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

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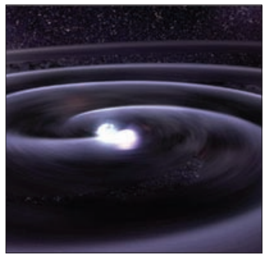

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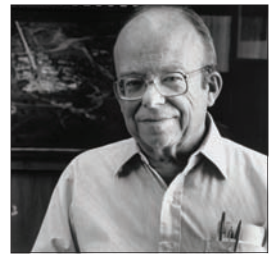

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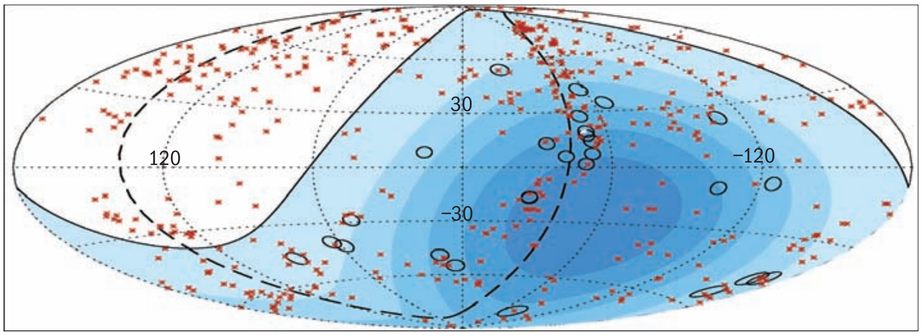
Cover: Work on installation of the tracking chambers for the muon spectrometer in the ALICE experiment at the LHC (p30). (Photo by Antonio Saba for CERN.)

COSMIC RAYS

Pierre Auger Observatory pinpoints source of mysterious highest-energy cosmic rays

The Pierre Auger Collaboration has discovered that active galactic nuclei are the most likely candidate for the source of the ultra-high-energy (UHE) cosmic rays arriving on Earth. Using the world's largest cosmic-ray observatory, the Pierre Auger Observatory (PAO) in Argentina, the team of 370 scientists from 17 countries has found that the sources of the highest-energy particles are not distributed uniformly across the sky. Instead, the results link the origins of these mysterious particles to the locations of nearby galaxies that have active nuclei at their centres (Pierre Auger Collaboration 2007).



The celestial sphere in galactic coordinates (Aitoff projection) showing the arrival directions of the 27 highest-energy cosmic rays detected by the Auger Observatory. (Pierre Auger Collaboration 2007, reprinted with permission from AAAS).

Low-energy charged cosmic rays (by far the majority) lose their initial direction when travelling through galactic or intergalactic magnetic fields, and therefore cannot reveal their point of origin when detected on Earth. UHE particles, by contrast, with energies of more than 40 EeV (4×10^{19} electron-volts) are only slightly deflected, so they come almost straight from their sources. These are the particles that the Auger Observatory was built to detect.

When UHE cosmic rays hit nuclei in the upper atmosphere, they create cascades of secondary particles that can spread across an area of around 30 km^2 as they arrive at the Earth's surface. The PAO records these extensive air showers using an array of 1600 particle detectors placed 1.5 km apart in a grid spread across 3000 km^2. A group of 24 specially designed telescopes record the emission of fluorescence light from excitation of the atmospheric nitrogen by the air shower, and water tanks record shower particles arriving at the Earth's surface by detecting Cherenkov radiation. The combination of particle detectors and fluorescence telescopes provides an exceptionally powerful instrument for determining the energy and direction of the primary UHE cosmic ray (*CERN Courier* July/August 2006 p12).

While the observatory has recorded almost a million cosmic-ray showers, the Auger team can link only the rare, highest-energy cosmic rays to their sources with sufficient precision. The observatory has so far recorded 81 cosmic rays with energy of more than 40 EeV – the largest number of cosmic rays at these energies ever recorded. At these ultra-high energies, there is only a degree or so uncertainity in the direction from which the cosmic ray arrived, allowing the team to determine the location of the particle's source.

The Auger Collaboration discovered that the 27 highest-energy events, with energy of more than 57 EeV, do not come from all directions equally. Comparing the clustering of these events with the known locations of 381 active galactic nuclei (AGNs), the collaboration found that most of these events correlated well with the locations of AGNs in some nearby galaxies, such as Centaurus A. Astrophysicists believe that AGNs are powered by supermassive black holes that are devouring large amounts of matter. They have long been considered sites where high-energy particle production might take place, but the exact mechanism of how AGNs can accelerate particles to such high energies is still a mystery.

These UHE events are rare and, even with its large size, the PAO can record only about 30 of them each year. The collaboration is already developing plans for the construction of a second, larger installation in Colorado. This will extend coverage to the entire sky while substantially increasing the number of high-energy events recorded; there are, it turns out, even more nearby AGNs in the northern sky than in the southern sky visible from Argentina.

Further reading

Pierre Auger Collaboration 2007 *Science* **318** 938.

Sommaire

NEUTRINO FACILITIES

Neutrino mixing at Daya Bay

On 13 October, members of the Daya Bay Collaboration and government officials from China and the US Department of Energy held a groundbreaking ceremony for the Daya Bay Reactor Neutrino experiment at the Daya Bay Nuclear Power Facility, located in Shenzhen, Guangdong Province, about 55 km north-east of Hong Kong in Southern China. The experiment is poised to investigate the least well known sector of the recently discovered phenomenon of neutrino mixing.

In recent years, several experiments have discovered that the three flavours of neutrino can oscillate among themselves – a result of the mixing of mass eigenstates. Among the three mixing angles required to describe the oscillation, θ_{13} is the least well known. Besides determining the amount of mixing between the electron-neutrino and the third mass eigenstate, θ_{13} is a gateway to the future study of CP violation in neutrino oscillation.

To date, the best limit on θ_{13} is $\sin^2 2\theta_{13} < 0.17$, reported by the CHOOZ reactor neutrino experiment using one detector on a baseline of 1.05 km. However, the current understanding of neutrino oscillation indicates that the disappearance of reactor antineutrinos at a distance of about 2 km would provide an unambiguous determination of θ_{13}. This is the goal of a new generation of reactor-neutrino experiments utilizing at least two detectors at different baselines. Such a near–far configuration eliminates most of the reactor-related systematic errors and some of the detector-related systematic uncertainties.

The Daya Bay experiment should discover neutrino oscillation due to θ_{13} mixing and measure $\sin^2 2\theta_{13}$ to an unprecedented sensitivity of better than 0.01 at 90% CL – an order of magnitude better than the present limits. The experiment will look for electron antineutrinos from the reactors via the inverse beta-decay reaction in a gadolinium-doped liquid scintillator target (figure 1). In the reaction, an electron-antineutrino interacts with a proton (hydrogen in the scintillator), producing a positron and a neutron. The energy of the antineutrino is determined by measuring the energy loss of the positron in the scintillator. The collaboration will extract the value of $\sin^2 2\theta_{13}$ by comparing the fluxes and energy distributions of the observed antineutrino events in the near and the far halls (figure 2).

The ceremony on 13 October marks the beginning of civil construction near the Daya Bay and Ling Ao reactors, the sources of the electron-antineutrinos for the experiment. When the Ling Ao II nuclear power plant is commissioned by 2011, the three pairs of reactors will be one of the most powerful nuclear-energy facilities in the world. Three underground experimental halls connected by long tunnels will be excavated in the nearby mountains, which will shield the experiment from cosmic rays. In each hall, the antineutrino detectors (two in each near hall and four in the far site) will be deployed in a water pool to protect the detectors from ambient radiation. Together with resistive plate chambers above, the water pool also serves as a segmented Cherenkov counter for identifying cosmic-ray muons.

The project is now ready to begin manufacturing and mass production of the detector components. The first experimental hall is scheduled to be ready by the end of 2008. Commissioning of the detectors in this hall will take place in 2009. Construction will continue for about two years, with installation of the last detector scheduled for 2010.

● The Daya Bay Collaboration consists of 35 institutions with more than 190 collaborators from three continents. The project is supported by the funding agencies in China and the US, and is one of the largest co-operative scientific projects between the two countries. Additional funding is being provided by the other countries and regions, including Hong Kong, Taiwan, the Czech Republic and Russia.

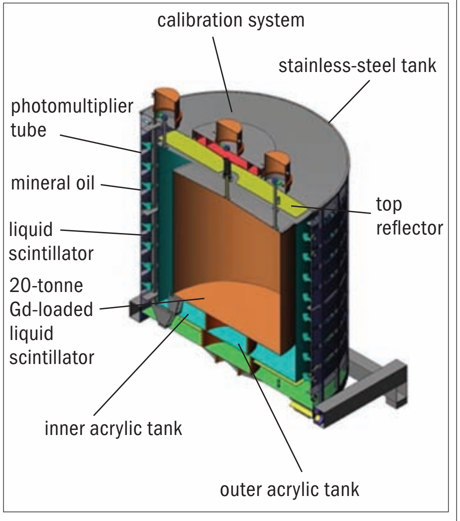


Fig. 1. Cross-section of a 5 m tall antineutrino detector for Daya Bay, showing the 20 tonne gadolinium liquid scintillator target enclosed by a layer of unloaded liquid scintillator and a layer of mineral oil that attenuates background radiation from the photomultiplier tubes and the stainless-steel tank.

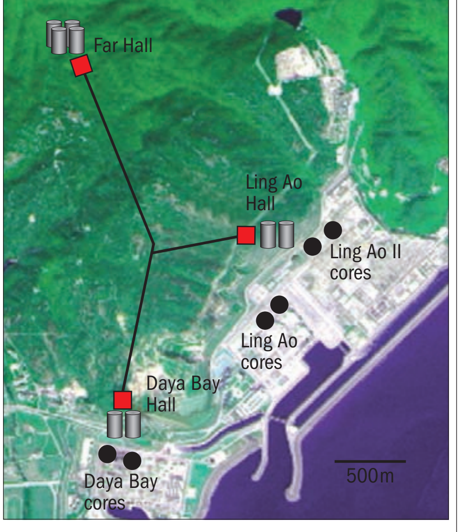


Fig. 2. Schematic of the experimental layout at Daya Bay, showing the locations of the three underground halls, connected by tunnels, and the number of antineutrino detectors in each hall. (Pictures Courtesy DAYA BAY Collaboration.)

LHC NEWS

Robert Aymar seals the final main magnet interconnection

At a brief ceremony on 7 November deep in the LHC tunnel CERN's director-general, Robert Aymar, sealed the last interconnection between the collider's main magnet systems. This is the latest milestone in commissioning the LHC, which is scheduled to start up in 2008 (*CERN Courier* July/August 2007 p5). The ceremony marks the end of a two-year programme of work to connect all of the main dipole and quadrupole magnets in the machine, a complex task that included both electrical and fluid connections.

CERN director-general Robert Aymar seals the last interconnect between the main magnets, with members of the LHC project management and the interconnection team.

The 27 km circumference LHC is divided into eight sectors, each of which can be cooled down to the operating temperature of 1.9 K and powered up independently. The first sector was cooled down and powered in the first half of 2007 and has now been warmed up for minor modifications. This was an important learning process, allowing subsequent sectors to be commissioned more quickly. Four more sectors will be cooling by the end of 2007 and the remaining three sectors that have not been cooled will begin the process early in 2008.

To cool the magnets, more than 10 000 tonnes of liquid nitrogen and 130 tonnes of liquid helium will be brought into use through a cryogenic system, which includes more than 40 000 leak-tight welds.

If all goes well, the first beams could be injected into the LHC in May 2008, and circulating beams established by June or July. With a project of this scale and complexity, however, the transition from construction to operation is a lengthy process. Every part of the system has to be brought on stream carefully, with each subsystem and component tested and repaired, if necessary. "If for any reason we have to warm up a sector, we'll be looking at the end of summer rather than the beginning," warns project leader Lyn Evans.

LHC EXPERIMENTS

LHCb installs its fragile precision silicon detector

One of the most fragile detectors for the LHCb experiment has been successfully installed in its final position. Installing the Vertex Locator (VELO) in the underground experimental cavern at CERN proved to be a challenging task for the collaboration.

The VELO is a precise particle-tracking detector that surrounds the collision point inside the LHCb experiment. At its heart are 84 half-moon-shaped silicon sensors, each connected to its electronics via a system of 5000 bond wires. These sensors are located close to the collision point, where they will play a crucial role in detecting b quarks (*CERN Courier* July/August 2007 p30).

The sensors are grouped in pairs to make a total of 42 modules arranged in two halves around the beamline in the VELO vacuum tank. A 0.3 mm thick aluminium sheet provides a shield between the silicon modules and the primary beam vacuum, with no more than 1 mm of leeway to the silicon modules. Custom-made bellows enable the VELO to retract from its normal position 5 mm from the beamline to a distance of 35 mm. This flexibility is crucial during the commissioning of the LHC beam.

The VELO project involves several institutes of the LHCb collaboration, including Nikhef, EPFL Lausanne, Liverpool, Glasgow, CERN, Syracuse and MPI Heidelberg. In particular, the sensor modules were constructed at the University of Liverpool, and Nikhef provided the special foil that interfaces with the LHC vacuum.

LHC NEWS

Second LHC transfer line passes beam test with flying colours

Three years after the initial commissioning of the SPS-to-LHC transfer line, TI 8 (*CERN Courier* March 2005 p26), the second transfer line, TI 2, has passed its first test with beam. Just as for TI 8 in October 2004, a low-intensity proton beam travelled down the entire new line at the first attempt.

The two LHC injection lines have a combined length of 5.6 km and comprise around 700 warm (normally conducting) magnets. While around 70 magnets were recuperated from earlier installations at CERN, the majority were produced by the Budker Institute for Nuclear Physics in Novosibirsk, as part of Russia's contribution to the LHC project.

TI 2 leads from the extraction in long straight-section 6 (LSS6) of the SPS to the injection point on the LHC for clockwise beam, which is near the interaction region for the ALICE experiment at Point 2. To transfer beam to the LHC, LSS6 has a new fast extraction, which underwent commissioning in 2006 and further testing in 2007. Following the extraction, the beam passes for 150 m through the TT60 line, formerly used for transfer to the West Area, before entering the TI 2 line in its purpose-built 3 m diameter tunnel.

Installation of the TI 2 beamline started at the beginning of 2005 in the upstream part of the new tunnel, followed by initial hardware commissioning that summer. However, as the downstream part of the TI 2 tunnel served as a transport path for the main LHC magnets, it had to remain free of beamline elements until the LHC magnets were all in place. With the descent of the last magnet in April 2007, installation of the TI 2 line resumed, reaching completion at the beginning of August. This was followed by some eight weeks of hardware commissioning for the whole beamline.

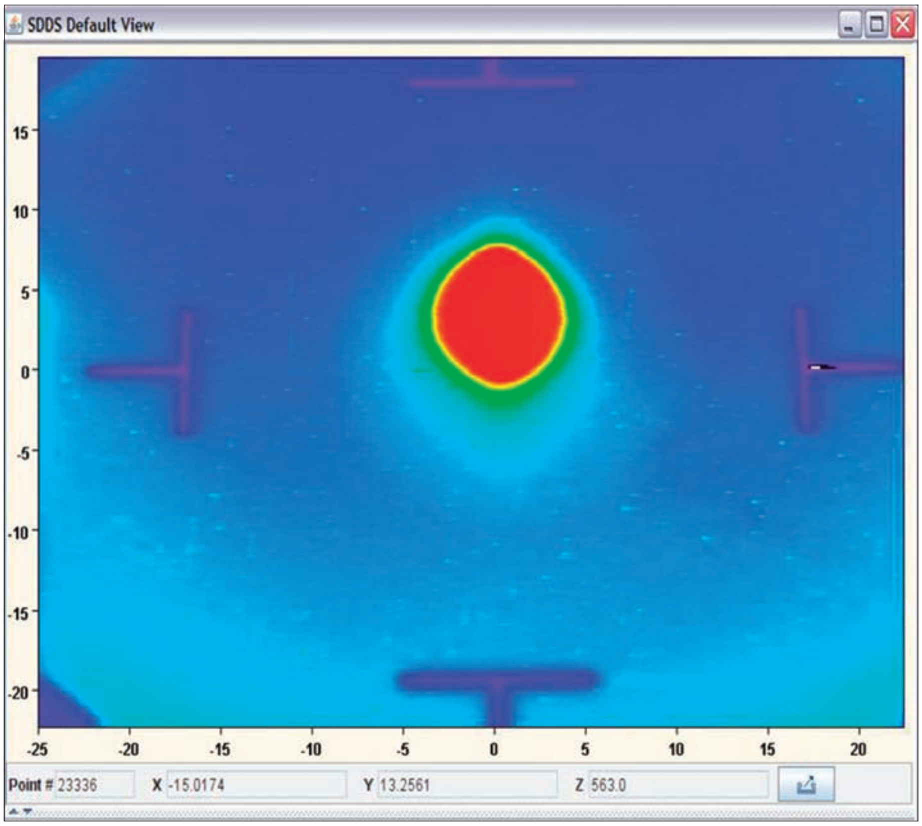


Image of the first proton beam in TI 2 on the last beam TV screen it traversed.

The beam test, which took place over a 22 hour period, started early on 28 October. The commissioning team first prepared a single-bunch beam of 5×10^9 protons and set the TI 2 line to the SPS energy before tuning the SPS extraction. Then, when they retracted the beam dump near the extraction, the beam travelled without any steering straight through the 2.7 km of beamline components to the temporary dump installed near the end of the TI 2 tunnel. During the time remaining, the team made a range of basic measurements; after an initial analysis the basic parameters are looking good, indicating that there are no major errors in the line.

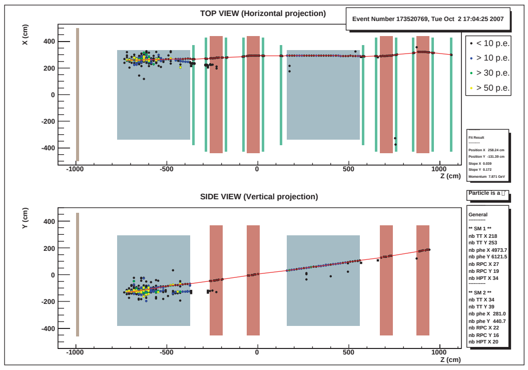
NEUTRINO OSCILLATIONS

OPERA takes first photographs

The first neutrino event of the 2007 run of the CERN Neutrinos Gran Sasso (CNGS) facility was recorded on 2 October, when one of the many millions of neutrinos in the beam from CERN interacted in the OPERA detector in the Gran Sasso National Laboratory, 730 km away in Italy. The interaction occurred in one of nearly 60 000 "bricks" already installed in the detector and provided the first detailed event-image in high-precision emulsion.

There is now plenty of evidence that neutrinos oscillate between three "flavour" states, associated with the charged leptons: electron, muon and τ. Several experiments have observed the disappearance of the initial neutrino flavour but "direct appearance" of a different flavour remains a major missing piece of the puzzle. The CNGS beam consists of muon-neutrinos, and the observation in OPERA of a few tau-neutrino interactions among many muon-neutrino events will provide the long-awaited proof of neutrino oscillation.

In 2006, OPERA collected about 300 neutrino events during the commissioning run of the CNGS facility (Acquafredda *et al* 2006). However, these did not include information about the event-vertex recorded in the thousands of small "bricks", each made of a sandwich of lead plates and nuclear emulsion films, which make up the "heart" of OPERA (*CERN Courier* November 2006 p24). The emulsion technique allows the collaboration to measure the neutrino interaction vertices with high precision. Installation of the bricks continues daily and the total is nearing the halfway mark, ultimately reaching 150 000 bricks with a total mass of 1300 tonnes.



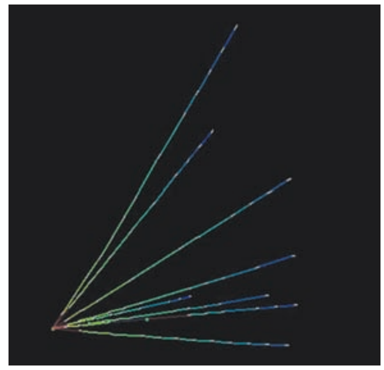


Fig.1 (left). A neutrino coming from the left intracts in the first set of scintillator planes in OPERA, producing a hadron shower and a muon, which penetrates the steel beyond. Fig. 2 (right). Reconstruction of the vertex recorded in a few cubic millimetres of emulsion. (Courtesy OPERA.)

