Astronomy at the University of Heidelberg** invites applications to fill – at the earliest possible date – a faculty position of

Professor (W3) in Experimental Physics

With this appointment, the Department intends to strengthen its research profile in the field of precision measurements in particle physics.

The successful candidate should have international standing in measuring the properties of heavy quarks and hadronic bound states. Experience with hadron colliders and interest in collaboration within the current LHCb experiment are desirable.

The professorship will be at the „Physikalische Institut“ of the Department of Physics and Astronomy. The teaching duties involve courses in experimental physics at all levels. Prerequisites for appointment are a university degree and (in accordance with Article 47, paragraph 2 of the Higher Education Law of the State of Baden-Württemberg) a Habilitation, a successfully evaluated junior professorship, or an equivalent qualification.

The Ruprecht-Karls-University in Heidelberg seeks to increase the proportion of female faculty and, for this reason, especially welcomes applications from women. Handicapped persons with the same qualifications will be given preference.

Qualified candidates are invited to submit their application until the 31st October 2012 with the usual documents and a research plan to the **Dean, Department of Physics and Astronomy, Im Neuenheimer Feld 226, D-69120 Heidelberg, Germany.**

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As founding members of the Cockroft Institute, the Universities of Liverpool and Manchester are seeking to appoint two post-doctoral research associates to contribute to the ongoing development of CLARA and ESS. The CLARA FEL research involves investigations of novel concepts for the production of ultra-short FEL pulses of varying colours for the next generation of FELs. There will also be opportunities to take part in experiments aimed at optimising and enhancing the ALICE FEL performance. The ESS research associate, will use state-of-the-art computer codes for modelling rf cavities and studying beam dynamics in multi-cavity systems. Both posts will involve analysis,simulation and experimental research in close collaboration with institute members in other universities as well as in Daresbury and Rutherford Appleton Laboratories.

Applicants must have a Ph.D. in accelerator physics, particle physics, electrical engineering or a related discipline. Informal inquiries about the institute may be made to Professor Swapan Chattopadhyay (swapan@cockcroft.ac.uk), about the ESS position to Professor Roger Jones (r.m.jones@cockcroft.ac.uk) and about the CLARA FEL positionto Dr. David Newton (D. Newton@liverpool.ac.uk).

The Cockcroft Institute
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Experimental Scientist

Full time fixed term for 2 years
(Reference IRC62488)

We are looking for an Experimental Scientist to develop high brightness laser driven X-ray sources. The vacancy is a 2 year fixed term post funded through the Centre for Advanced Laser Technology Group (CALTA) to examine and develop potential X-ray sources for imaging applications requiring high penetration. The Vulcan and Gemini lasers can deliver ultra-high intensity interactions, which produce bursts of highly energetic electrons. As these electrons propagate through matter they radiate bright beams of 0.1-2 MeV X-rays in a highly directional cone. You will be involved in modelling (using PIC and Monte-Carlo simulation packages) and conducting full experimental investigations with both the Vulcan and Gemini laser systems to determine the optimum conditions for producing such penetrating beams. As well as optimising the source, detector developments concentrating on producing high quality images in terms of resolution, contrast and sensitivity will also be undertaken.

Closing date: 12 Septmber 2012

Instrumental Scientist (Muon Spectroscopy)

Permanent (Reference IRC61268)

The ISIS Muon Group operates three muon spectrometers for condensed matter and molecular studies using the muon spin rotation/relaxation/resonance technique. These spectrometers are used by researchers from around the world for muon measurements in the areas of magnetism, superconductivity, charge transport, molecular and chemical studies, and modelling hydrogen behaviour in, for example, semiconductors or proton conductors. We are seeking an instrument scientist to join the Muon Group. You will be involved in providing experimental support for visiting researchers using the ISIS muon facilities and will be concerned with the on-going development of these facilities.

Closing date: 1 October 2012

Both roles are paying between £26,610 - £37,534 dependent on skills and experience and are based at the STFCs Rutherford Appleton Laboratory.

For more information on the Science & Technology Facilities Council please visit www.stfc.ac.uk Applications are handled by the RCUK Shared Services Centre; to apply please visit our job board at www.topcareer.jobs If you are unable to apply online please contact us on 01793 867003.

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IceCube Computing Facilities Manager

The **University of Wisconsin-Madison** is seeking candidates to manage the computing facilities for the IceCube project. UW-Madison is responsible to the National Science Foundation and the IceCube Collaboration for maintenance and operations of the IceCube Neutrino Observatory, a kilometer-scale neutrino detector at the South Pole. The collaboration includes scientists from over thirty research institutions worldwide who collectively participate in studies of high-energy neutrinos from cosmic sources and a range of scientific topics in Astroparticle Physics.