The event of 2 October was the first to be registered in a brick, and some 37 more events occurred in the following days. An automated system immediately removed the bricks containing these events from the detector. They were then dispatched to the various laboratories of the OPERA collaboration, which are equipped with the automatic microscopes required to scan the emulsion films and make relevant measurements. Figure 2 shows the microscope display for one of these events, representing a volume of only a few cubic millimetres but rich in valuable information for the OPERA physicists.

This is a crucial milestone in an enterprise that started about 10 years ago. The OPERA detector was designed and realized by a large team of researchers from all over the world (Belgium, Bulgaria, Croatia, France, Germany, Israel, Italy, Japan, Korea, Russia, Switzerland, Tunisia and Turkey), with strong support from CERN, INFN, Japan and the main European funding agencies. Numerous hi-tech industrial companies were also involved in the supply of the many parts of the equipment necessary for building the large detector.

Further reading

R Acquafredda *et al 2006 New J. Phys.* **8** 303

FACILITIES

J-PARC accelerates protons to 3 GeV

On 31 October a team at the Japan Proton Accelerator Research Complex (J-PARC) accelerated a proton beam to the design energy of 3 GeV in the new Rapid-Cycling Synchrotron (RCS). This is an important step for this joint project between KEK and the Japan Atomic Energy Agency (*CERN Courier* March 2007 p5).

The team began beam commissioning the RCS during the run that started on 10 September. The linac was once again in operation and on 2 October the beam was successfully transported from the linac to the RCS. Two days later, the H^- beam was transported to the H-0 dump located at the injection section of the RCS without the charge-exchange foil.

The charge-exchange foil was installed during the following scheduled two-week shutdown. On 25 October the proton beam produced by the stripping of two electrons from the H^- ions in the foil was transported through one arc of the RCS and extracted to the beam transport to the muon and neutron production targets, known as 3BNT. As the targets are not yet ready, the beam currently goes to a 4 kW beam dump just beyond the extraction system. The following day, the beam circulated in the RCS and was extracted to 3NBT. Finally, on 31 October, the team accelerated a beam in the RCS to the design energy of 3 GeV and extracted it to the 3NBT dump via the kicker system.

One aim during commissioning has been to minimize the radioactivation of the accelerator components, because the team will have to replace items such as the charge-exchange foil-replacement system after the beam commissioning. To achieve this the team did the commissioning with one shot of the linac beam with a peak current of 5 mA and a pulse length of 50 μs. This allowed it to accumulate useful beam data "shot by shot" with a minimum radioactivation of the accelerator components.

SCIENCEWATCH

Compiled by Steve Reucroft and John Swain, Northeastern University

Semiconductor splits the energy of water

A new approach to producing usable energy from solar power not only makes hydrogen gas from water but also separates it. Peter Ritterskamp and colleagues at the Max Planck Institutes for Bioinorganic Chemistry and for Coal Research have shown that titanium disilicide, an inexpensive semiconductor that had not been identified as useful for splitting water, will do the job.

The titanium disilicide has a wide variation in band-gap (unusual for semiconductors), allowing it to absorb light efficiently across a broad spectrum. When a powder of the material is added to water, the light energy will split the water into hydrogen and oxygen. The hydrogen is freely released, but the oxygen remains bound to the surfaces of the powder. Heating to more than 100 °C in the dark releases the oxygen and reactivates the powder. More important is that this powder is not degraded as a catalyst, unlike some other semiconductors.

Further reading

Peter Ritterskamp *et al.* 2007 *Angewandte Chemie International Edition* **46** 7770.

Is relativity all in the mind?

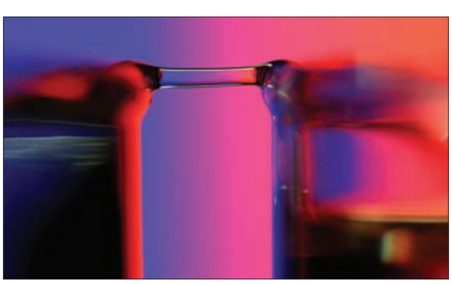
Physicists are familiar with how measured quantities can depend on the reference frame in which the measurements are made, but less well known are psychological analogies. Emily Balcetis of Ohio University in Athens and David Dunning of Cornell University in Ithaca have shown that psychological states can alter perceptions of the physical world.

The researchers surveyed students who were asked to walk across a campus wearing embarrassing clothes with fruit and vegetable themes. Students who felt that they had little choice about doing the task mentally shortened their estimates of the distance by 40%. Those who felt they had freely chosen to do the task tended to cover the distance more slowly, by about 10%.

Further reading

Emily Balcetis and David Dunning 2007 *Psychological Science* **18** 917.

Electrified water creates a liquid bridge



A bridge of water forms between two beakers. (Courtesy Fuchs/Woisetschläger.)

Researchers at the Graz University of Technology have found that a strong electric field will support a 25 mm long horizontal bridge of water between two beakers. Elmar Fuchs and colleagues demonstrated the phenomenon with 25 kV and two containers of highly deionized water. The details of just how the bridge forms and how it holds up are still not clear. Suggestions have included a new form of organization of water with large macroscopic alignments of the electric dipoles in the liquid of the bridge.

Further reading

Elmar C Fuchs *et al.* 2007 *J. Phys. D. Appl. Phys.* **40** 6112.

Chilli peppers to target pain

An unlikely combination of a not-so-useful anaesthetic and the stuff that makes chilli peppers hot, could ease future visits to the dentist. Alexander Binshtock, Bruce Bean and Clifford Wolf from Massachusetts General Hospital and Harvard Medical School have combined a painkiller with capsaicin, the vital ingredient in chilli peppers, to create a targeted anaesthetic.

QX-314 is a sodium-channel blocking painkiller that has not found medical use because of its inability to penetrate fatty layers around nerve cells. However, the team found that, with the help of capsaicin, it can make it through. More important, the capsaicin only lets QX-314 into the nerve cells that are particularly responsible for the sensation of pain – a selectivity that is completely novel. In short, pain relief is achieved without any numbness or associated paralysis.

Further reading

Alexander Binshtock *et al.* 2007 *Nature* **449** 607.

Phonon logic could lead to thermal computing systems

Heat is usually an unwanted by-product of computation, but new ideas turn this notion on its head with a suggestion to use the flow of heat to perform computations. Lei Wang and Baowen Li of the National University of Singapore have built on earlier work in which Li proposed the construction of a thermal "diode", which was realized in 2006. Li and Wang have now demonstrated how to use nonlinear lattices to build logic gates for phonons. These phononic analogues of electronic devices may be realizable in suitable nanoscale experiments.

Further reading

Lei Wang and Baowen Li 2007 *Phys. Rev. Lett.* **99** 177208.

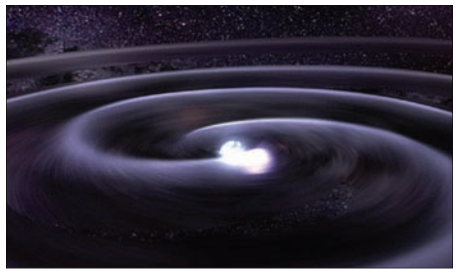
Compiled by Marc Türler, INTEGRAL Science Data Centre and Observatory of Geneva University

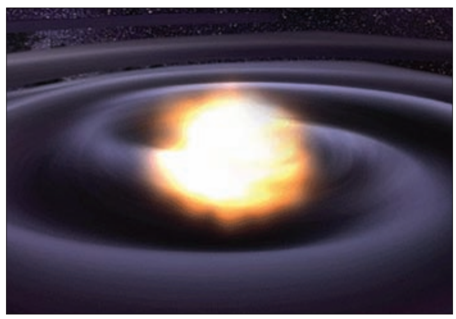
When white dwarfs collide...

A peculiar supernova discovered last year could be the first that is known to have originated from the coalescence of two white dwarfs. These compact stars orbiting each other slowly spiralled inward until they merged, triggering the giant explosion.

A supernova is the explosion of a star that, for several days, becomes as luminous as about thousand million stars similar to the Sun. They are bright enough to be detected in remote galaxies (*CERN Courier* October 2007 p13). Astronomers classify them according to whether their spectrum shows evidence of hydrogen (Type II), or not (Type I). This difference in spectrum reflects a completely different explosion mechanism. Type II supernovae (SN II) originate from the core collapse of massive, short-lived stars running out of nuclear power, whereas the most common Type I supernovae (SN Ia) occur when catastrophic nuclear fusion blasts apart a white dwarf that has accreted too much gas from a normal companion star.

White dwarfs are the remaining cores of stars not large enough to end their lives in SN II explosions. In about five thousand million years, the Sun will become such a compact star, as small as the Earth and mainly composed of carbon and oxygen. The possibility of producing a supernova by the merger of two white dwarfs remained purely theoretical until now. However, there is strong evidence that a supernova discovered on 26 September 2006, called SN 2006gz, comes from such a peculiar origin. This is at least the conclusion of a team of astronomers led by Malcolm Hicken, a graduate student of the Harvard-Smithsonian Center for Astrophysics (CfA). They found three observational features that suggest that this explosion – first classified as a Type Ia supernova – was caused by some different mechanism. The most important evidence for this is that SN 2006gz has the strongest signature of unburnt carbon ever reported. Merging white dwarfs are expected to have carbon in their outer layer that would be pushed off by the explosion from the inside. The spectrum of SN 2006gz also shows evidence for silicon that would have been compressed by the shock wave rebounding from the surrounding layers of carbon and oxygen. Additionally, SN 2006gz was brighter than expected, indicating that its progenitor exceeded the 1.4 solar-mass Chandrasekhar limit – the upper bound for a single white dwarf. Only one other potential example of a super-Chandrasekhar supernova has been seen (SN 2003fg), but this supernova did not show the carbon and silicon spectral characteristics of SN 2006gz, which are predicted for merging white dwarfs by computer models.





An artist's impression of two white dwarf stars spiralling in towards each other until they collide and explode as a luminous supernova like SN 2006gz. (Courtesy NASA/Dana Berry, Sky Works Digital.)

As a first example of a different kind of supernova, the observations of SN 2006gz will allow astronomers to distinguish these more powerful explosions more clearly from the single white dwarf blasts. This is particularly important for cosmology, as the similarities among normal Type Ia supernovae was used to reveal the accelerated expansion of the universe thought to be driven by dark energy (*CERN Courier* September 2003 p23).

Further reading

M Hicken *et al.* 2007 *Astroph. Journal* **669** L17.

Picture of the month

Arp 87 is a stunning pair of interacting galaxies located in the constellation of Leo, the Lion, approximately 300 million light-years away. This image by the Hubble Space Telescope reveals the stream of stars, gas and dust flowing from the large spiral galaxy NGC 3808 (on the right) to form an enveloping arm around its smaller companion. Computer simulations show that the graceful dance of this pair will go on for about a hundred million years before merging, as the Antennae galaxies did, to form an elliptical galaxy (*CERN Courier* December 2006 p14). (Courtesy NASA, ESA and The Hubble Heritage Team (STScI/AURA).)

CERN COURIER ARCHIVE: 1964

A look back to *CERN Courier* vol. 4 December 1964, compiled by Peggie Rimmer

POLARIZED TARGETS

Saclay and CERN polarize protons

Early in November, the first run was carried out at CERN's proton synchrotron on an experiment to determine the parity of the negative xi. This experiment relies on an important and interesting new piece of equipment, the polarized-proton target, brought into use through the fruitful collaboration of groups at Saclay (Centre d'Études Nucléaires) and CERN.

One of the fundamental properties of both atomic nuclei and sub-nuclear particles is their "spin", a quantum-mechanical concept best imagined as the amount of rotation (angular momentum) about an axis in the particle. Spin is related to "parity", another quantum-mechanical property that determines whether a particle is, or is not, indistinguishable from its mirror image, and measurements of both play an important role in high-energy physics research.

Such measurements involve the interaction between a beam of incoming particles and the nuclei (at low energy) or nucleons (at high energy) of a target. It is a fact of everyday experience that the direction taken by a ball after bouncing from a flat surface depends on the way the ball is spinning. Similarly, a non-spinning ball bounced off a revolving globe will have a preferred direction of flight, and repeated throws of an arbitrarily spinning ball will show a specific pattern according to the sense and speed of rotation of the globe. In most of the corresponding experiments with particles, although both the beam and target particles have a specific magnitude of spin, the direction is in both cases arbitrary and the resulting patterns are difficult to analyse. For this reason, attention has turned to the production of sources and targets of polarized particles in which an enhanced proportion of the particles not only have their spin axes parallel to a given direction but also spin in the same sense.

The new target uses the principle of "dynamic polarization", in which a paramagnetic crystal is cooled to below liquid-helium temperature in a strong magnetic field and subjected to radio-frequency radiation of a particular (very high) frequency. It consists of four main parts: the cryogenic apparatus for producing the low temperature; the magnet, which must provide an extremely uniform field; the microwave system, which polarizes the protons; and the high-frequency system, which measures the sign and amount of the polarization. Except for the magnet, which was designed and made at CERN, the target was developed at Saclay.

● Compiled from the article on pp168–172.

LAST MONTH

Sprechen sie… CERN FORTRAN?

Various "automatic programming languages" have been developed in recent years to simplify the preparation of the sets of instructions (or "programs") required for the solution of each specific problem on a computer. These languages were a big step towards simplifying the task of preparing long programs, but a change of computer, especially to one from a different manufacturer, still meant that a considerable number of alterations had to be made to the program. In particular, this left a number of problems in the exchange of computer programs between CERN and other collaborating laboratories.

In November, however, "CERN FORTRAN" was announced by CERN's Data Handling Division. This new programming language, a version of the FORTRAN series, allows programs to be run with only minor modifications on computers that otherwise use FORTRAN IV. Considerable work has been done to convert large programs into the new language and test them on both IBM and CDC computers. This experience has shown that, correctly used, CERN Fortran goes a long way towards making programs easily interchangeable between these computers, and it has been adopted for all programs to be used on CERN's new computer, the CDC 6600.

● Because English and French are the official languages of CERN, many readers have to be content with a journal that is not of their own tongue. As a very slight recompense for them, the following contribution, alluding to the literal translation of the word "antiparticle", is included in its original German form:

DIE GROSSE LAMENTEI

Schonheit vergeht:
    Denn neben jedem Veilchen
    wachst schon sein Gegen-Veilchen.
Zeit anch verweht:
    Denn neben jedem Weilchen
    blast schon sein Gegen-Weilchen.
Raum auch zergeht:
    Denn neben jedem Meilchen
    lauft schon sein Gegen-Meilchen.
Ding auch zerweht:
    Denn neben jedem Teilchen,
    Ach Gott, da hockt sein
Gegen-Teilchen.
Gegenteilchen
    enteil-chen
        Teilchen
            Eilchen ...

Gertrude Weisskopf.

● Compiled from "Last Month at CERN" pp166–168.

COMPILER'S NOTE

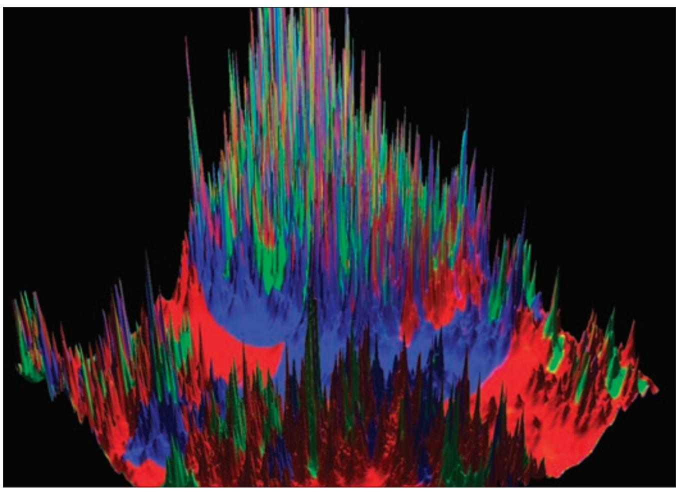
In 1964, Gertrude Weisskopf von Desch co-authored the book *Das Wunder des Wissens* with CERN's director-general "Viki" Weisskopf. The common surname appears to have been fortuitous. Who was Gertrude? Does anyone know?

And here is the December 1964 cover photograph as a reminder of winters past – we may not see their like again!

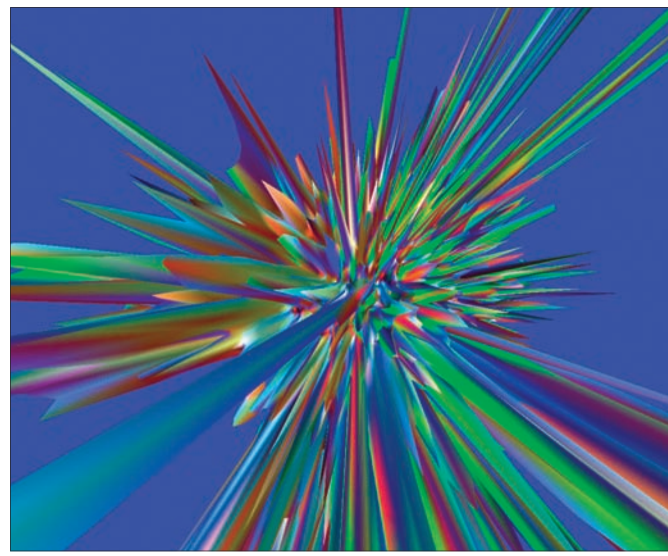
"...the first covering of snow in front of the restaurant..."

Physics in the multiverse

The idea of multiple universes is more than a fantastic invention. It appears naturally within several theories, and deserves to be taken seriously, explains **Aurélien Barrau**.



A self-reproducing universe. This computer-generated simulation shows exponentially large domains, each with different laws of physics (associated with different colours). Peaks are new "Big Bangs", with heights corresponding to the energy density. (Simulations by Andrei and Dimitri Linde.)



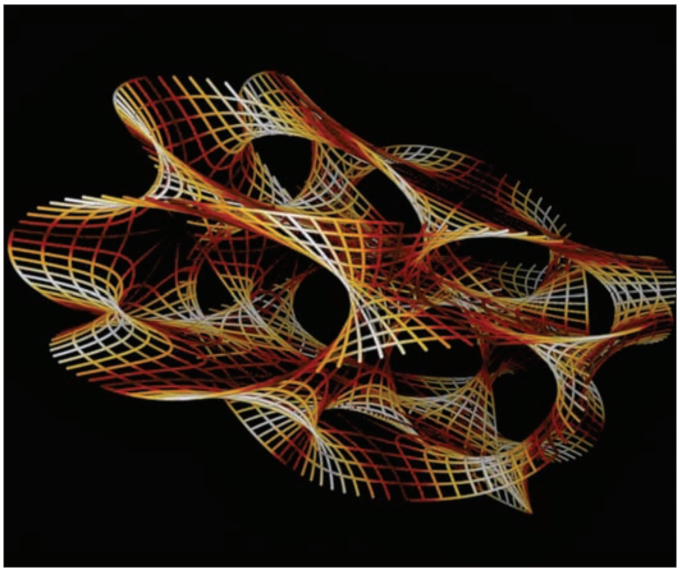
An exploding universe. This simulation illustrates the fractal-like nature of the inflationary multiverse when a second scalar field is added to the usual picture.

Is our entire universe a tiny island within an infinitely vast and infinitely diversified meta-world? This could be either one of the most important revolutions in the history of cosmogonies or merely a misleading statement that reflects our lack of understanding of the most fundamental laws of physics.

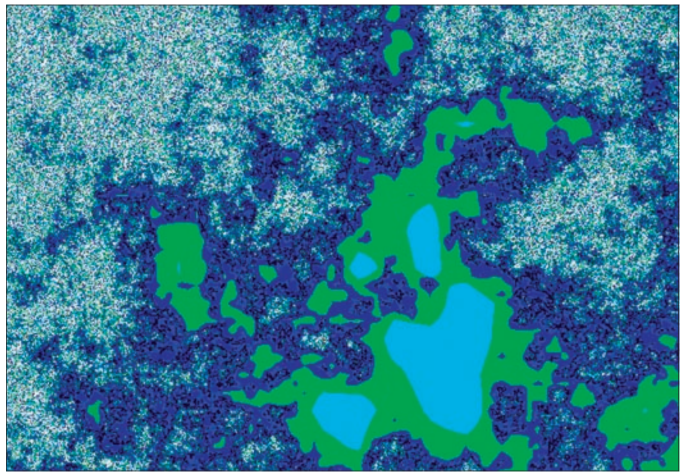
The idea in itself is far from new: from Anaximander to David Lewis, philosophers have exhaustively considered this eventuality. What is especially interesting today is that it emerges, almost naturally, from some of our best – but often most speculative – physical theories. The multiverse is no longer a model; it is a consequence of our models. It offers an obvious understanding of the strangeness of the physical state of our universe. The proposal is attractive and credible, but it requires a profound rethinking of current physics.

At first glance, the multiverse seems to lie outside of science because it cannot be observed. How, following the prescription of Karl Popper, can a theory be falsifiable if we cannot observe its predictions? This way of thinking is not really correct for the multiverse for several reasons. First, predictions can be made in the multiverse: it leads only to statistical results, but this is also true for any physical theory within our universe, owing both to fundamental quantum fluctuations and to measurement uncertainties. Secondly, it has never been necessary to check all of the predictions of a theory to consider it as legitimate science. General relativity, for example, has been extensively tested in the visible world and this allows us to use it within black holes even though it is not possible to go there to check. Finally, the critical rationalism of Popper is not the final word in the philosophy of science. Sociologists, aestheticians and epistemologists have shown that there are other demarcation criteria to consider. History reminds us that the definition of science can only come from within and from the praxis: no active area of intellectual creation can be strictly delimited from outside. If scientists need to change the borders of their own field of research, it would be hard to justify a philosophical prescription preventing them from doing so. It is the same with art: nearly all artistic innovations of the 20th century have transgressed the definition of art as would have been given by a 19th-century aesthetician. Just as with science and scientists, art is internally defined by artists.

For all of these reasons, it is worth considering seriously the possibility that we live in a multiverse. This could allow understanding of the two problems of complexity and naturalness. The fact that the laws and couplings of physics appear to be fine-tuned to such an extent that life can exist and most fundamental quantities assume extremely "improbable" values would appear obvious if our entire universe were just a tiny part of a huge multiverse where different regions exhibit different laws. In this view, we are living in one of the "anthropically favoured" regions. This anthropic selection has strictly teleological and no theological dimension and absolutely no link with any kind of "intelligent design". It is nothing other than the obvious generalization of ▷



A tri-dimensional representation of a quadri-dimensional Calabi–Yau manifold. This describes the geometry of the extra "internal" dimensions of M-theory and relates to one particular (string-inspired) multiverse scenario. (Simulation by Jean-François Colonna, CMAP/École Polytechnique.)



A simulation of eternal inflation. The space–time is 2+1-dimensional and adding an increment in each sub-square modifies the scalar field at each step of the simulation. The bluish-white colour denotes inflating regions, while other colours denote thermalized regions. In this case, the required functions are chosen to simulate larger inflation rates at the top of the potential (around $\phi=0$) and deterministic slow roll near the end of inflation. (Simulation by Serge Winitzki.)

the selection effect that already has to be taken into account within our own universe. When dealing with a sample, it is impossible to avoid wondering if it accurately represents the full set, and this question must of course be asked when considering our universe within the multiverse.

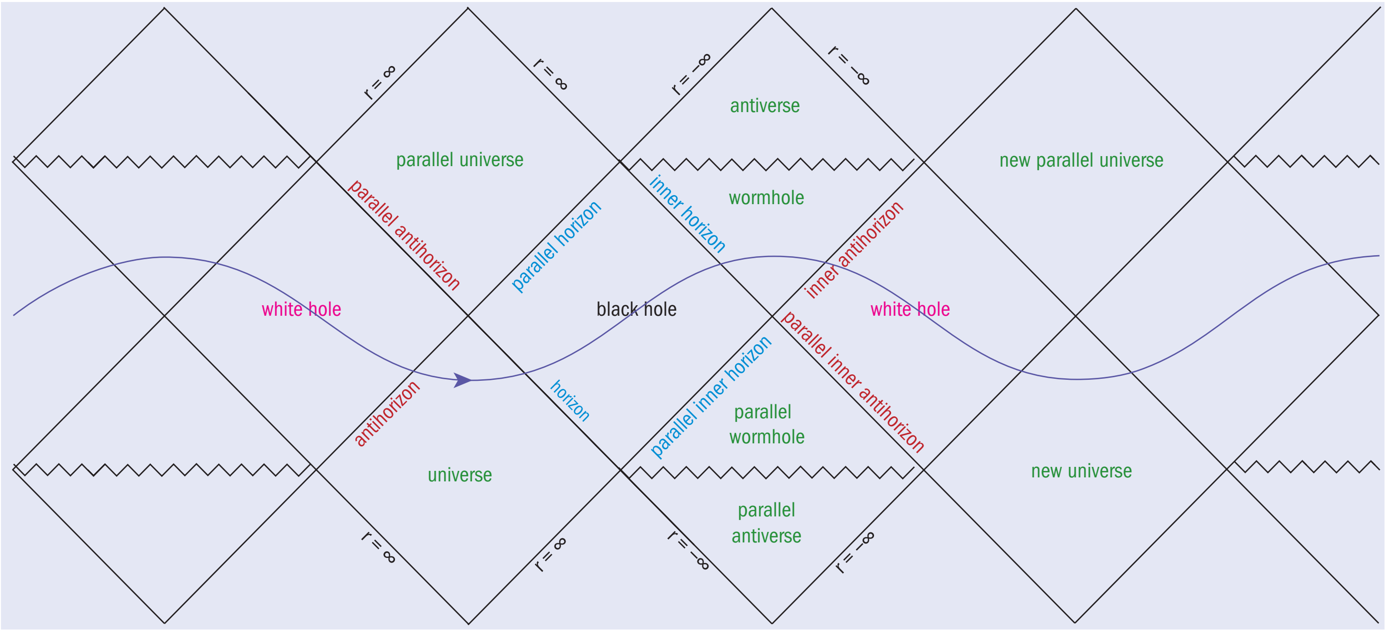
The multiverse is not a theory. It appears as a consequence of some theories, and these have other predictions that can be tested within our own universe. There are many different kinds of possible multiverses, depending on the particular theories, some of them even being possibly interwoven.

The most elementary multiverse is simply the infinite space predicted by general relativity – at least for flat and hyperbolic geometries. An infinite number of Hubble volumes should fill this meta-world. In such a situation, everything that is possible (i.e. compatible with the laws of physics as we know them) should occur. This is true because an event with a non-vanishing probability has to happen somewhere if space is infinite. The structure of the laws of physics and the values of fundamental parameters cannot be explained by this multiverse, but many specific circumstances can be understood by anthropic selections. Some places are, for example, less homogenous than our Hubble volume, so we cannot live there because they are less life-friendly than our universe, where the primordial fluctuations are perfectly adapted as the seeds for structure formation.

General relativity also faces the multiverse issue when dealing with black holes. The maximal analytic extension of the Schwarzschild geometry, as exhibited by conformal Penrose–Carter diagrams, shows that another universe could be seen from within a black hole. This interesting feature is well known to disappear when the collapse is considered dynamically. The situation is, however, more interesting for charged or rotating black holes, where an infinite set of universes with attractive and repulsive gravity appear in the conformal diagram. The wormholes that possibly connect these universes are extremely unstable, but this does not alter the fact that this solution reveals other universes (or other parts of our own universe, depending on the topology), whether accessible or not. This multiverse is, however, extremely speculative as it could be just a mathematical ghost. Furthermore, nothing allows us to understand explicitly how it formed.

A much more interesting pluriverse is associated with the interior of black holes when quantum corrections to general relativity are taken into account. Bounces should replace singularities in most quantum gravity approaches, and this leads to an expanding region of space–time inside the black hole that can be considered as a universe. In this model, our own universe would have been created by such a process and should also have a large number of child universes, thanks to its numerous stellar and supermassive black holes. This could lead to a kind of cosmological natural selection in which the laws of physics tend to maximize the number of black holes (just because such universes generate more universes of the same kind). It also allows for several possible observational tests that could refute the theory and does not rely on the use of any anthropic argument. However, it is not clear how the constants of physics could be inherited from the parent universe by the child universe with small random variations and the detailed model associated with this scenario does not yet exist.

One of the richest multiverses is associated with the fascinating meeting of inflationary cosmology and string theory. On the one hand, eternal inflation can be understood by considering a massive scalar field. The field will have quantum fluctuations, which will, in half of the regions, increase its value; in the other half, the fluctuations will decrease the value of the field. In the half where the field jumps up, the extra energy density will cause the universe to expand faster than in the half where the field jumps down. After some time, more than half of the regions will have the higher value of the field



Conformal Penrose–Carter diagram (rotated from the usual axis convention) of a Kerr–Newman black hole (i.e. with mass, charge and angular momentum) exhibiting other possible universes. (From a drawing by Andrew Hamilton.)

simply because they expand faster than the low-field regions. The volume-averaged value of the field will therefore rise and there will always be regions in which the field is high: the inflation becomes eternal. The regions in which the scalar field fluctuates downward will branch off from the eternally inflating tree and exit inflation.

On the other hand, string theory has recently faced a third change of paradigm. After the revolutions of supersymmetry and duality, we now have the "landscape". This metaphoric word refers to the large number (maybe 10^{500}) of possible false vacua of the theory. The known laws of physics would just correspond to a specific island among many others. The huge number of possibilities arises from different choices of Calabi–Yau manifolds and different values of generalized magnetic fluxes over different homology cycles. Among other enigmas, the incredibly strange value of the cosmological constant (why are the 119 first decimals of the "natural" value exactly compensated by some mysterious phenomena, but not the 120th?) would simply appear as an anthropic selection effect within a multiverse where nearly every possible value is realized somewhere. At this stage, every bubble-universe is associated with one realization of the laws of physics and contains itself an infinite space where all contingent phenomena take place somewhere. Because the bubbles are causally disconnected forever (owing to the fast "space creation" by inflation) it will not be possible to travel and discover new laws of physics.

This multiverse – if true – would force a profound change of our deep understanding of physics. The laws reappear as kinds of phenomena; the ontological primer of our universe would have to be abandoned. At other places in the multiverse, there would be other laws, other constants, other numbers of dimensions; our world would be just a tiny sample. It could be, following Copernicus, Darwin and Freud, the fourth narcissistic injury.

Quantum mechanics was probably among the first branches of physics leading to the idea of a multiverse. In some situations, it inevitably predicts superposition. To avoid the existence of macroscopic Schrödinger cats simultaneously living and dying, Bohr introduced a reduction postulate. This has two considerable drawbacks: first, it leads to an extremely intricate philosophical interpretation where the correspondence between the mathematics underlying the physical theory and the real world is no longer isomorphic (at least not at any time), and, second, it violates unitarity. No known physical phenomenon – not even the evaporation of black holes in its modern descriptions – does this.

These are good reasons for considering seriously the many-worlds interpretation of Hugh Everett. Every possible outcome to every event is allowed to define or exist in its own history or universe, via quantum decoherence instead of wave function collapse. In other words, there is a world where the cat is dead and another one where it is alive. This is simply a way of trusting strictly the fundamental equations of quantum mechanics. The worlds are not spatially separated, but exist more as kinds of "parallel" universes. This tantalizing interpretation solves some paradoxes of quantum mechanics but remains vague about how to determine when splitting of universes happens. This multiverse is complex and, depending on the very quantum nature of phenomena leading to other kinds of multiverses, it could lead to higher or lower levels of diversity.

More speculative multiverses can also be imagined, associated with a kind of platonic mathematical democracy or with nominalist relativism. In any case, it is important to underline that the multiverse is not a hypothesis invented to answer a specific question. It is simply a consequence of a theory usually built for another purpose. Interestingly, this consequence also solves many complexity and naturalness problems. In most cases, it even seems that the existence of many worlds is closer to Ockham's razor (the principle of simplicity) than the *ad hoc* assumptions that would have to be added to models to avoid the existence of other universes.

Given a model, for example the string-inflation paradigm, is it possible to make predictions in the multiverse? In principle, it is, at least in a Bayesian approach. The probability of ▷

observing vacuum i (and the associated laws of physics) is simply $P_i = P_i^{prior} f_i$ where P_i^{prior} is determined by the geography of the landscape of string theory and the dynamics of eternal inflation, and the selection factor f_i characterizes the chances for an observer to evolve in vacuum i. This distribution gives the probability for a randomly selected observer to be in a given vacuum. Clearly, predictions can only be made probabilistically, but this is already true in standard physics. The fact that we can observe only one sample (our own universe) does not change the method qualitatively and still allows the refuting of models at given confidence levels. The key points here are the well known peculiarities of cosmology, even with only one universe: the observer is embedded within the system described; the initial conditions are critical; the experiment is "locally" irreproducible; the energies involved have not been experimentally probed on Earth; and the arrow of time must be conceptually reversed.

However, this statistical approach to testing the multiverse suffers from severe technical short cuts. First, while it seems natural to identify the prior probability with the fraction of volume occupied by a given vacuum, the result depends sensitively on the choice of a space-like hypersurface on which the distribution is to be evaluated. This is the so-called "measure problem" in the multiverse. Second, it is impossible to give any sensible estimate of f_i. This would require an understanding of what life is – and even of what consciousness is – and that simply remains out of reach for the time being. Except in some favourable cases – for example when all the universes of the multiverse present a given characteristic that is incompatible with our universe – it is hard to refute explicitly a model in the multiverse. But difficult in practice does not mean intrinsically impossible. The multiverse remains within the realm of Popperian science. It is not qualitatively different from other proposals associated with usual ways of doing physics. Clearly, new mathematical tools and far more accurate predictions in the landscape (which is basically totally unknown) are needed for falsifiability to be more than an abstract principle in this context. Moreover, falsifiability is just one criterion among many possible ones and it should probably not be over-determined.

When facing the question of the incredible fine-tuning required for the fundamental parameters of physics to allow the emergence of complexity, there are few possible ways of thinking. If one does not want to use God or rely on an unbelievable luck that led to extremely specific initial conditions, there are mainly two remaining possible hypotheses. The first would be to consider that since complexity – and in particular, life – is an adaptive process, it would have emerged in nearly any kind of universe. This is a tantalizing answer, but our own universe shows that life requires extremely specific conditions to exist. It is hard to imagine life in a universe without chemistry, maybe without bound states or with other numbers of dimensions. The second idea is to accept the existence of many universes with different laws where we naturally find ourselves in one of those compatible with complexity. The multiverse was not imagined to answer this specific question but appears "spontaneously" in serious physical theories, so it can be considered as the simplest explanation to the puzzling issue of naturalness. This of course does not prove the model to be correct, but it should be emphasized that there is absolutely no "pre-Copernican" anthropocentrism in this thought process.

It could well be that the whole idea of multiple universes is misleading. It could well be that the discovery of the most fundamental laws of physics will make those parallel worlds totally obsolete in a few years. It could well be that with the multiverse, science is just entering a "no through road". Prudence is mandatory when physics tells us about invisible spaces. But it could also very well be that we are facing a deep change of paradigm that revolutionizes our understanding of nature and opens new fields of possible scientific thought. Because they lie on the border of science, these models are dangerous, but they offer the extraordinary possibility of constructive interference with other kinds of human knowledge. The multiverse is a risky thought – but, then again, let's not forget that discovering new worlds has always been risky.

Further reading

B Carr (ed.) 2007 *Universe or Multiverse?* Cambridge University Press, see contibutions by Weinberg, Wilzcek, Rees, Tegmark, Linde, Bjorken and Mukhanov.
L Smolin 2006 *The Trouble With Physics: the Rise of String Theory, the Fall of Science, and What Comes Next.* Houghton Mifflin Company.
L Susskind 2005 *The Cosmic Landscape*. Little, Brown and Company.

Résumé

Quelle physique dans le multivers?

Notre univers ne serait-il qu'un îlot dérisoire au sein d'un immense «multivers» infiniment vaste et diversifié? Beaucoup de nos models actuels, admis (comme la relativité générale) ou spéculatifs (comme la théorie des cordes), conduisent naturellement à des multivers. Ces univers multiples ne sont pas des théories mais des conséquences de théories élaborées pour répondre à des questions claires de physique des particules ou de gravitation. Beaucoup de problèmes centraux de physique théorique – complexité et naturalité – trouvent ainsi une explication naturelle. Reste que cette proposition révolutionnaire n'est pas exempte de dangers conceptuels et impose une profonde réflexion épistémologique.

Aurélien Barrau, *Laboratoire de Physique Subatomique et de Cosmologie (UJF/CNRS/IN2P3).*

A global network listens for ripples in space–time

Detectors in Europe and the US have linked up for the task of detecting gravitational waves and pinpointing their sources. The first combined data-taking illustrates the power of working together, as **Carlo Bradaschia** and **Riccardo Desalvo** explain.

Fig. 1. Aerial view of the Virgo interferometer at the European Gravitational Observatory, Cascina, Pisa. (Courtesy INFN/EGO.)

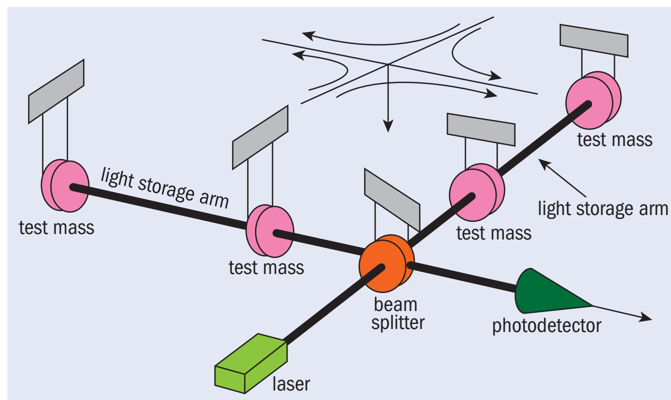


Fig. 2. Schematic diagram of a gravitational-wave interferometer. Suspended mirrors (pink) act as test masses.

Albert Einstein predicted the existence of gravitational waves, faint ripples in space–time, in his general theory of relativity. They are generated by catastrophic events of astronomical objects that typically have the mass of stars. The most predictable generators of such waves are likely to be binary systems, black holes and neutron stars that spiral inwards and coalesce. However, there are many other possible sources, such as: stellar collapses that result in neutron stars and black holes (supernova explosions); rotating asymmetric neutron stars, such as pulsars; black-hole interactions; and the violent physics at the birth of the early universe.

In a similar way that a modulated radio signal can carry the sound of a song, these gravitational-wave ripples precisely reproduce the movement of the colliding masses that generated them. Therefore, a gravitational-wave observatory that senses the space–time ripples is actually transducing the motion of faraway stars. The great challenge is that these ripples are a strain of space (a change in length for each unit length) of the order of 10^{-22} to 10^{-23} – tremors so small that they are buried by the natural vibrations of everyday objects. As inconspicuous as a rain drop in a waterfall, they are difficult to detect.

During the past few years, a handful of gravitational-wave projects have dared to make a determined attempt to detect these ripples. The Italian–French Virgo project (figure 1), the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the US, the British–German GEO600 project and the TAMA project in Japan have all constructed gravitational-wave observatories of impressive size and ambition. Several years ago, the GEO team joined the LIGO Scientific Collaboration (LSC) to analyse the data collected from the two interferometers.

The gravitational-wave observatories are based on kilometre-length, L-shaped Michelson interferometers in which powerful and stable laser beams precisely measure this differential distance using heavy suspended mirrors that act as test masses (see figure 2). The space–time waves "drag" the test masses in the interferometer, in effect transducing (at a greatly reduced scale) the movement of the dying stars millions of parsecs away, much in the way that ears transduce sound waves into nerve impulses.