The IceCube Computing Facilities Manager is responsible for computing facilities located within the Wisconsin IceCube Particle Astrophysics Center (WIPAC), other UW-Madison campus locations, and at the South Pole. The manager also has responsibility to the IceCube Collaboration to provide timely access to IceCube data and upgrades to computing systems.

The IceCube data center includes approximately 3 PB of disk storage, over 1500 CPUs, and various tape storage facilities, including a 1.2 PB HSM. Computing systems at the South Pole consist of ~200 servers in various configurations for data reduction and storage.

A master's degree or higher in Physics, Computer Science, Electrical Engineering, or related field will be considered, Ph.D. is preferred.

Highly qualified candidates will have at least five years of direct experience managing large computing facilities used in a collaborative scientific research environment.

Pay range is USD $90,000 – $130,000 depending on qualifications, plus excellent benefits.

To view the full Position Vacancy Listing (PVL), go to
http://www.ohr.wisc.edu/pvl/pv_073267.html

Applicants should email their CV and cover letter referring to:
PVL #73267 to **hr@icecube.wisc.edu**.

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Bookshelf

The Quantum Exodus: Jewish Fugitives, the Atomic Bomb, and the Holocaust

By Gordon Fraser

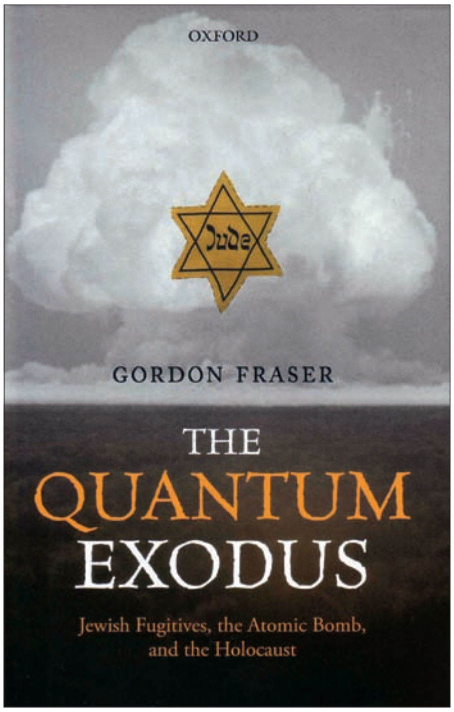
Oxford University Press

Hardback: £25

Don't be misled by the title of this book. It contains a surprising amount of information, much more than focusing on the exodus of Jewish scientists from Germany after the rise of the Nazi Party. The book puts anti-Semitism into a broad historical perspective, starting with the destruction of the Temple in Jerusalem, the expelling of the Jews all across Europe and the growth of a mild and sometimes hidden anti-Semitism. This existed in Germany in the 19th century and even to some extent under the Nazis, when the initial objective was to cleanse German culture of all non-Aryan influences. However, various phases led eventually to the Holocaust. A political spark was ignited when the parliamentary building in Berlin went up in flames in February 1933 and Adolf Hitler became Chancellor. The Civil Service Law was soon introduced that forbade Jews from being employed by the state, followed by the burning of books and the *Kristallnacht*, during which Jewish shops were destroyed – all of which were further steps towards the "final solution".

In parallel to these political developments, *Quantum Exodus* describes the rise of quantum physics in Germany during the 19th century, with protagonists such as Alexander von Humboldt, Wilhelm Röntgen, Hermann von Helmholtz, Max Planck, Walther Nernst and Arnold Sommerfeld. They attracted many Jewish scientists from all over Europe, among them Hans Bethe, Max Born, Peter Debye, Albert Einstein, Lise Meitner, Leó Szilárd, Edward Teller and Eugene Wigner, who went on to become key players in 20th-century physics. Most of them left Germany, some at an early time, others escaping at the last moment and most of them going to the UK or US, often via Denmark, with Niels Bohr's institute as a temporary shelter. An exodus also started from other countries such as Austria and Italy. The book recounts the adventurous and disheartening fates of many of these physicists. Arriving as refugees, they were initially often considered aliens and during the war sometimes even as spies. The author gives some spice to his narrative by adding amusing details from the private lives of some of the protagonists.

A detailed account is given of the Manhattan Project project and how the famous letter by Einstein to President Franklin Roosevelt initiated the building of the fission bomb. It was written as a result of pressure by Szilárd, the main mover behind the scenes. What is less known is the primordial importance of a paper by Otto Frisch and Rudolf Peierls in the UK, which already contained the detailed ideas of the fission bomb. Robert Oppenheimer, an American Jew, became scientific director of the Manhattan Project after his studies in Europe, bringing the European mindset to the US. He attracted many émigrés to the project, such as Bethe, Teller, Felix Bloch and Victor Weisskopf. The book relates vividly how Teller, because of his stubborn character, could not be well integrated into this project; rather, he pushed in parallel for the H-bomb.