The main problem in gravitational-wave detection is that the largest expected waves from astrophysical objects will strain space–time by a factor of 10^{-22}, resulting in movements of 10^{-18} to 10^{-19} m of the test masses on the kilometre-length interferometer arms. This is smaller than a thousandth of a proton diameter, and this signal is so small that Einstein, after predicting the existence of gravitational waves, also predicted that they would never be susceptible to detection.

To surmount this challenge requires seismic isolators with enormous rejection factors to ensure that the suspended mirrors are more "quiet" than the predicted signal that they lie in wait to ▷

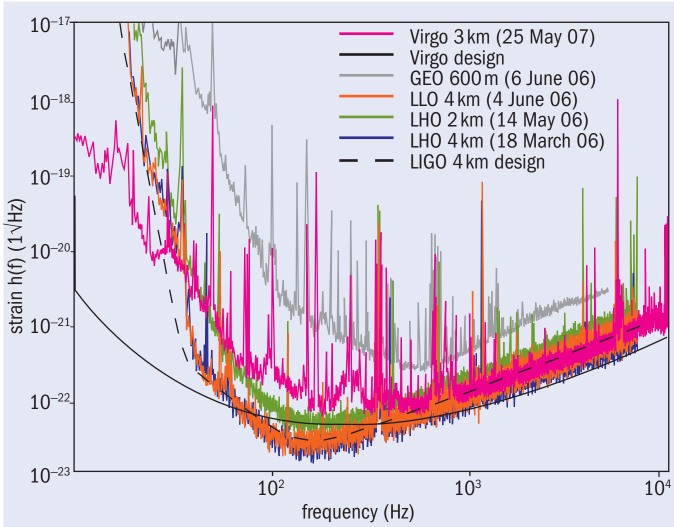


Fig. 3. The sensitivity of the LIGO detectors (red, green and blue), the Virgo detectors (purple) and the GEO600 detectors (dark grey), compared with the design sensitivity of LIGO (dashes) and of Virgo (solid black). Note the strain vertical scale.

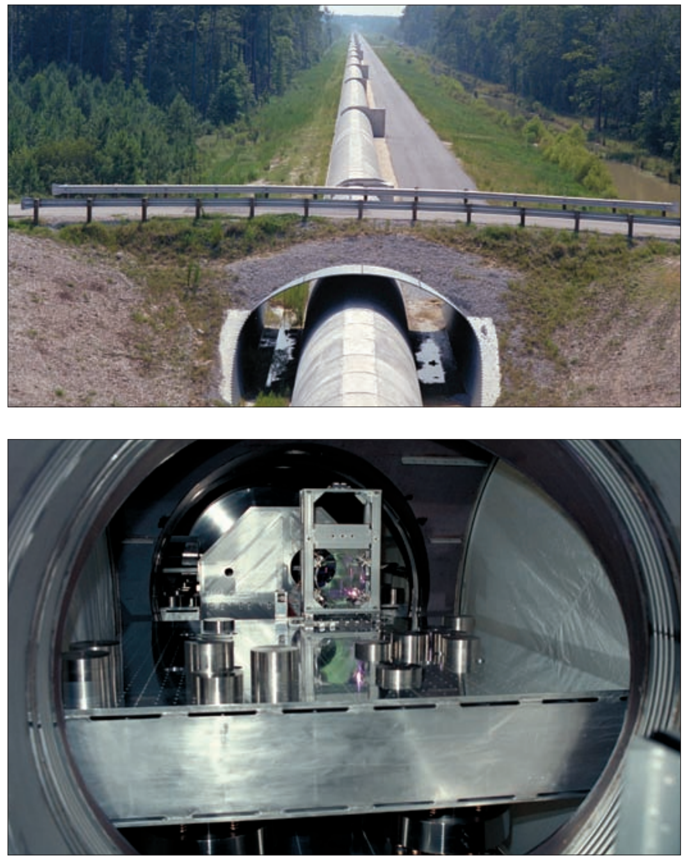


Fig. 4. One of the 4 km arms of the Livingston Observatory (top); one of the optical benches (bottom) carrying a small injection telescope mirror inside one of the mirror vacuum chambers at LIGO. (Courtesy J Kern/LIGO.)

perceive (the typical motion of the Earth's crust, in the absence of earthquakes, is of the order of a micrometre at 1 Hz). The instruments use extremely stable and powerful laser beams to measure the mirror separations with the required precision, but without "kicking" them with a radiation pressure exceeding the sought-after signal. The mirrors being used are marvellous, state-of-the-art constructions, and the thermal motion on their surface is more hushed than the signal amplitude. All of this is housed in large diameter (1.2 m for Virgo and LIGO) ultra-high vacuum (UHV) tubes that bisect the countryside. In fact, the vacuum pipes represent the largest UHV systems on Earth, and their volume dwarfs the volume of the longest particle-collider pipes.

The detectors are extremely complex and difficult to tune. The installation of the LIGO interferometers finished in 2000 and complete installation of Virgo followed in 2003. Both instruments then went through several years of tuning, with LIGO reaching its design sensitivity about a year ago and Virgo fast approaching its own design target (figure 3).

On 22 May, a press conference in Cascina, Pisa, announced the first Virgo science run, as well as the first joint Virgo–LIGO data collection. That week also saw the first meeting of Virgo and the LSC in Europe. It was a momentous occasion for the entire field of gravitational-wave detection. Although the LIGO network was already into its fifth science run, which had started in November 2005, many in the community saw the announcement as marking the birth of a global gravitational-wave detector network.

The collaborative first and fifth science runs of Virgo and LIGO, respectively, ended on 1 October. The effort proved to be a tremendous success, demonstrating that it is possible to operate gravitational-wave observatories with excellent sensitivity and solid reliability for prolonged periods. The accumulated LIGO data amount to an effective full-year of observation at design sensitivity with all three LIGO interferometers in coincident operation, and the four-month-long joint run produced coincidence data between the two observatories with high efficiency. Although no gravitational waves were detected, the collected data are being analysed and will produce upper limits and other astrophysically significant results.

Running gravitational-wave detectors in a network has a fundamental importance related to the goal of opening up the field of gravitational-wave astronomy. Gravitational waves are best thought of as fluctuating, transversal strains in space–time. In an oversimplified analogy, they can be likened to sound waves, that is, as pressure waves of space–time travelling in vacuum at the speed of light. Like sound waves, gravitational waves come in the acoustic frequency band and, since gravitational-wave interferometers act essentially as microphones and lack directional specificity, the waves can be "heard" rather than "seen." This means that a single observatory may detect a gravitational-wave burst but would have difficulty pinpointing its source. Just as two ears at opposite sides of the head are necessary to locate the origin of a sound, a network of several detectors at distant points around the Earth can triangulate the sources of gravitational waves in space. This requires a global network and is critical for pinpointing the location of the source in the sky so that other instruments, such as optical telescopes, can provide additional information about the source. In addition, signals as weak as gravitational waves require coincidence detection in several distant locations to confirm their validity by rejecting spurious events generated by local noise.

Before Virgo joined, the LSC already consisted of two major

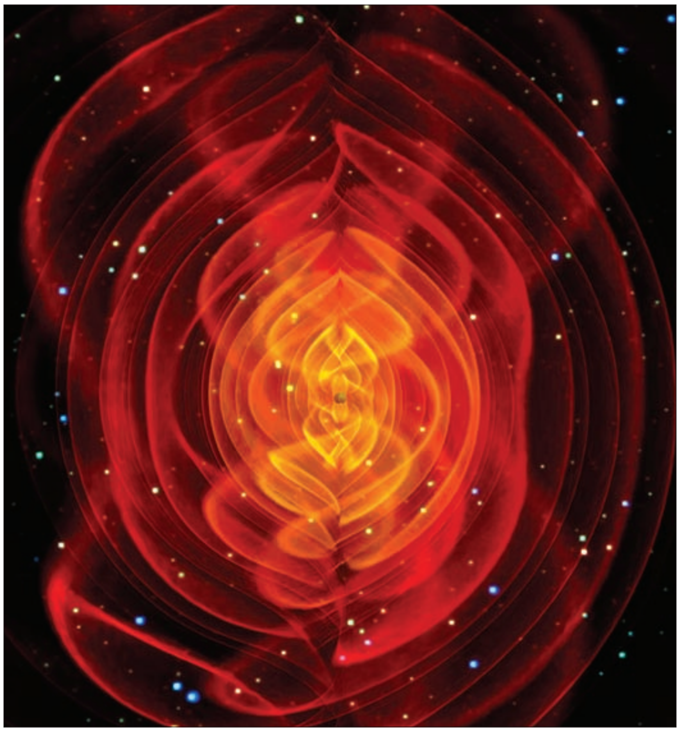


Fig. 5. Simulation of gravitational waves emitted by two black holes merging. (Courtesy Joan Centrella, Gravitational Astrophysics Laboratory, NASA Goddard Space Flight Center.)

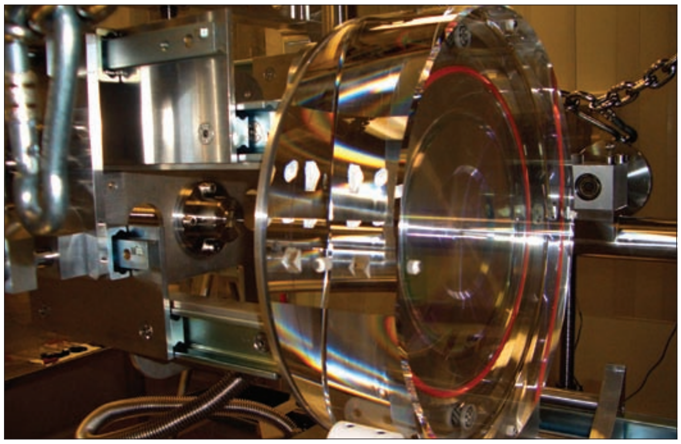


Fig. 6. A Virgo mirror being prepared for installation in the vacuum chamber. It comprises a fused silica disc 100 mm thick and 350 mm in diameter, which is coated with a high-efficiency dielectric, multilayer reflector that is tuned to the Nd:YAG laser's infrared light, but is transparent to visible light. (Courtesy INFN/EGO.)

gravitational-wave observatories in the US – one in Livingston, Louisiana, and the other in Hanford, Washington – as well as the smaller European GEO600 observatory in Germany. The addition of the Virgo interferometer to this network has greatly reinforced its detection and pointing capabilities. The Livingston observatory hosts a single interferometer with a pair of 4 km arms. Hanford has two instruments: a 4 + 4 km interferometer like that at Livingston and a smaller 2 + 2 km one. GEO has a single 0.6 + 0.6 km interferometer, while Virgo operates a 3 + 3 km one. The introduction of Fabry–Perot cavities in the arms boosts the sensitivity of the three larger interferometers, extending the effective lengths of the arms to hundreds of kilometres. GEO600 increases its effective arm length to 1.2 km by using a folded beam.

Japan has a somewhat smaller (0.3 + 0.3 km) interferometer, known as TAMA, located in Mitaka, near Tokyo. It is currently being refurbished with advanced seismic isolators and should soon join the growing gravitational-wave network. Japan is also considering the construction of the Large-scale Cryogenic Gravitational-Wave Telescope (LCGT). This would be a 3 + 3 km, underground interferometer with cryogenic mirrors, which would later become part of the global array of gravitational-wave interferometers. Australia is also developing technologies for gravitational-wave instruments and is planning to build an interferometer.

The effectiveness of gravitational-wave observatories is characterized both by their "reach" and by their duty cycle. The reach is conventionally defined as the maximum distance at which the inspiral signal of two neutron stars (each 1.4 solar masses) would be detectable with the available sensitivity. In gravitational-wave astronomy, improvements in sensitivity achieve more than they do in optical astronomy. Doubled sensitivity equals double reach, resulting in an eightfold increase in the observed cosmic volume and in the expected event rate. Similarly, because of the coincidence requirements between multiple interferometers, the duty cycle of a gravitational-wave observatory is more important than in a stand-alone optical instrument.

During the fifth science run, the two larger LIGO interferometers showed a detection range for the inspiral of two neutron stars of 15–16 Mpc, while the half-length interferometer had a reach of 6–7 Mpc. Virgo, with its partial commissioning, achieved a reach of 4.5 Mpc during the recent first joint run with LIGO. Virgo did not yet reach its design sensitivity in this run. However, its seismic isolation system helped it to achieve a superior seismic event immunity, resulting in longer "locks" (with a record of 95 hours) and an excellent observational duty factor. (The interferometer can only take data when it is "locked" – when all of the mirrors are controlled and held in place to a small fraction of a wavelength of light.) LIGO reached a duty cycle of 85–88% at the end of its fifth science run, while Virgo reached the same level on its first run.

The duty cycle of the triple coincidence of Virgo, LIGO–Hanford and LIGO–Livingston exceeded 58% (or 54% when including the smaller, second Hanford interferometer) and 40% in conjunction with GEO600. This was an amazing achievement given the tremendous technical finesse required to maintain all of these complex instruments in simultaneous operation.

The gold-plated gravitational-wave event would be the detection of a neutron star (NS) or black hole (BH) inspiral. However, even at the present design sensitivity, the Virgo–LIGO network has a relatively small chance of detecting such events. Currently, LIGO could expect a probability of a few per cent each year of ever detecting NS–NS inspirals, with perhaps a larger probability of detecting NS–BH and BH–BH inspirals, and an unknown probability of detecting supernova explosions (only if asymmetric and in nearby galaxies) and rotating neutron stars (only if a mass distribution asymmetry is present).

As scientists analyse the valuable data just acquired from the successful science run, the three main interferometers will now ▷

undergo a one- to two-year period of moderate enhancements and final tuning, and then resume operation for another year of joint data acquisition with greater sensitivity and an order of magnitude better odds of detection. At the end of that period, the interferometers will undergo a more drastic overhaul to boost their sensitivity by an order of magnitude with respect to the present value. A tenfold increase in sensitivity will result in a thousandfold increase of the listened-to cosmic volume, and correspondingly, up to a thousand times improvement in detection probability.

At that point (expected in 2015–16), the network will be sensitive to inspiral events within at least 200 Mpc and we can expect to detect and map several such events a year, based on our current understanding of populations of astrophysical objects. This will mark the beginning of gravitational-wave astronomy, a new window to explore the universe in conjunction with the established electromagnetic-wave observatories and the neutrino detectors.

Beyond this already ambitious programme, the gravitational-wave community has begun tracing a roadmap to design even more powerful observatories for the future. Interferometers based on the surface of the Earth can operate with high sensitivity only above 10 Hz, as they are limited by the seismically activated fluctuations of Earth's Newtonian attraction. This limits detection to the ripples generated by relatively small objects (tens to hundreds of solar masses) and to "modest" distances (redshift $Z = 1$). Third-generation observatories built deep underground, far from the perturbations of the Earth's surface, would be able to detect gravitational waves down to 1 Hz, and be sensitive enough to detect the lower-frequency signals coming from more massive objects, such as intermediate-mass black holes. Finally, space-based gravitational-wave detection interferometers such as the Laser Interferometer Space Antenna (LISA) are being designed to listen at an even lower frequency band. LISA would detect millihertz signals coming from the supermassive black holes lurking at the centre of galaxies. The aim is to launch the interferometer around 10 years from now, as a collaboration between ESA and NASA.

Although gravitational waves have not yet been detected, the gravitational-wave community is poised to prove Einstein right and wrong: right in his prediction that gravitational waves exist, wrong in his prediction that we will never be able to detect them.

Résumé

Un réseau mondial à l'écoute des vagues de l'espace–temps

Les ondes gravitationnelles sont des vaguelettes formées dans l'espace–temps qui pourraient résulter d'événements catastrophiques survenus dans le cosmos, tels que des explosions de supernovas. Toutefois, ces vaguelettes presque imperceptibles sont très difficiles à détecter. Des expériences situées en Europe et aux États-Unis se sont regroupées pour détecter ces ondes et, peut-être, trouver leur source. La première prise de données commune effectuée par le projet franco-italien Virgo et le projet étasunien LIGO, qui s'est achevée le 1er octobre, a montré l'efficacité du travail en réseau.

Carlo Bradaschia, *INFN, Pisa, and* **Riccardo Desalvo**, *Caltech, Pasadena.*

EPS conference sets the scene for things to come

Europe's biennial summer conference visited Manchester for its 2007 meeting, which surveyed the state of particle physics and its readiness for the imminent future.

Manchester's Bridgewater Hall – an international concert venue – was the setting for HEP 2007. (Photos courtesy P Osland.)

The English summer, renowned for being fickle, smiled kindly on the organizers of the 2007 European Physical Society (EPS) conference on High Energy Physics (HEP), which was held in Manchester on 19–25 July. In a city that is proud of both its industrial heritage and a bright commercial future, HEP 2007 surveyed the state of particle physics, which also seems to be at a turning point. While certain areas of the field pin down the details of the 20th-century Standard Model, others seek to prise open new physics as the LHC prepares to open a new frontier.

The conference had a packed programme of 12 plenary sessions and 69 parallel sessions. In his opening talk, CERN's John Ellis took a lead from Paul Gauguin's painting *Life's Questions*, and interpreted the questions in terms of the status of the Standard Model (where are we coming from?), searches beyond the Standard Model (where are we now?) and the search for a "theory of everything" (where are we going?). More than 400 talks covered all three aspects, in particular the status of the Standard Model and the current and future efforts to go beyond it. This report summarizes some of the highlights within these broad themes.

A beautiful model

The success of the Standard Model underpinned the 2007 award of the EPS High Energy and Particle Physics prize to Makoto Kobayashi of KEK and Toshihide Maskawa of the University of Tokyo for their work in 1972 that showed that CP violation occurs naturally if there are six quarks, rather than the original three. Kobayashi was at the conference to receive the prize and to give a personal view of the early work and the current understanding of CP violation. The idea of six quarks began to attract attention with the discovery of the τ lepton in 1976. The rest, as they say, is history, ▷

and the Cabibbo–Kobayashi–Maskawa (CKM) matrix describing six quarks is now a key part of the Standard Model.

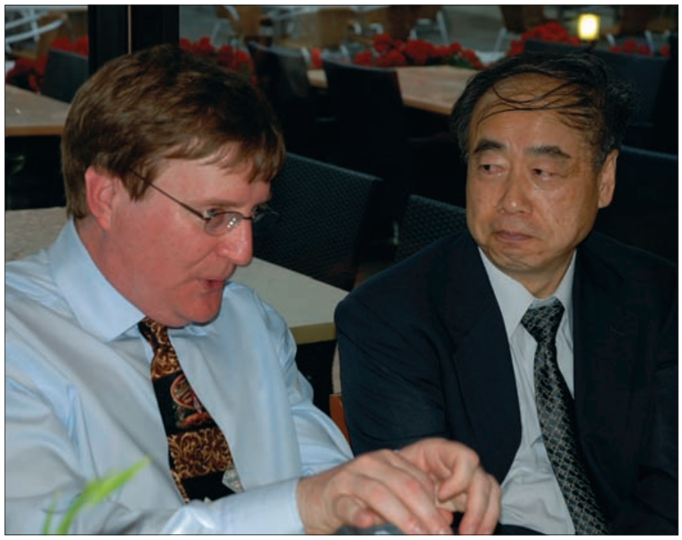
Moving to the present, Kobayashi pointed to the work of the experiments at the B-factories – BaBar at the PEPII facility at SLAC and Belle at KEK-B. They have played a key role in pinning down the well known triangle that expresses the unitarity of the CKM matrix. The two experiments have shown that the three sides of the triangle really do appear to close – a leitmotif that ran throughout the conference. Measurements of $\sin 2\beta$ ($\sin 2\phi_1$) now give a clear value of 0.668 ± 0.028 – a precision of 4% – and even measurements of the angle γ (ϕ_3) are becoming quite good thanks to the performance of B-factories.

Both facilities have provided high beam currents and small beam sizes, leading to extremely high luminosities. With a peak luminosity of $1.21 \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$ – four times the design value – PEPII has delivered a total luminosity of $460\,\text{fb}^{-1}$ but is now feeling the stress of the high currents. Nevertheless, there are plans to try for still-higher luminosity and deliver the maximum possible before the facility closes down at the end of September 2008. KEK-B, with a peak luminosity of $1.71 \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$, has reached a total of $715\,\text{fb}^{-1}$ and there are also plans for increasing luminosity in this machine, using the recently tested "crab crossing" technique, to bring the angled beams into a more direct collision (*CERN Courier* September 2007 p8).

The extra luminosity is important now that the experiments are moving on to a new phase, searching for new physics. This may be manifest in small deviations from the Standard Model at the 1% level, although guidelines from theory are made difficult – not least by uncertainties in QCD. The charmless B decay, $B \rightarrow \phi K^0$ – where at the quark level $b \rightarrow s s \bar{s}$ – currently shows a small systematic deviation from theory. However, many agree with Kobayashi's opinion that it is premature to derive any conclusion. "Super B-factories", as proposed for example at KEK, will probably be necessary to clarify this and other hints of new physics.

B physics is not only the preserve of the B-factories, nor is interest in heavy flavours restricted only to B physics. The CDF and DØ experiments at Fermilab's Tevatron have measured B_s oscillations for the first time, in a 5σ effect with $\Delta M_s = 17.77 \pm 0.10 \pm 0.07\,\text{ps}^{-1}$. This result presents no surprises, but the award of the 2007 EPS Young Physicist prize reflected its importance. This went to Ivan Furic of Chicago, Guillelmo Gomez-Ceballos of Cantabria/MIT, and Stephanie Menzemer of Heidelberg, for their outstanding contributions to the complex analysis that provided the first measurement of the frequency of B_s oscillations. In the physics of the lighter charm particles, the BaBar and Belle experiments have made the first observations of D mixing, at the level of about 4σ, with no evidence for CP violation. Neither B_s nor D mixing is easy to measure, the first being very fast, the second being very small. Moreover, D mixing is difficult to calculate as the charm quark is neither heavy nor particularly light. On the other hand, the Standard Model clearly predicts no CP violation. Elsewhere in the heavy-flavour landscape, CDF and DØ have found new baryons that help to fill the spaces remaining in the multiplets of various quark combinations.

The electroweak side of the Standard Model has known precision for many years, with the coupling constants α and G_F, and more recently the mass of the Z boson, M_z, available as precise input parameters for calculations of a range of observables. Now

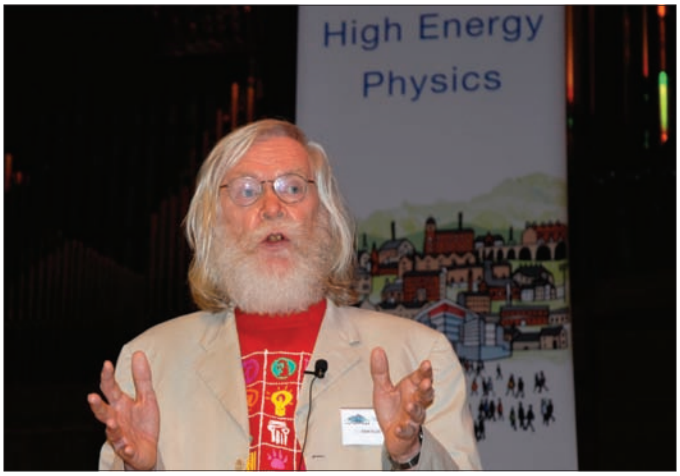


Conference chair, David Wark (left), talks with EPS prizewinner Makoto Kobayashi from KEK during a break between sessions.

with a steadily increasing total integrated luminosity in Run II – $2.72\,\text{fb}^{-1}$ in DØ, for example, by the time of the conference – the mass of the W boson, M_W, is measured with similar precision at both the Tevatron and LEP, and is known to $\pm 25\,\text{MeV}$. CDF and DØ also continue to pin down other observations, in particular in the physics of top, with studies of top decays and measurements of the top mass, M_t, with a latest value of $170.9 \pm 1.8\,\text{GeV}/c^2$. DØ also has evidence for the production of single top – produced from a W rather than a gluon – which gives a handle on $|V_{tb}|^2$ in the CKM matrix. A comparison of M_w and M_t from the Tevatron with the results from LEP and the SLAC Linear Collider provides a powerful check on the Standard Model – M_t is measured at the Tevatron, whereas it was inferred at the e^+e^- colliders – and constrains the mass of the Higgs boson. There will be no beam in the LHC until 2008, so the Tevatron is currently the only hunting ground for the Higgs; with upgrades planned to take its total luminosity to at least $6\,\text{fb}^{-1}$, there are interesting times ahead.

While the Tevatron is still going strong, HERA – the first and only electron–proton collider – shut down for the last time this past summer, having written the "handbook" on the proton. HERA provided a unique view inside the proton through deep inelastic scattering, which is still being refined as analysis continues. Once the final pages are written they will provide vital input, in particular on the density of gluons, for understanding proton collisions at the LHC. This effort continues at the Tevatron, where the proton–antiproton collisions provide a complementary view to HERA, in particular regarding what is going on underneath the interesting hard scatters. Additionally, the HERMES experiment at HERA, COMPASS at CERN and experiments at RHIC are investigating the puzzle of what gives rise to the spin of the proton (or neutron) in terms of gluons or orbital angular momentum.

Measurements at HERA and the Tevatron have challenged the strong arm of the Standard Model by testing QCD with precision measurements that involve hadrons in the initial state, not just in the final state, as at LEP. In particular, they provide a testing ground for perturbative QCD (pQCD) in hard processes where the coupling strength is relatively weak, and show good agreement



John Ellis considers French artist Paul Gauguin's questions in terms of particle physics; in the background, the HEP 2007 poster, following in the style of L S Lowry, the local artist famous for his scenes of the industrial north of England.

The Fairey Band, nine times holders of the National Champion Band of Great Britain title, gave a "taste" of northern England for the HEP p32007 participants, revealing the breadth and quality of a top brass band. (Courtesy Paul S Miyagawa.)

with theoretical predictions. The challenge now is to apply the theory to the more complex scenario of collisions at the LHC, in particular to calculate processes that will be the backgrounds to Higgs production and new physics.

QCD enters a particularly extreme regime in the relativistic collisions of heavy ions, where hundreds of protons and neutrons coalesce into a hot, dense medium. Results from RHIC at Brookhaven National Laboratory (BNL) are already indicating the formation of deconfined quark–gluon matter in an ideal fluid with small viscosity. Here the anti-de Sitter space/conformal field-theory correspondence offers an alternative view to pQCD, with predictions for the higher energies at the LHC.

Beyond the Standard Model

Experiments at the Tevatron and HERA have all searched for physics beyond the Standard Model and find nothing beyond 2σ. At HERA, however, the puzzle remains of the excess of isolated leptons, which H1 still sees with the full final luminosity (reported at the conference only three weeks after the shutdown), although ZEUS sees no effect. This excess will have to be seen elsewhere to demonstrate that it is new physics, and not nature being unkind.

While the high-energy collider experiments see no real signs of new physics, at least neutrino physics is beginning to provide a way beyond the Standard Model. Neutrinos have long been particles about which we know hardly anything, but as Ken Peach from the University of Oxford commented in his closing summary talk, at least now we "clearly know what we don't know". Research has established neutrino oscillations, and with them neutrino mass. However, we still need to know more about the amounts of mixing of the three basic neutrino states to give the flavour states that we observe, and about the mass scale of those basic states.

Clarification in one area has come from the MiniBoone experiment at Fermilab, which finds no evidence for oscillations as reported by the LSND experiment (*CERN Courier* May 2007 p8). However, there are signs of a new puzzle as MiniBoone sees an excess of events at neutrino energies at 300–475 MeV. The Main Injector Neutrino Oscillation Search collaboration presented a new result for mixing in the 23 sector, with $\Delta m^2_{23} = 2.38 + 0.20 - 0.16 \times 10^{-3}$ eV^2 and $\sin^2 2\theta_{23} = 1.00$ with an error of 0.08. For the 13 sector, however, there is still a desperate need for new experiments. The Karlsruhe Tritium Neutrino experiment will try to measure directly the electron neutrino (an incoherent sum of mass states) using the classic technique of measuring the endpoint of the tritium beta-decay spectrum, with a sensitivity of 0.2 eV. Neutrinoless double beta-decay experiments provide another route to neutrino mass and could constrain the lightest state in the mass hierarchy. Taking what we already know from oscillations, one or two of the lightest neutrinos (depending on mass hierarchy) should have masses of at least 0.05 eV. Much now depends on experiments to come.

Dark matter in the cosmos seems to be another sure sign of physics beyond the Standard Model. Cosmology indicates that it is composed of non-baryonic particles and is mostly "cold" – low energy – and so cannot consist of the known lightweight neutrinos. Current direct searches for dark-matter particles are reaching cross-sections of around 10^{-44} cm^2, and the next generation of experiments are aiming to reach a factor of 10 lower. Dark-matter annihilation can affect the gamma-ray sky, so the GLAST mission, due to be launched in December, could complement the searches for dark-matter candidates that will take place at the LHC.

The cosmos holds other mysteries for particle physics, in particular the long-standing question of the origin of ultra high-energy cosmic rays. Clues to the location of the natural accelerators lie in the precise shape of the spectrum at high energies: are there particles with energies above the Greisen–Kuzmin–Zatsepin cut-off? The Pierre Auger Observatory has ushered in a new age of hybrid detection based on a combination of scintillation and air fluorescence detectors. Together, the two techniques reveal both the footprint and the development of an extensive air shower, so reducing the dependence on interaction models. Auger now has more events above 10 EeV than previous experiments, and confirms the "ankle" and steepening at the end of the spectrum (and, since the conference, the first evidence for sources of ultra-high-energy cosmic rays, see p5). Understanding thie spectrum depends on determining the mass of the incoming particles. ▷

Photons constitute less than 2% of the cosmic radiation at these high energies; is the remainder all protons, or are there heavier components, as the data from Auger hint at?

Back on Earth, the LHC is uniquely poised to go beyond the Standard Model, as Ellis pointed out in his opening talk. So a key question for everyone is: when will the LHC start-up? Lyn Evans, LHC project leader at CERN, brought the latest news, but first reminded the audience just how remarkable the project is. He began by paying homage to Kjell Johnsen, who died on 18 July, the week before the conference. Johnsen led the project to build the world's first proton–proton collider, the Intersecting Storage Rings (ISR) at CERN. The LHC is a magnificent tribute to Johnsen, explained Evans, for without the ISR, there would be no LHC. The idea of storing protons, without the synchrotron radiation damping effects inherent in electron beams, was a leap of faith; respected people thought that it would never work.

Now, the LHC is built and the effort to cool down and power-up is underway. Unsurprisingly in a project so complex, problems arise, but they are being overcome; the schedule now foresees that beam commissioning should begin in May 2008, with the aim for first collisions at 14 TeV two months later. The injection system can already supply enough beam for a luminosity of 10^{34} cm^{-2} s^{-1}, but in practice commissioning will start with only a few bunches for each beam, to ensure the safety of the collimation and protection systems.

For the LHC experiment collaborations, commissioning will also start with an emphasis on safety. They will study the first collisions with minimum-bias triggers while they gain full understanding of their detectors, before moving on to QCD dijet triggers to "rediscover" physics of the Standard Model. With 1 fb^{-1} of data collected, there will be the opportunity to begin searching for new physics, with signs of supersymmetry perhaps appearing early. A major goal will of course be to discover the Higgs boson – or whatever mechanism it is that underlies electroweak symmetry-breaking. This is a key issue that the LHC should certainly resolve. Beyond it lie other more exotic questions, concerning extra dimensions and tests of string theory, for example, and even "unparticles" – denizens of a scale-invariant sector weakly coupled to the particles of the Standard Model, as recently proposed by Howard Georgi.

As the LHC nears completion, there is plenty of activity on projects to complement it. The largest is the proposed International Linear Collider (ILC) to provide e^+e^- collisions at a centre-of-mass energy of 500 GeV. The collaboration released the *Reference Design Report* in February, putting the estimated price tag for the machine at $6.4 thousand million (*CERN Courier* April 2007 p4). Like the LHC, it will be a massive undertaking, involving some 1700 cryogenic units for acceleration. To reach still higher energies with an e^+e^- collider, the Compact Linear Collider study is an international effort to develop technology to go up to 3 TeV in the centre-of-mass. The key feature is a double-beam delivery system, with a main beam and a drive beam, and normal conducting structures. It will require an accelerating gradient of more than 100 MV/cm to reach 3 TeV in a total length less than 50 km. The aim is to demonstrate the feasibility by 2010, with a technical design report in 2015.

In other areas, there are proposals for super B-factories and neutrino factories to produce the intense beams needed to study rare and/or weak processes in both fields. The idea behind the neutrino factories is to generate large numbers of pions, which will decay to muons that can be cooled and then accelerated before they decay to produce the desired neutrinos. An important requirement will be a high-intensity proton driver to produce pions in primary proton collisions. Such drivers have, of course, other uses: the Spallation Neutron Source in Oak Ridge, for example, is operating with the world's first superconducting proton linac, currently delivering 0.4×10^{14} protons with each pulse. Other issues for a future neutrino factory are the cooling and acceleration of the muons. The Muon Ionisation Cooling Experiment at the UK's Rutherford Appleton Laboratory will test one such concept, using liquid hydrogen absorbers to reduce the muon momentum in all directions. The subsequent acceleration will have to be fast, before the muons decay, and in this respect researchers are revisiting the idea of fixed-field alternating gradient (FFAG) accelerators, which dates back to the early 1950s. To test the principle, a consortium at the Daresbury Laboratory in the UK plans to build the world's first non-scaling FFAG machine, a 20 MeV electron accelerator.

The design of particle detectors will have to adapt to the more exacting conditions at future machines, to deal with larger numbers of particles, higher densities of particles and higher radiation doses. Issues to consider include: segmentation to deal with the high density of particles; speed to handle large events quickly; and thin structures to keep down the material budget. For the ILC, various collaborations are working on four concepts for the collider detectors; the aim is to select two of these in 2009 and have engineering designs completed by 2010.

The next conference in the series is in Krakow, in 2009. It will be interesting to learn how the new ideas presented at HEP 2007 have advanced, to see the first steps across the new frontier with the LHC and to find out if we can see further towards where we are going.

● HEP 2007 was organized by the universities of Durham, Leeds, Lancaster, Liverpool, Manchester and Sheffield, together with the Cockcroft Institute and Daresbury Laboratory.

Further reading

For presentations from the plenary and parallel sessions, see the conference website at www.hep.man.ac.uk/HEP2007/.

Résumé

Conférence de l'EPS: perspectives de la physique des particules

La Conférence de la Société européenne de physique sur la physique des hautes énergies s'est tenue en 2007 à Manchester. Au programme, plus de 400 sessions parallèles ou plénières, pour un panorama de l'état de la physique des particules en 2007, qui pourrait être une année décisive. Alors que certains secteurs de la discipline travaillent sur l'affinage du modèle standard, d'autres s'efforcent d'accéder à une nouvelle physique grâce au LHC. L'un des thèmes récurrents était le succès du modèle standard, en particulier dans le domaine de la physique des saveurs, ainsi que la nécessité du LHC, qui devrait aider à percer le mystère de la matière noire et de l'énergie sombre.

Christine Sutton, *CERN.*

Cockcroft's subatomic legacy: splitting the atom

This year marks the 75th anniversary of the world's first, and probably most famous, accelerator-based subatomic physics experiment. In splitting the atom at the Cavendish Laboratory, it brought a remarkable scientist, John Cockcroft, to the world's attention.

Ernest Rutherford (centre) encouraged Ernest Walton (left) and John Cockcroft (right) to build a high-voltage accelerator to split the atom. Their success marked the beginning of a new field of subatomic research. (Courtesy AIP Emilio Segrè Visual Archives.)

In April 1932 John Cockcroft and Ernest Walton split the atom for the first time, at the Cavendish Laboratory in Cambridge in the UK. Only weeks earlier, James Chadwick, also in Cambridge, discovered the neutron. That same year, far away in California, Carl Anderson discovered the positron while working on cosmic rays. So 1932 was a veritable *annus mirabilis* in which experiments discovered, and worked with, nucleons; exploited Albert Einstein's relativity and energy-mass equivalence principle; took advantage of the newly emerging quantum mechanics and its prediction of "tunnelling" through potential barriers; and even verified the existence of "antimatter" predicted by Paul Dirac's relativistic quantum theory of the electron. It is hard to think of a more significant year in the annals of science.

The experiment by Cockcroft and Walton split the nucleus at the heart of the atom with protons that were lower in energy than seemed possible, by virtue of quantum mechanical tunnelling – a phenomenon new to physics. In 1928 George Gamow had applied the new quantum mechanics to show how particles could tunnel through potential barriers, and how this could explain the decay of nuclei through alpha emission. He also realized that tunnelling could lower the energy required for an incident positively charged particle to overcome the Coulomb barrier of a target nucleus. It was this insight that underpinned the commitment of Cockcroft and Walton.

The entire sequence of events that led to the pioneering experiment (the specification of particle beam parameters based on contemporary theoretical application and phenomenology; the innovation and development of the necessary technologies to create such beams; and the use of the beams to do experiments on a subatomic scale to achieve a deeper understanding of the structure and function of matter) have been repeated many times as high-energy physics has advanced with the construction of accelerators to the current Standard Model of particles and forces. That Cockcroft realized the immense potential of accelerators ▷

John Cockcroft (left) with George Gamow. Cockcroft realized that Gamow's new theory of quantum mechanical tunnelling provided a way to penetrate the nucleus. (Courtesy AIP Emilio Segrè Visual Archives, Bainbridge Collection.)

James Chadwick (left) and John Cockcroft at Daresbury Laboratory in 1966, celebrating Chadwick's 75th birthday. (Courtesy AIP Emilio Segrè Visual Archives, Kowarski Collection.)

in research, and in particular for progress in fundamental physics, is manifest in his instrumental role in later years to establish large accelerator laboratories, in particular CERN in 1954.

Cockcroft was born on 27 May 1897 to a family of cotton manufacturers in Todmorden, straddling the Lancashire–Yorkshire border in northern England. In his early years he experienced a varied educational background. He studied mathematics at Manchester University in 1914–1915, but the First World War interrupted his studies with service in the Royal Field Artillery. After the war, he returned instead to the College of Technology in Manchester to study electrical engineering. Later he joined the Metropolitan Vickers ("Metrovick") Electrical Company as an apprentice for two years, but subsequently went to St John's College, Cambridge, and took the Mathematical Tripos in 1924. This wide-ranging education served him well in later years. Nowadays, modern accelerator science and engineering relies on such a broad application of skill and innovation.

Such a diverse and formidable combination of training in mathematics, physics and engineering, plus practical experience with a local electrical company, primed Cockcroft for his future success. He joined Ernest Rutherford, who had recently moved from Manchester to the Cavendish Laboratory and with whom he had worked as an apprentice back in Manchester. Initially Cockcroft worked with Peter Kapitsa in the high-magnetic-field laboratory, where he used his industrial links to obtain the necessary large-scale equipment.

At the time, Cockcroft was in many ways the Cavendish Laboratory's only true "theoretician", bringing his mathematical abilities as well as his pragmatic engineering skills to a group that was strong in the experimentalist tradition of Rutherford. Cockcroft realized in 1928, before anyone else, the implications of Gamow's tunnelling theory, namely that an energy of 300 keV might be sufficient for protons to penetrate a nucleus of boron, and even less for lithium. In a seminar at the Cavendish Laboratory in 1928 the young Soviet physicist Georgij Gamov (who became better known as George Gamow) reported on his calculations of potential-barrier tunnelling, its successful application to alpha-decay, and its importance for barrier penetration. Encouraged by Rutherford, Cockcroft initiated the high-voltage accelerator programme, and was joined by a student, Ernest TS Walton from Ireland.

Walton was a Methodist minister's son, born in 1903 and educated in Belfast and Dublin. He was very much the lead experimentalist, though the junior partner. The aim was to build an accelerator to achieve an energy up to 1 MeV in order to be sure to penetrate the nuclear potential barrier. Walton had abandoned work on a circular accelerator for his thesis topic and now pursued the linear solution with Cockcroft. They took advantage of strong links with Cockcroft's old employer in Manchester, Metrovick, which at the time was pioneering equipment for the UK electrical grid at transmission voltages up to 130 kV. Metrovick supplied the high-voltage transformers for what became the Cockcroft–Walton generator. So even at the start of the nuclear age, academic–industrial collaboration underpinned progress.