The author implies, although somewhat indirectly, that the rise of Nazism and the development of the nuclear bomb have a deeper correlation, without giving convincing details. However, the interaction of science (its stars) and politics is well described. Bohr's influence, although at the centre of nuclear physics, was limited – partly because of his mumbling and bad English (something that I witnessed at the Geneva Atoms for Peace Conference in 1957, where his allocution in English had to be translated simultaneously into English.)

Many of the exiled physicists who worked on the Manhattan Project developed considerable remorse after the events of Hiroshima and Nagasaki. When I invited Isidor Rabi to speak at the 30th anniversary of CERN he considered his involvement in the foundation of CERN as a kind of recompense for his wartime activities.

The descriptive account of science in the US and Europe after the Second World War is interesting. In the US, politicians' interest in science decreased substantially and a change was introduced only when the shock of Sputnik led eventually to the "space race". Basic science also benefited from this change, leading for example to the foundation of various national laboratories such as Fermilab. In Europe, a new stage for science emerged when a pan-European centre to provide resources on a continental rather than a national scale was proposed and CERN was founded in 1954.

The book benefits from the fact that the author is competent in physics, which he sometimes describes poetically, but never wrongly. He has done extremely careful research, giving many references and a long list of Jewish emigrants. I found few points to criticise. Minor objections concern passages about CERN, although the author knows the organization so well. For example, the response of CERN towards the Superconducting Super Collider was the final choice of the circumference of the LEP tunnel (27 km) in view of the possibility of a later proton–proton or proton–electron collider in the same tunnel, while the definite LHC proposal came only in 1987; and the LHC magnets are superconducting to achieve the necessary high magnetic fields and not so much to save electricity.

The various chapters are not written in chronological order, and political or scientific developments are integrated with human destinies. This assures easy and entertaining reading. Like me, older readers who have known many of the protagonists, will not avoid poignant emotions. For young readers, the book is recommended because they will learn many historical facts that should not be forgotten.

One intriguing question (probably unanswerable) that was not considered, is: what would have happened to US science without the contribution of Jewish immigrants?

● *Herwig Schopper, University of Hamburg and CERN.*

Viewpoint

ESO and CERN: 50 years later

Catherine Cesarsky reflects on the long-standing relationship between the two flourishing European organizations.

Catherine Cesarsky. (Image credit: ESO.)

1948: The 5 m Hale telescope is inaugurated in Palomar, California. 1954: At the instigation of Jan Oort and Walter Baade, a group of renowned European astronomers meets to discuss how, by pooling the efforts of several countries, Europe could rise to the challenge and keep an important place in astronomical research; Jan Bannier, president of the CERN Council, is also present. A statement is adopted: "There is not a more urgent task for astronomers than to install powerful instruments in the southern hemisphere, and in particular a telescope … of at least 3 m." But the scars of the Second World War are there and it will take several years of discussion before, on 5 October 1962, five governments (Belgium, France, the Federal Republic of Germany, the Netherlands and Sweden) sign the convention that creates the European Southern Observatory, ESO. The convention was drafted by Bannier, largely adapted from the CERN convention in its constitutional set-up, its financial basis and its personnel regulations (p26). Thus, in a sense, ESO is a younger sibling of CERN.

Soon, it was decided to establish the observatory at a site in Chile, in the Atacama Desert, chosen for its large proportion of clear nights and its excellent sky quality. A suitable piece of land was purchased at La Silla, close to La Serena. By 1969, a number of 1-m-class telescopes were in operation. Attention then focused on the construction of a 3.6 m telescope. The young organization had not yet mastered the skills necessary for such an endeavour and problems appeared on many fronts. CERN offered its help and soon the ESO Telescope Project Division moved to the CERN. A participant in the preceding discussions, CERN's Kees Zilverschoon reported that "practically everyone … emphasized the importance of the collaboration between astronomy and high-energy physics [and] common technical developments … and the political aspect: formation of a 'Communauté scientifique européenne'." This was long before the discussions on a European area of research started at the political level. With the help of some CERN engineers, the 3.6 m telescope was completed by 1976. It is still in use today, in particular for the successful search for extra-solar planets with the HARPS spectrometer.

ESO was offered new headquarters in Garching by the German government, settling there in 1980. By then, it had an excellent set of experienced engineers and in 1989 deployed a revolutionary 3.5 m telescope, the New Technology Telescope (NTT). This introduced "active optics" in which the effects of gravity, winds and temperature on image quality are counteracted by controlling the shape of the primary mirror and the position of the secondary mirror.