There were formidable challenges to overcome in each component: motor, generator and transformer; rectifier; 40 kV proton source; glass vacuum vessel; and so on. To this day working with such voltages, even below 500 kV, causes difficulties, as witnessed by the performance issues faced in DC photo-injectors at Jefferson Laboratory and Daresbury Laboratory. The interesting story of scrounging for the proper ceramic tubes to be used in the ultimate Cockcroft–Walton generator is a saga in itself.

Records show that life at the Cavendish Laboratory under Rutherford did not begin early in the day and finished strictly at 6.00 p.m. Rutherford insisted that it was to preserve health and to aid contemplation. Perhaps it partly explains the relatively slow progress by Cockcroft and Walton between 1929 and the ultimate triumph in 1932, although perhaps also it was, by all accounts and like all experimentalists, because both enjoyed the fun of building and perfecting their new experimental "toy". Another reason was the relocation of their laboratory and a rebuild of their apparatus to a nominal 800 keV rating, primarily because of their own lack of confidence in the predictions of the new tunnelling calculations.

The day that transformed subatomic physics was 14 April 1932

Cockcroft's expertise was valued around the world. He was consulted, for example, by India's foreign diplomat Vijayalakshmi Pandit, who is seen here (centre) with Cockcroft (behind and to her right) and other honorary graduands at the University of Leeds in 1956. (Courtesy J Dainton.)

John Cockcroft's son (right) and three daughters at the opening of the Cockcroft Institute by Lord Sainsbury of Turville on 19 September 2006. (Courtesy S Eyres/ Daresbury Lab Media Services.)

when Cockcroft and Walton split the lithium atom with a proton beam. Accounts have it that Rutherford had become frustrated at the lack of results from the generator, which was Cockcroft and Walton's pride and joy, and insisted that they get some results. Initially they used a beam of 280 keV, but later demonstrated atom splitting by a beam with energy below 150 keV. The experimenters closeted themselves in a lead-lined wooden hut in the accelerator room, and then peered through a microscope to look for scintillations due to alpha particles, which they counted by hand. If a zinc sulphide screen hanging on the wall glowed, they added a little more lead – so much for health and safety 75 years ago. Of course, they found scintillations, thereby observing the splitting of lithium nuclei by the incident protons, to form two alpha particles.

Ironically, as Gamow's idea of barrier penetration proved to be correct, the experiment could have been performed at least a year earlier in a previous version of the apparatus. This is also true of a successful experiment in October 1932 at the Kharkov Institute, Ukraine, and for Ernest Lawrence's cyclotron in Berkeley, California, soon after Cockcroft and Walton's results. (In early August 1931, Gamow, and later Cockcroft, had visited the Kharkov Institute and discussed the new idea.) Many laboratories repeated and added to the work of the Cavendish Laboratory during the following six months, leading to a flood of experiments around the world. But it was Cockcroft and Walton who first split the atom, albeit later than might have been.

The so-called Cockcroft–Walton multiplier, based on a ladder-cascade principle to build up the voltage level by switching charge through a series of capacitances, is still in use today. Only in 2005, for example, was the version used on the injector for ISIS, the spallation neutron source at the Rutherford Appleton Laboratory, replaced by a new 665 keV RF quadrupole. The old multiplier will soon be on display at the entrance to the UK's newly created Cockcroft Institute of Accelerator Science and Technology in Cheshire. The original version used by Cockcroft and Walton was, in fact, a refinement of a much earlier circuit by M Schenkel, a German engineer, which Heinrich Greinacher had already improved and so could never be patented.

Cockcroft and Walton naturally had close links with Chadwick, whose Nobel prize-winning discovery of the neutron occurred only a few weeks earlier in the same laboratory, making 1932 an extraordinary year for an extraordinary laboratory. Chadwick eventually built the first synchrocyclotron at the University of Liverpool, which was then reproduced at CERN at its inception in the early 1950s.

Cockcroft took over the Magnet Laboratory in Cambridge in 1934 following the departure of Kapitsa, and Walton moved to Trinity College, Dublin. In 1939, Cockcroft started work on radar systems for defence. In 1944 he became director of the Chalk River Laboratory, Canada. Two years later he was back in the UK, where he was appointed inaugural director of the Atomic Energy Research Establishment (AERE), Harwell, and played a major leadership role in ensuring the eventual operation of the world's first nuclear power station at Windscale. He was also influential with the newly founded Indian government, whose foreign diplomat Vijayalakshmi Pandit visited Cockcroft in the UK for advice on the creation of an atomic-energy enterprise in India under physicist Homi J Bhabha's leadership and initiative.

The week of 8–12 October 2007 marked the 50th anniversary of an event that was as notorious in its day as Three Mile Island in Pennsylvania or Chernobyl: the fire in the reactor at Windscale on the coast in north-west England. This was an environmental disaster that followed a standard procedure to release Wigner (thermal) energy stored in the graphite pile. The cause is still controversial. However, it would have been much worse without a feature widely known as "Cockcroft's folly", which was added late in the construction of the reactor. Cockcroft was head of AERE at the time and he intervened to insist on filters on the chimneys, which were retrofitted and were therefore at the top, so giving the chimneys their distinctive shape with large concrete bulges. Cockcroft's intervention undoubtedly saved a much bigger disaster.

Cockcroft took charge of the AERE at a time when it was almost the sole repository of particle-accelerator expertise in Europe. In addition to early linear-accelerator construction, there was pioneering work on what was then a new and exciting device, the synchrotron. Several small 30 MeV rings were built and larger ▷

ones designed for universities at Oxford, Glasgow and Birmingham. Then when planning started for CERN – which was not greeted with much enthusiasm by some in the UK who already had their own machines – it was Cockcroft who appointed Frank Goward from Harwell to assist Odd Dahl and Kjell Johnsen in the design of the PS. Soon afterwards he also encouraged two other important figures from Harwell to join in, with lasting impact on CERN: Donald Fry and John Adams.

In 1951, Cockcroft and Walton shared the Nobel Prize in Physics for the "transmutation of atomic nuclei by artificially accelerated particles". Why had it taken so long to recognize the achievement, when Lawrence was instantly rewarded in 1932 for the invention of the cyclotron? The reason seems to be that there was a long list of giants still waiting to be recognized – Heisenberg among them – before Cockcroft and Walton could take their proper place. The awarding of the Nobel prize to Lawrence for the cyclotron helped to establish the pattern of rewarding instrument building for its own sake, introducing "innovation" into the criteria of the Nobel committee, in addition to "discovery".

Cockcroft later held many important and influential scientific and administrative positions. He was president of the UK Institute of Physics and the British Association for the Advancement of Science, and was chancellor of the Australian National Academy, Canberra. His work was also acknowledged in many ways, including honorary doctorates and membership of many scientific academies. In 1959 he was appointed master of Churchill College, Cambridge. He died, aged 70, on 18 September 1967 – a year after the celebration of Chadwick's 75th birthday at the newly created Daresbury Laboratory. It is at Daresbury that another important step forward for accelerator physics has begun, with the Cockcroft Institute named in honour of the accelerator "giant" who, along with Walton, first split the atom 75 years ago.

Résumé

Fission de l'atome: l'héritage de Cockcroft

En avril 1932, John Cockcroft et Ernest Walton réalisaient la première fission de l'atome, à Cambridge (Royaume-Uni). La séquence qui a conduit à cette expérience révolutionnaire a depuis été répétée maintes fois, pour d'autres expériences en physique des hautes énergies: définition des paramètres des faisceaux de particules, en s'appuyant sur la théorie et la phénoménologie du temps, innovation et développement des technologies nécessaires à la création des faisceaux, et enfin utilisation des faisceaux pour réaliser des expériences à l'échelle subatomique, afin de mieux connaître la matière. Cockcroft lui-même a ensuite joué un rôle important dans la création de grands laboratoires d'accélérateurs, en particulier le CERN, en 1954.

Mike Poole, **John Dainton** *and* **Swapan Chattopadhyay**, *Cockcroft Institute.*

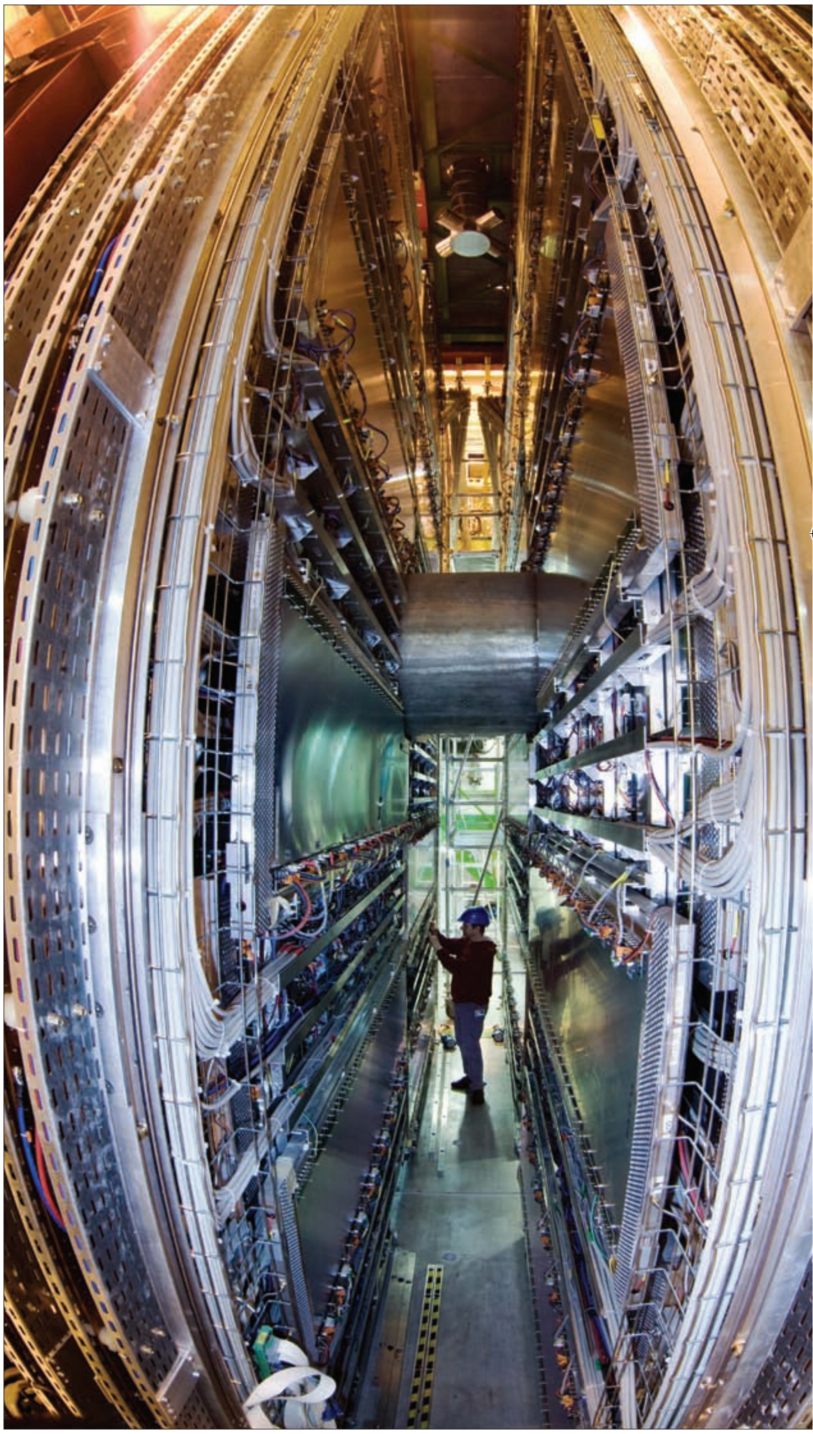
ALICE gets ready to p

The muon spectrometer will play an important role in the ALICE experiment's studies of hot qua

When the LHC begins to open up a new high-energy frontier, it will achieve the highest concentration of energy in operations with lead ions. The collisions, each involving around 400 nucleons with a total energy of more than 1000 TeV, will create strongly interacting, hot, dense matter – a melting pot of quarks and gluons called quark–gluon plasma. This matter will exist for only an instant, and the main goal of the ALICE experiment is to search for evidence of its existence among the many thousands of particles emerging from each collision. One important piece of evidence will be the detection of dimuons – pairs of muons of opposite sign. For this reason, the muon spectrometer, which incorporates some of the first detectors installed in the ALICE underground cavern at Point 2 on the LHC ring, has a key role.

Dimuons are emitted in the decays of vector mesons containing heavy quarks, such as the J/Ψ, the Ψ', and members of the Υ family. Dimuons will also reveal the decays of light vector mesons (ϕ, ρ and ω) and of particles with open charm and beauty. The heavy quarkonia states represent one of the most powerful methods to probe the nature of the medium produced in the early stages of the heavy-ion collisions. Indeed, more than 20 years ago, Tetsuo Matsui and Helmut Satz pointed out that J/Ψ production should be suppressed if a quark–gluon plasma is formed in the collision. This provides a strong motivation for experimental studies of J/Ψ and Ψ' production, undertaken at the energies of the SPS at CERN and RHIC at Brookhaven National Laboratory (BNL). The LHC will be special, however, because two families of resonances (J/Ψ and Υ) rather than one will be experimentally accessible, thanks to the higher beam energy. In addition, the temperature of the quark–gluon "bath" at the LHC is expected to be high enough to "melt" all or most of the Υ states.

As in many experiments, including ATLAS and CMS at the LHC, the role of the muon spectrometer is to detect muons and measure their momenta from the bending of their tracks in a magnetic field. However, there are some very specific aspects of the spectrometer's design because the ALICE experiment will specialize in studying heavy-ion collisions. In ATLAS and CMS, the muon spectrometer follows the "barrel and endcaps" construction based on a toroidal or solenoidal magnetic field. ALICE also has a central "barrel" of detectors inside the large-aperture solenoid magnet from the L3 experiment at LEP, but the muon spectrometer – with its own large dipole magnet – is located at one side of the barrel, where it will detect muons emitted at small angles with respect to the beam. Isolating muons in heavy-ion collisions requires a large amount of material (absorber) to reduce the huge numbers of hadrons, but the absorbers also stop low-energy muons. So, the measurement of vector mesons (in particular the J/Ψ and Ψ')



Trigger planes of resistive plate chambers. (Courtesy A Muller for CERN.)

pinpoint muon pairs

uark matter in heavy-ion collisions at the LHC. **Florent Staley** and **Ermanno Vercellin** report.

Installing tracking planes. (Courtesy A Saba for CERN.)

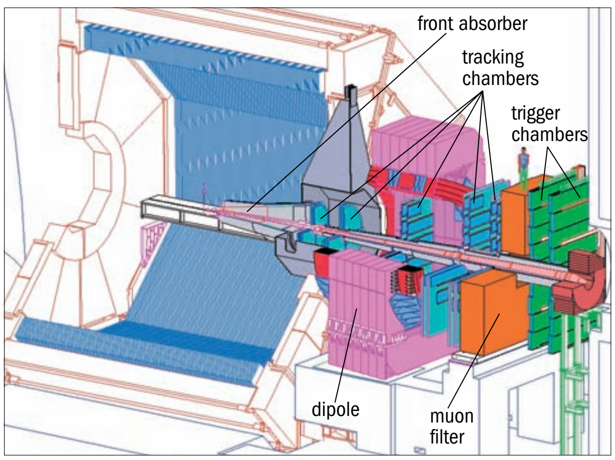


Fig. 1. The layout of the ALICE muon spectrometer.

of low transverse momentum (p_t) is feasible only at small angles, where the muons emitted in their decay have rather high energies owing to the Lorentz boost.

Both the special environment of the heavy-ion collisions and the physics involved have led to other important criteria for the design of the spectrometer. For example, the tracking detectors must be able to handle the high multiplicity of charged particles that are produced. Also, the accuracy of the dimuon measurements is limited by statistics (at least for the Υ family), so the geometrical acceptance must be as large as possible.

The main goal will be to resolve the peaks of the Υ, Υ' and Υ'', which requires resolutions of 100 MeV/c^2 for masses around 10 GeV/c^2. This in turn determines the bending strength of the spectrometer magnet as well as the spatial resolution of the muon tracking system. It also imposes the need to minimize multiple scattering in the structure and carefully optimize the absorber. Finally, the spectrometer has to be equipped with a dimuon trigger system that matches the maximum trigger rate handled by the ALICE data acquisition.

Figure 1 shows the main components of the spectrometer. Closest to the interaction region, there is a front absorber, to remove hadrons and photons emerging from the collision. Five pairs of high-granularity detector planes form the tracking system within the field of the large dipole magnet. Beyond the magnet is a passive muon filter wall, followed by two pairs of trigger chamber planes. In addition, there is an inner beam shield to protect the chambers from particles and secondaries produced at small angles.

The absorbers have a crucial role, so the collaboration has taken great care in their design. The front absorber has to remove hadrons coming from the interaction region without creating further particles and without affecting muons that come from vector meson decays. This absorber is located inside the L3 magnet. It has a composite structure of different materials to limit small-angle scattering and energy lost by the muons and to protect other detectors in ALICE from secondary particles produced in the absorber itself.

Building such a complex item was an impressive international effort. The tungsten came from China, the aluminium from Armenia, the steel from Finland, the graphite from India, the borated polyethylene from Italy, the lead from the UK and the concrete from France. Engineers from Russia and CERN designed the absorber, the Chinese assembled it at CERN and the International Science and Technology Centre in Moscow provided part of the funding.

The spectrometer itself is shielded throughout its length by the beam shield. This is a dense absorber tube made of some 100 tonnes of tungsten, lead and stainless steel, which ▷

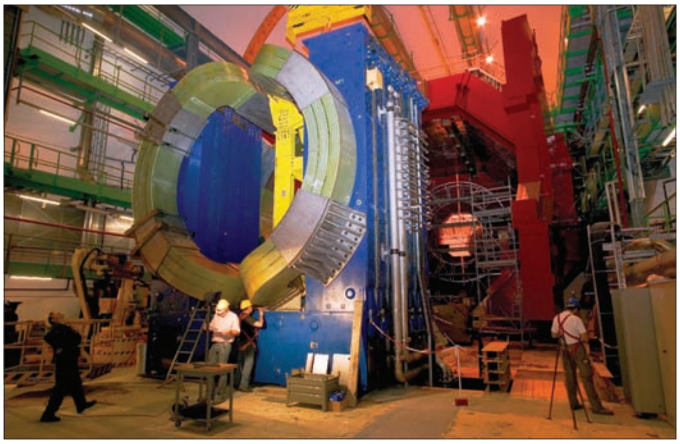


Fig. 2. The dipole magnet, with its huge resistive coils, is installed in the cavern, with the yoke of the L3 magnet (red) behind.

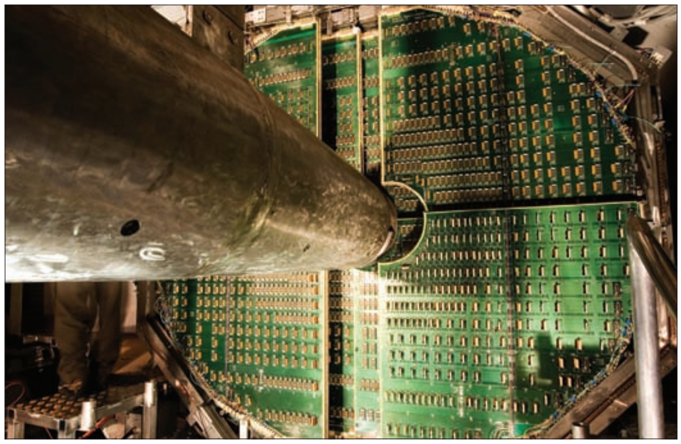


Fig. 3. Chambers in tracking station 2, showing the quadrant structure. (Courtesy Aurélien Muller for CERN.)

surrounds the beam pipe. The inner vacuum chamber has an open-angle conical geometry to reduce background particle interactions along the length of the spectrometer.