Even before the first light of the NTT, ESO had begun the Very Large Telescope (VLT) project. It all started in December 1977 with a lively conference at CERN on "Optical Telescopes of the Future". Detailed studies led to the selection of an array of four telescopes of 8.2 m aperture and with active optics, with the NTT serving as a prototype for the construction of the VLT. An impressive suite of first- and second-generation instruments, most of them developed in national laboratories, have been placed at the 11 available foci, while the 12th is reserved for visitor instruments. The second ESO observatory, on Mt Paranal – with its four large VLT telescopes, four 1.8 m telescopes dedicated to interferometry and two telescopes devoted to surveys of the sky in the optical and the infrared – is now the most productive observatory in the world, allowing major advances in virtually all fields of astrophysics.

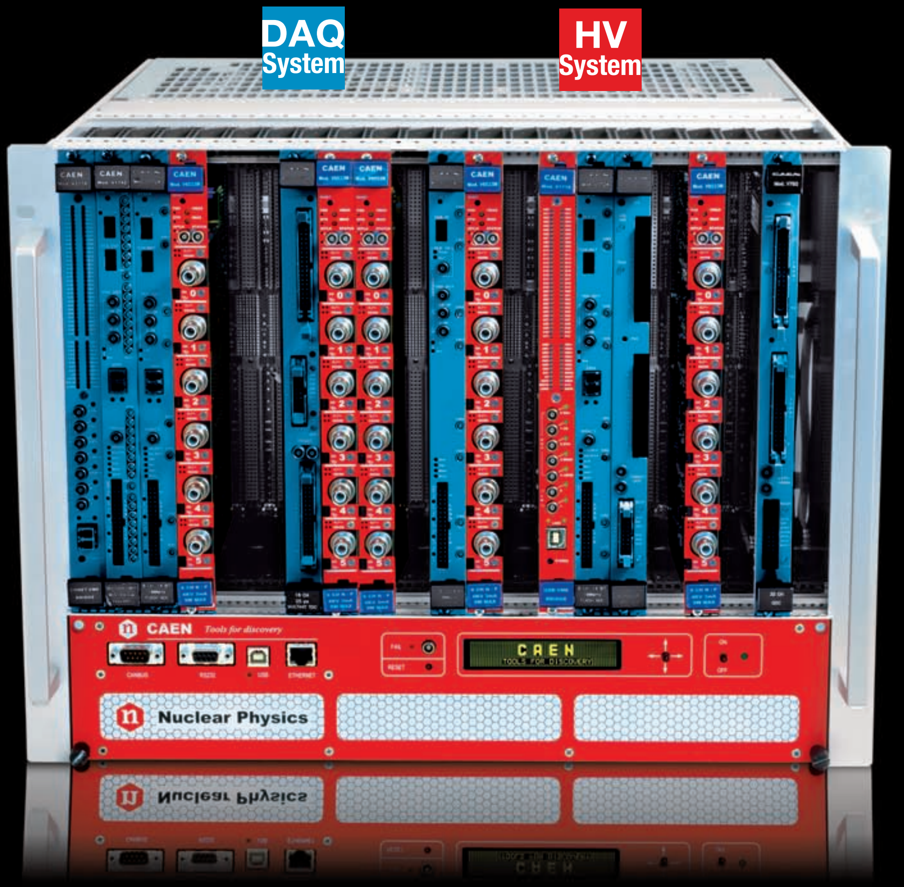
It is in the same vicinity, on Mt Armazones, that ESO plans to erect its Extremely Large Telescope (ELT), based on a novel concept that features five mirrors in sequence instead of the usual two, with a segmented primary mirror 39 m in diameter. Corrections for blurring owing to turbulence in the atmosphere, which are today made with small deformable mirrors at the level of the instruments ("adaptive optics"), will – in the ELT – be made partially by two of the five mirrors of the telescope itself.

Following an agreement signed by ESO and the US National Science Foundation in 2003, which was soon joined by the National Astronomical Observatory of Japan in collaboration with Taiwan, ALMA, an ambitious millimetre and submillimetre observatory featuring 66 antennas has been under construction for the past few years on the Chajnantor plateau in the Atacama, at an altitude of 5000 m. The inauguration will take place next March but early science, with 16 telescopes, is already bringing highly exciting results (see, for example, p13).

In 2000, ESO fostered the creation of EIROforum, a partnership of seven European research organizations with the mission of combining the resources, facilities and expertise of its members to support European science in reaching its full potential. Chaired most recently by CERN in 2011–2012, it has just been joined by a new member, the European X-ray free-electron laser project, XFEL.

ESO and CERN share a range of scientific interests and have held stimulating joint conferences in the past, the last ones also involving ESA. Today, cosmology, dark matter, dark energy, high-energy gamma rays, neutrinos, gravitational waves, general relativity and processes in the vicinity of black holes are all hot topics for both communities and would deserve a new joint conference in the near future.

● *Catherine Cesarsky, CEA Saclay. A former director-general of ESO (1999–2007), she is currently the scientific delegate for France on the CERN Council.*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