While the front absorber and the beam shield are sufficient to protect the tracking chambers, the trigger chambers need additional protection. This is provided by an iron wall about 1 m thick – the muon filter – located between the last tracking chamber and the first trigger chamber. Together, the front absorber and the muon filter stop muons with momentum of less than 4 GeV/*c*.

The spectrometer design is constructed around a dipole magnet that is among the largest ever built using resistive coils (figure 2). With a gap between poles of about 3.5 m and a yoke about 9 m high, it weighs 850 tonnes. To provide the required resolution on the dimuon mass, it has a field of 0.7 T, with a field integral between the interaction point and the muon filter of 3 Tm.

There are two main requirements that underpin the design of the tracking system: a spatial resolution better than 100 μm and the capability to operate in the high-multiplicity environment. For central lead–lead collisions, even after the absorbers have done their work, a few hundred particles will nevertheless hit the muon chambers, with a maximum hit density of about 5×10^{-2} cm^{-2}. Moreover, the system has to cover an area of about 100 m^2.

These demands all led to the choice of cathode-pad chambers to detect the muons. There are 10 planes of chambers in all, arranged in pairs to form five stations: two pairs before the dipole magnet; one inside it; and two after. Each chamber has two cathode planes to provide 2D hit information. The read-out pads are highly segmented to keep the occupancy down to around 5%. For example, in the region of the first station close to the beam pipe, where the multiplicity will be highest, the pads are as small as 4.2×6.3 mm^2. Then, as the hit density decreases with the distance from the beam, larger pads are used at larger radii. This keeps the total number of electronics channels to about 1 million.

To minimize the multiple scattering of the muons, the chambers are constructed of composite materials such as carbon fibre. This technology allows for extremely thin and rigid detectors, resulting in the chamber thickness as small as 0.03 radiation lengths. The tracking stations vary in size, ranging from a few square metres for station 1 to more than 30 m^2 for station 5. This led to two different basic designs for the chambers. The chambers in the first two stations have a quadrant structure, with the read-out electronics distributed on their surface (figure 3). For the other stations, the chambers have an overlapping slat structure (figure 4) with the electronics implemented on the side of the slats. The maximum size of the slats is 40×240 cm^2.

The front-end electronics for reading out the signals from the tracking chambers is based on custom-designed VLSI chips, developed within the ALICE collaboration. The system uses the MANAS chip (*CERN Courier* December 2004 p5), which was derived from the GASSIPLEX chip used for other detectors in ALICE, and the MARC chip. The gain dispersion between the different channels is about 3% – essential for achieving the desired invariant mass resolution. The electronics are completed by the CROCUS system, which was specifically designed and developed to perform the read out of the tracking chambers.

The alignment of the tracking chambers is crucial for achieving the required invariant mass resolution, so there will be a strict procedure to follow when ALICE is running. There will be dedicated runs without magnetic field for aligning the chambers with straight muon tracks. Then, during standard datataking, a dedicated monitoring system will record any displacement with respect to the initial geometry, which can occur for a variety of reasons, including the switching on of the magnet. The geometry-monitoring system consists of 460 optical sensors installed on the tracking chambers. It projects the image of an object onto a CCD sensor and the analysis of the recorded image then provides a measurement of the displacement. The aim is to monitor the position of all of the tracking chambers with a precision better than 40 μm.

Trigger chambers beyond the muon filter form the final important component of the muon system. The role of the trigger detectors is to select dimuons produced (e.g. by J/Ψ or Υ decays) from the background of low-p_t muons produced by the decays of pions and kaons. The selection is made on the p_t of each individual muon, yielding a dimuon trigger signal when there are at least two tracks above a predefined p_t. This p_t selection needs a position-sensitive trigger detector with a spatial resolution of better than 1 cm – a requirement that is fulfilled by resistive plate chambers (RPCs). These detectors will be operated in streamer mode during heavy-ion runs.

The trigger system consists of four RPC planes, with a total active area of about 150 m^2, arranged in two stations, 1 m apart, behind

Fig. 4. *Tracking stations 4 and 5, with the overlapping slat structure. (Courtesy Aurélien Muller for CERN.)*

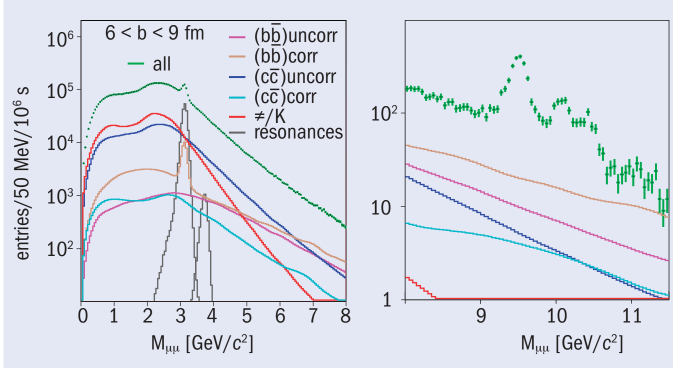


Fig. 5. An example of dimuon invariant mass distributions for a month-long lead–lead run at the LHC. With the quarkonia peaks, the different contributions to the dimuon continuum (including correlated and uncorrelated muon pairs) are shown.

the muon filter. The RPC electrodes are made of low-resistivity Bakelite (about $3 \times 10^9\,\Omega$cm) so as to achieve the rate capability in the heavy-ion collisions. They are coated with linseed oil to improve the smoothness of the electrode surface. Extensive tests have shown that the RPCs will be able to tolerate several years of data taking in ALICE with heavy-ion beams.

The front-end electronics for the trigger detectors is based on the ADULT integrated circuit, also developed within the ALICE collaboration. Although designed for optimizing the time resolution when the RPCs operate in streamer mode, the circuit also allows the chambers to operate in "avalanche mode" during the long proton–proton runs that will occur at the LHC. The signals from the trigger detectors pass to the trigger electronics, which performs the p_t selection on each muon. If the muon trigger is fired, a dedicated electronics card called the DARC allows the transfer of the trigger data to the ALICE data acquisition. Thanks to a short decision time of about 700 ns with these electronics, the dimuon trigger forms part of the level-0 trigger for ALICE. A high-level trigger system – based on the analysis by a PC farm of the final two tracking stations – further refines the selection of good events.

The collaboration has developed a detailed simulation to evaluate the performance of the muon spectrometer for the vector meson and heavy-flavour studies, using as input current knowledge about the different processes that contribute to dimuon production at LHC energies. Figure 5 shows an example of such studies, in this case the invariant mass distributions in the regions of the J/Ψ and Υ mass for lead–lead collisions in ALICE. This demonstrates the spectrometer's capability to detect these resonances against various sources of background.

For the past few years, components built for the spectrometer have arrived at CERN from many different collaborating institutes and suppliers. The two coils for the spectrometer dipole magnet arrived at CERN in September 2003 (*CERN Courier* November 2003 p7) and the complete magnet was installed in its final position underground in summer 2005. A year later, dimuon trigger and tracking chambers were the first detectors to be installed in ALICE's underground cavern in July 2006 (*CERN Courier* October 2006 p7). Since then installation and commissioning have maintained a good pace, and the dimuon spectrometer should be ready for the first global tests of ALICE at the end of the year.

● The design and construction of the ALICE muon spectrometer have been made possible through the joint efforts of many institutions in different countries: CEA/DAPNIA Saclay, IPN Lyon, IPN Orsay, LPC Clermont-Ferrand, LSPC Grenoble and Subatech Nantes (France); CERN Geneva (Switzerland); INFN/University of Cagliari, INFN/University of Torino, University of Piemonte Orientale and INFN Alessandria (Italy); JINR Dubna, PNPI Gatchina and VNIIEF Sarov (Russia); KIP Heidelberg (Germany); Muslim University of Aligarh and SAHA Institute Kolkata (India); University of Cape Town (South Africa); and Yer-Phi Yerevan (Armenia).

Further reading

ALICE Collaboration 1999 ALICE *Dimuon Forward Spectrometer: Technical Design Report*. CERN/LHCC **99-22**.
ALICE Collaboration 2000 *ALICE Dimuon Forward Spectrometer: Addendum to the Technical Design Report*. CERN/LHCC **046**.
ALICE Collaboration 2004 ALICE: physics performance report, volume I, *J Phys. G Nucl. Part. Phys*. **30** 1517.
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Résumé

ALICE en quête de muons

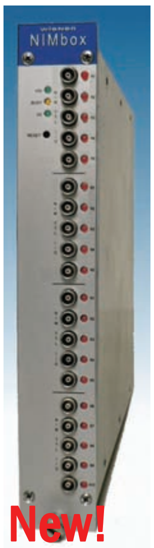
L'expérience ALICE, menée au LHC, vise avant tout à percer le mystère de la matière chaude et dense qui est créée brièvement lors des collisions d'ions lourds aux hautes énergies. La détection des muons produits lors des désintégrations de particules contenant des quarks lourds devraint permettre d'éclaircir la question. Aussi le spectromètre à muons joue-t-il un rôle clé dans le détecteur d'ALICE. Les conditions dans lesquelles s'opèrent les collisions d'ions lourds imposent des contraintes particulières à la conception du spectromètre, du point de vue de son emplacement, des absorbeurs utilisés pour arrêter les hadrons, de l'ouverture de l'aimant et des détecteurs requis pour traquer les particules et assurer le déclenchement du système pour muons.

Florent Staley, *DAPNIA, and* **Ermanno Vercellin**, *INFN/University of Torino.*

Modules

NIM

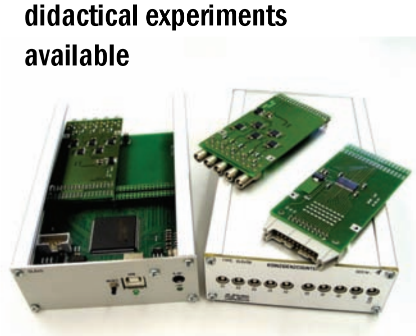
NIMbox
A programmable NIM Module with USB Interface



- **NPN20** - Progr.Logic Unit, 20 NIM I/O
- **NPT20** - Progr. Logic Unit, 20 TTL I/O
- **NDL8** - Leading Edge 8-fold Discriminator
- **NAD4** - 100 MHz 4 channel F-ADC
- **NDA8** - 100 MHz 8 channel DAC, e.g. for detector simulation
- Scaler, TDC, MLU, and more...

USB cable, driver and software included

Desk version (Nembox) for didactical experiments available



Developed in collaboration with University of Heidelberg

CAMAC

CC-USB
Controller with USB Interface

PCI and VME adapters for CAMAC are also available

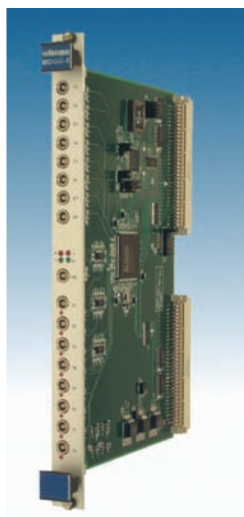
CQ16
16 channel 12 bit CAMAC QDC, down to 25fC/count

VME

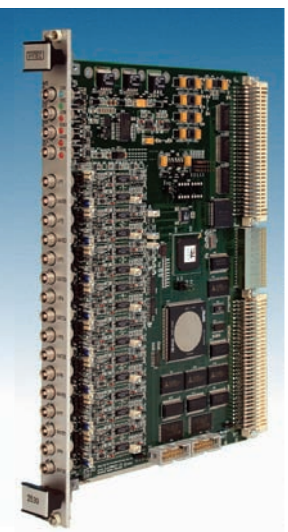
VME-USB
Controller with USB Interface

VDIS2
Diagnostic Module for VME

MDGG8
Progr. Delay and Gate Generator, Scaler



ADC2530
8 channel peak sensing 13 bit ADC



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TD Lee: a bright future for particle physics

Fifty years after receiving the Nobel prize, TD Lee's view of the health of particle physics continues to be overwhelmingly optimistic, as he revealed during a recent visit to CERN.

On 10 December 1957, two young Chinese-Americans arrived in Stockholm to collect the Nobel Prize for Physics – the first Chinese to achieve this award. Tsung-Dao Lee and Chen Ning Yang received their share of the best-known prize in science for work done in the summer of 1956, in which they proposed that the weak force is not symmetric with respect to parity – the reversal of all spatial directions. The bestowal of the Nobel was a fitting end to a tumultuous year for physics, which began with results from an experiment on nuclear beta-decay in which Chien-Sung Wu and collaborators had shown that Lee and Yang were correct: nature violates parity symmetry in weak interactions.

Half a century later, Lee continues to focus on understanding the basic constituents of matter and, in particular, symmetry in fundamental particles, though much has changed in the intervening years. "Our concept of what matter is made of, 50 years later, is very different," he points out. "Today, we now know that all matter is made of 12 particles: six quarks and six leptons. The constituents of all matter – not dark matter, not dark energy but our kind of matter – every star, our Milky Way, all the galaxies in the universe are made of these 12."

These 12 particles, divided into four families, each with three particles of the same charge, form the basis of the current Standard Model of particle physics. They are what students first learn about the subject. In 1957, however, physicists had a clear knowledge of only two of these – the electron and the muon, both charged leptons. Quarks lay in the future, and the neutrino associated with nuclear beta-decay had been detected for the first time only the previous year. Since then, the field has blossomed with the discovery of a total of six kinds of quark, a third charged lepton (the τ) and three kinds of neutrino. Five decades ago, Lee explained: "We knew a form of neutrino, but we didn't know how to make a coherent mixture of all these three." Now, one of Lee's main interests lies in the phenomenon of mixing in the leptons and quarks, described by two 3×3 matrices, which he calls the cornerstones of particle physics.

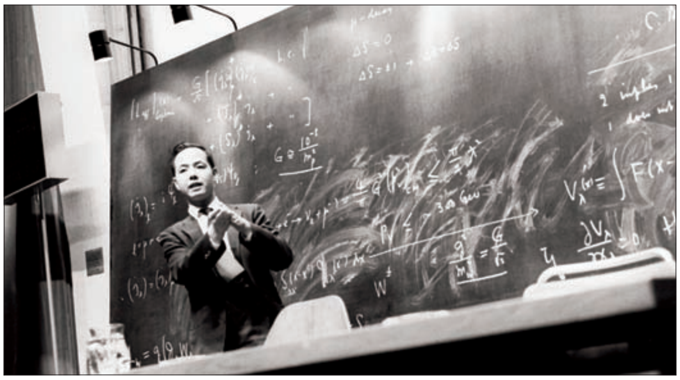
Lee is fiercely proud of the progress in particle physics, and believes that the second half of the 20th century was as rich as the latter part of the 19th century. The 1890s saw the discovery of the electron, and Ernest Rutherford opened the door to a new world with his work on alpha, beta and gamma radiation. Here

Lee enthuses about the enormous progress in particle physics over the past 50 years during his colloquium at CERN.

already, Lee observes, was much of 20th-century physics – alpha, beta and gamma decay, respectively, occur through the strong, weak and electromagnetic interactions, which underpin the Standard Model. "Now, 100 years later, we realize that all of our kind of matter is made of 12 particles, divided into four families, each of three particles of the same charge – that is fantastic." He believes that the field is poised to lead to more great physics out of a better understanding of these basic constituents.

Lee's contributions to particle physics during the past 50 years have been equally impressive. Growing up in China, he proved to be an excellent student and in 1946 he was able to go to the University of Chicago on a Chinese government scholarship. He gained his PhD under Enrico Fermi in 1950 and in 1953 was appointed assistant professor of physics at Columbia University, where he remains an active member of the faculty. His work in particle physics ranges from the ethereal, almost insubstantial world of the weakly interacting neutrinos to the rich, dense soup of the strongly interacting quark–gluon plasma.

At Columbia in the late 1950s, Lee's enthusiasm for studying weak interactions at higher energies than in particle decays helped to inspire an experimentalist colleague, Melvin Schwartz, to work out how to make a beam of neutrinos. This led to the famous experiment at Brookhaven National Laboratory in 1962, which showed that there are two different neutrinos associated with the electron and the muon. Two years later, Brookhaven was again ▷



Lee, eight years after his Nobel win, speaking about the weak interaction at a neutrino conference at CERN in 1965.

Lee with Peter Jenni, spokesperson of the ATLAS collaboration, during his tour of the experiment in its underground cavern.

the scene of a ground-breaking experiment, when James Cronin, Val Fitch and colleagues discovered that the combined symmetry of charge-conjugation and parity (CP) is violated in the decays of neutral kaons. This phenomenon was eventually understood in the context of six kinds of quark and their 3×3 mixing matrix – a major focus of Lee's current work.

At around this time, Lee also made a seminal contribution to field theory, which would ultimately be an important part of QCD, the theory of strong interactions. What is now known as the Kinoshita–Lee–Nauenberg theorem deals with a problem of infrared divergences in gauge theories. In QCD, this underlies our understanding of the production of jets from quarks and gluons – a topic of key importance at particle colliders, from the early days of SPEAR at SLAC to the LHC, about to start up at CERN.

However, it is in the physics of hot dense QCD matter in the form of a quark–gluon plasma that Lee has made one of his most important marks, pushing people to realize that it was indeed possible to observe this exciting new state of matter. In 1974, at a time when experimentalists were concentrating on smaller and smaller scales, he put forward the idea that "It would be interesting to explore new phenomena by distributing high energy or high nuclear density over relatively large volume." In particular, he saw the possibility of restoring broken symmetries of the vacuum in collisions of heavy nuclei. This was one of the inspirations behind those who pushed for the RHIC collider at Brookhaven, and Lee witnessed the results emerging on strongly interacting quark–gluon plasma during the past few years with excitement. He also sees a possible link between the physics of heavy-ion collisions and the physics of dark energy. Both could involve a collective field – a scalar – that in the presence of a matter field can generate a negative pressure. "I believe the heavy-ion programme at the LHC will be very important to explore this possibility."

During Lee's recent visit to CERN, he saw the enormous effort now going into preparations for the LHC. So what does he think the experiments there will find? While he expects the LHC to make important discoveries, including evidence for new particles such as the Higgs boson, his continuing thoughts about symmetry in the universe lead to more personal predictions.

He believes that asymmetries in parity, charge conjugation and time reversal are not asymmetries of the fundamental laws of physics. Instead, he thinks it is likely that they are "asymmetries of the solutions, namely the Big Bang universe we live in – it is the solution that is not symmetrical". In other words, he sees CP violation as an effect of spontaneous symmetry-breaking. In this case, says Lee, there is a possibility of finding right-handed W and Z particles to match the left-handed Ws and Z already known. Other new particles could be massive partners for the massless graviton, just as the massless photon has heavy partners in the W and Z. "They will have to be uncovered, and the LHC might also be the first window on that."

The promise that the LHC holds for the future fits well with Lee's overall view of the state of particle physics. "It will be a turning point. By what we discover here we will also know what to do as a next step. We expect that the LHC will give us a world of discoveries that will set the route for our future explorations," he says. Half a century after his Nobel prize, he retains an inspiring optimism: "I believe that the beginning of the 21st century will be as important for physics as the beginning, the first 50 years, of the 20th century, and the LHC is going to be the first machine to make the first discovery – so it is very lucky to be here."

Further reading

For a video of TD Lee's colloquium at CERN on "Symmetry and asymmetry in electro-weak interaction" (50 years after the discovery of parity nonconservation), see http://indico.cern.ch/conferenceDisplay.py?confId=19674.

Résumé

TD Lee: un grand avenir pour la physique des particules

Cinquante ans après avoir reçu le prix Nobel de physique, TD Lee garde une vision très optimiste de l'avenir de la physique des particules, comme il l'a confié lors d'une récente visite au CERN. Pour lui, cette discipline, qui a réalisé des progrès fulgurants durant la deuxième moitié du XXème siècle, s'oriente vers de nouvelles découvertes, grâce à une meilleure connaissance des constituants fondamentaux de la matière, les quarks et les leptons. Dans ses propres recherches, Lee s'attache à l'exploration de ces constituants fondamentaux, en particulier par l'étude de la symétrie dans les particules fondamentales, domaine qui lui a valu le prix Nobel en 1957.

Christine Sutton, *CERN.*

The drip line: nuclei on the edge of stability

Efforts to identify the heaviest isotopes for chemical elements beyond oxygen are beginning to bear fruit. But, as **Dave Morrissey** explains, the pursuit of the neutron drip line and a more thorough theory of the nuclear force is not straightforward.

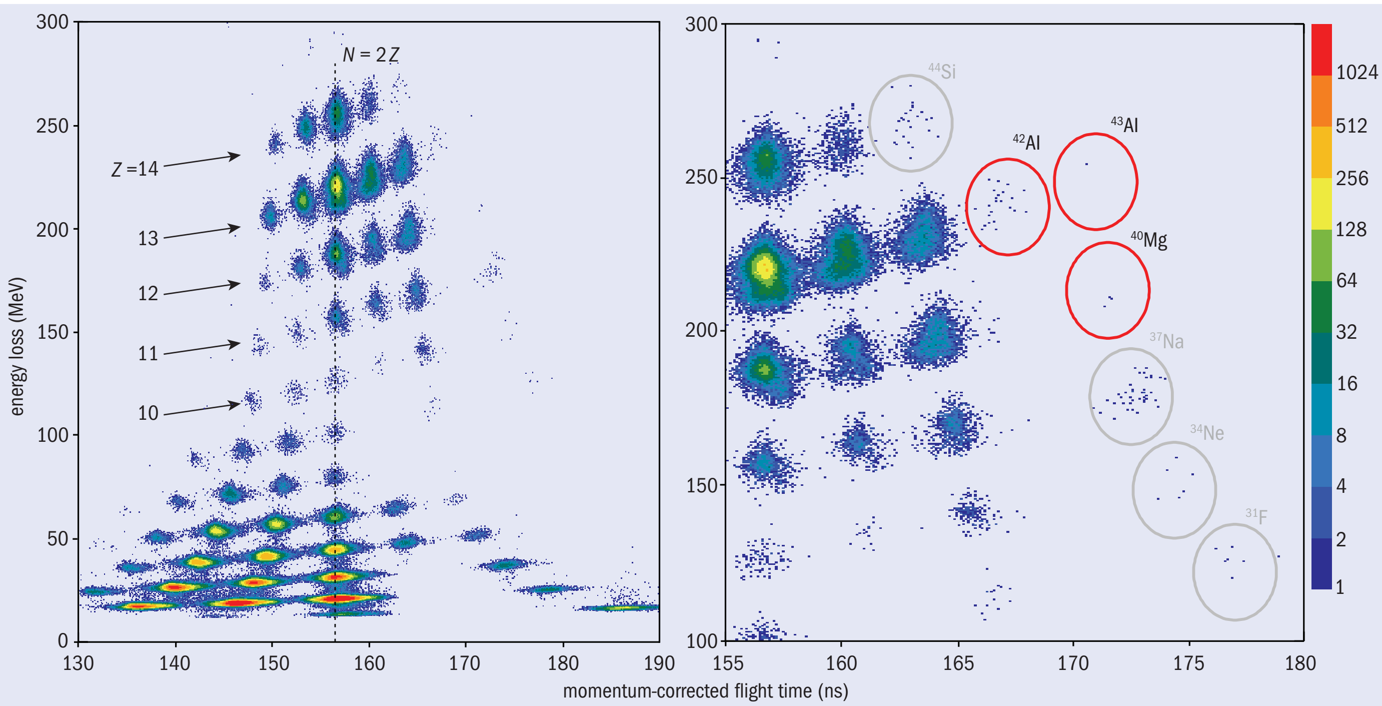


Fig. 1. Left: Energy loss versus flight time for neutron-rich isotopes up to silicon (Z = 14) produced at NSCL. Right: This expanded region shows clearly the new isotopes ^{40}Mg and ^{42}Al, as well as the single event for ^{43}Al. (Baumann et al. *2007.)*

What combinations of neutrons and protons can form a bound nucleus? The long-elusive answer continues to stimulate nuclear physicists. (*CERN Courier* May 2004 p26). Even now, decades after most of the basic properties of stable nuclei have been discovered, a fundamental theory of the nuclear force is still lacking, and theoretical predictions of the limits of nuclear stability are unreliable. So, the task of finding these limits falls to experimentalists – who continue to find surprises among super-heavy isotopes of elements immediately beyond oxygen.

At the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University we recently discovered several new neutron-rich isotopes: ^{44}Si, ^{40}Mg, ^{42}Al and ^{43}Al (Tarasov *et al.* 2007 and Baumann *et al.* 2007; see also *CERN Courier* September 2007 p7). These are at the neutron drip line – the limit in the number of neutrons that can bind to a given number of protons. The result confirms that these exotic neutron-rich nuclei gain stability from an unpaired proton, which narrows the normal gaps between shells and provides the opportunity to bind many more neutrons (Thoennessen 2004). This feature was firmly established in 2002 by the significant difference between the heaviest isotopes of oxygen ($^{24}O_{16}$) and fluorine ($^{31}F_{22}$). However, our observation of such ostensibly strange behaviour is still novel, since in stable nuclei, the attractive pairing interaction generally enhances the stability of "even–even" isotopes with even numbers of protons and neutrons.

The recent experiment at NSCL clearly identified three events of ^{40}Mg in addition to many events of the isotopes previously ▷

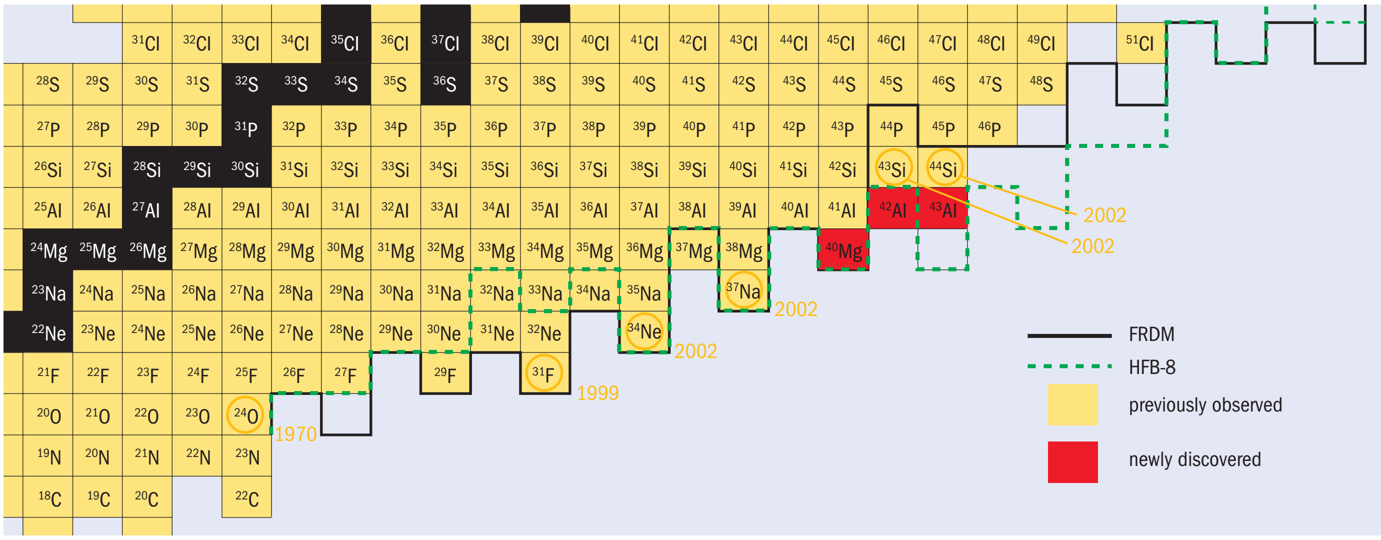


Fig. 2. A section of the chart of nuclides for light, neutron-rich nuclei in which the proton number increases vertically and the neutron number horizontally. Black squares indicate stable nuclei; yellow squares denote previously observed nuclei (the most recently observed drip-line nuclei are within orange circles with their year of discovery); and the isotopes discovered in the recent National Superconducting Cyclotron Laboratory experiment are in red. The neutron drip lines predicted by the finite-range droplet model (FRDM) and the Hartree–Fock–Bogoliubov model (HFB-8) are shown by the black and dashed green lines, respectively.

observed, namely ^{31}F, ^{34}Ne, ^{37}Na and ^{44}Si (figure 1, p37). It also confirmed that ^{30}F, ^{33}Ne and ^{36}Na are unbound as there were no events; the lack of events corresponding to ^{39}Mg indicates that it too is unbound. Furthermore, the 23 events of ^{42}Al establish its discovery. The data also contain one event consistent with ^{43}Al. Owing to the attractive neutron pairing interaction, the firm observation of the odd–odd isotope $^{42}Al_{29}$ supports the existence of $^{43}Al_{30}$ and lends credibility to the interpretation of the single event as evidence for the existence of this nucleus.

The discovery of the even–even isotope $^{40}Mg_{28}$ is consistent with the predictions of two leading theoretical models, as well as with the experimentally confirmed staggered pattern of the drip line in this region (figure 2). It is interesting to note that if this experiment had not observed ^{40}Mg, the drip line might have been considered to have been determined up to magnesium. However, with the observation of ^{40}Mg, the question remains open as to whether ^{31}F, ^{34}Ne, ^{37}Na and ^{40}Mg are in fact the last bound isotopes of fluorine, neon, sodium and magnesium, respectively.

More important than the observation of the even–even ^{40}Mg is the discovery of the odd–odd ^{42}Al, which two leading theoretical models predicted to be unbound. The latest observation breaks the pattern of staggering at the drip line, somewhat akin to the situation at fluorine. In fact, it now appears possible that heavier nuclei up to ^{47}Al may also be bound.

For many decades, the point at which the binding energy for a proton or a neutron goes to zero has been a clear-cut benchmark for models of the atomic nucleus. The drip line is the demarcation line between the last bound isotope and its unbound neighbour and each chemical element has a lightest (proton drip line) and a heaviest (neutron drip line) nucleus.

The proton drip line is relatively well established for most of the elements because the Coulomb repulsion among protons has a dramatic destabilizing effect on nuclei with significantly fewer neutrons than protons. On the other hand, the neutron-binding energy only gradually approaches zero as the neutron number increases. Subtle quantum-mechanical effects such as neutron pairing and energy-level bunching end up determining the stability of the heaviest isotope of each element. The weak binding of the most neutron-rich nuclei leads to the phenomena of neutron "skins" and "halos", which give these nuclei some unusual properties.

The only method available at present to produce nuclei at, or near, the neutron drip line is through the fragmentation of stable nuclei followed by the separation and identification of the products in less than a microsecond (Thoennessen 2004). The fragmentation reactions produce a statistical distribution of products with a large range of excitation energies. The excitation energy is dissipated by particle emission through strong decay (primarily neutrons and protons) and then by electromagnetic decay before the fragments reach the detectors. The Coulomb force also favours the emission of neutrons, suppressing the production of the most neutron-rich products.

Current knowledge of the neutron drip line is limited to only the lightest nuclei. The portion of the chart of nuclides in figure 2 shows the known geography of the drip line and the variation in the predictions from two widely respected theoretical models. Researchers first observed the heaviest bound oxygen isotope, ^{24}O, in 1970. However, it was much later before experiments showed that the nuclei ^{25}O through ^{28}O are unbound with respect to prompt neutron emission. Only in 1997 did nuclear physicists consider the drip line for oxygen to be established. Subsequently, the isotopes ^{31}F, ^{34}Ne and ^{37}Na have been observed. Although no experiment has established that ^{33}F, ^{36}Ne, and ^{39}Na are unbound, these heavier isotopes probably do lie beyond the neutron drip line. These earlier experiments also failed to observe the even–even nucleus ^{40}Mg, and researchers even speculated that ^{40}Mg might be unbound.

On the theoretical side, the finite-range droplet model (FRDM) uses a semi-classical description of the macroscopic contributions to the nuclear binding energy, which is augmented with microscopic corrections arising from local single-particle shell structure and the pairing of nucleons (Möller *et al.* 1995) – this gives the solid black line in figure 2. Another theoretical framework, the fully microscopic Hartree–Fock–Bogoliubov model (HFB-8), is a state-of-the-art quantum-mechanical calculation that puts the nucleons into a mean-field with a Skyrme interaction with pairing (Samyn *et al.* 2004). This is the dashed green line in figure 2. Although in many cases both models correctly predict the location of the neutron drip line, they cannot account for the detailed interplay of valence protons and neutrons, even among the oxygen and fluorine isotopes. The discrepancies between the models is still more apparent in the magnesium to silicon region.

The recent observations at NSCL required high primary beam intensity, high collection efficiency, high efficiency for identification and – perhaps most importantly – a high degree of purification, as the sought-after rare isotopes are produced infrequently, in approximately 1 in 10^{15} reactions. Currently, the worldwide nuclear science community is anticipating several new facilities, including the Facility for Antiproton and Ion Research in Germany, the Radioisotope Beam Factory in Japan and the Facility for Rare-Isotope Beams in the US (*CERN Courier* March 2005 p24 and May 2007 p23). The facilities are needed for many reasons, including advancing the study of rare isotopes and investigating the limits of existence of atomic nuclei.

The result from NSCL is one among many that hints at scientific surprises associated with the ongoing pursuit of exotic, neutron-rich nuclei. A thorough and nuanced understanding of the nuclear force may remain beyond the collective understanding of nuclear science, but the drip line beyond oxygen – even if further out than previously expected – continues to beckon.

Further reading

T Baumann *et al.* 2007 *Nature* **449** 1022.
P Möller *et al.* 1995 *At. Data Nucl. Data Tables* **59** 185.
M Samyn *et al.* 2004 *Phys. Rev. C* **70** 044309.
O Tarasov *et al.* 2007 *Phys. Rev. C* **75** 064613.
M Thoennessen 2004 *Rep. Prog. Phys.* **67** 1187.

Résumé

Noyaux au bord de la désintégration

La plupart des propriétés élémentaires des noyaux stables sont connues depuis des décennies, mais la théorie fondamentale de la force nucléaire reste à forger, et les prédictions théoriques sur les limites de la stabilité du noyau ne sont pas toujours fiables. C'est donc aux expérimentateurs qu'il appartient de déterminer ces limites. Les efforts entrepris pour identifier les noyaux les plus lourds dans les éléments chimiques au-delà de l'oxygène commencent à porter leurs fruits: une équipe située au laboratoire NSCL (Etats-Unis) vient de découvrir plusieurs nouveaux isotopes riches en neutrons situés sur la ligne de stabilité. Les résultats tendent à indiquer que ces noyaux nous réservent quelques surprises.

Dave Morrissey, *NSCL, Michigan State University.*

APPOINTMENTS

Stöcker succeeds Henning at GSI

Horst Stöcker, who took over the reins at GSI earlier this year.

Walter Henning steps down at GSI. (Photos courtesy G Otto.)

On 1 August, Horst Stöcker officially took over as scientific director and chair of the directorate at GSI. He succeeds Walter Henning, who served in these capacities for eight years. An event celebrating the change in management took place during the International Symposium on Modern Trends in Nuclear Physics, which was held at GSI on 18–20 October.

Government dignitaries attended the celebration, including Andreas Storm, parliamentary state secretary of the Federal Ministry of Education and Research, and Ralph Alexander Lorz, state secretary in the Hessian Ministry of Higher Education, Research and the Arts. They paid tribute to Henning's achievements and promised Stöcker continuing support for the future of GSI and the planned new Facility for Antiproton and Ion Research. Stöcker noted that: "Implementing FAIR, the international Facility for Antiproton and Ion Research, at GSI is one of my most important tasks." His predecessor Henning played a key role in getting FAIR off the ground – from the generation of the original concept to obtaining expert opinions and securing pledges of financial support from the Federal Ministry of Education and Research, the federal state of Hesse, and the Helmholtz Association of German Research Centres. The negotiations that Henning initiated regarding the participation of foreign partners in FAIR are currently under way.

Stöcker is the Judah M Eisenberg Professor Laureate for Theoretical Physics at Johann Wolfgang Goethe University in Frankfurt and at the Frankfurt Institute for Advanced Studies. His research relates directly to work with heavy ions at GSI and FAIR. Henning is joining the scientific staff at the Argonne National Laboratory to lead Argonne's efforts to build a proposed exotic beam facility for nuclear physics research.

JINR

Gell-Mann takes part in latest JINR Council session

American Nobel-laureate Murray Gell-Mann took part in the work of the 102nd session of the JINR Scientific Council on 27–28 September, at the invitation of the JINR directorate. He received the title of honorary doctor of JINR in recognition of his outstanding contributions to elementary-particle physics. He also visited the Bogoliubov Laboratory of Theoretical Physics at JINR where he delivered two lectures, "Getting creative ideas" and "Nature conformable to herself".

Gell-Mann's visit to Russia began in Moscow on 22 September at the invitation of the city's mayor, Yury Luzhkov. He then took part in the work of the International Symposium on Recent Developments of Quantum Physics in Moscow on 24 September. The following day Moscow State University awarded him the title of honorary doctor at the ceremonial session of the Scientific Council, where he delivered a public lecture "Getting creative ideas". During his stay in Moscow and Dubna, Gell-Mann also had numerous meetings with students, scientists and public authorities.

JINR's director, Alexei Sissakian (right) congratulates Murray Gell-Mann on conferring the title of honorary doctor of JINR during the 102nd session of the JINR Scientific Council. (Courtesy JINR.)

SCHOOLS

CAS joins forces with Cheshire's Cockcroft Institute

Course attendees at Daresbury Laboratory.

The CERN Accelerator School (CAS) and the Cockcroft Institute, one of the UK's new centres for accelerator science, have jointly organized an intermediate-level course on general accelerator physics. This took place at the Cockcroft Institute in Cheshire on 16–28 September, taking advantage of both the excellent new facilities in the institute and the existing infrastructure of the adjacent Daresbury Laboratory.

The course followed established practice, with lectures on core topics in the mornings and specialized sessions in the afternoons. The latter provided "hands-on" education and experience in the three selected topics: RF Measurements Techniques, Beam Instrumentation and Diagnostics, and Optics Design and Correction. These were highly successful, with participants choosing one course and following the topic throughout the school. Guided studies, tutorials, seminars and a poster session completed the programme. The school also included an excursion to the city of York and a Welsh medieval-style dinner.

With 80 participants representing 26 nationalities, the school was a resounding success. Feedback from the participants was extremely positive, praising the expertise and enthusiasm of the lecturers, as well as the high standard of their lectures.

● The organizers from CAS and the Cockcroft Institute are grateful to the various British sponsors, from both industry and academia, for their financial support, without which the school would not viable.

CELEBRATION

Mexican fiesta honours Paić

Guy Paić celebrated his 70th birthday on 21 September with his home institute, the Institute for Nuclear Sciences (ICN) of the National University of Mexico (UNAM), at an academic gathering highlighting work relating to his research.

Paić obtained his PhD as a low-energy nuclear physicist in Croatia, where he continued his career as a user at many research centres while helping to establish nuclear science during numerous stints in Africa for the International Atomic Energy Agency. He came to CERN in 1986 for the first heavy-ion run of the NA35 experiment, and he has been active in CERN's ultra-relativistic heavy-ion programme ever since – from experiments at the SPS to the conception and development of the ALICE experiment at the LHC. He has a keen interest in the experimental and theoretical parts of the programme, and was prominent in the conception and R&D for the high-momentum particle identification detector for ALICE, as well as physics coordinator for many years.

Paić began another career five years ago, joining ICN, where he has driven the experimental heavy-ion programme in Mexico. He has contributed significantly to Mexican teams developing detectors for ALICE, and had an important influence on the academic growth of both students and peers involved in the effort. The detector laboratory, which he established at ICN, has become an essential centre coordinating the efforts of different groups in Mexico that are involved in the ALICE collaboration.

Paić's Mexican colleagues organized a fiesta for his birthday, with a one-day workshop for a small selection of scientists who had shared his rich academic life. Contributors included Paolo Giubellino, deputy spokesperson of ALICE, Jean-Pierre Revol, ALICE team leader at CERN, and long-term colleague Ivica Puljak from Croatia, as well as Paić's son and many Mexican colleagues. Jean-Pierre Revol, on behalf of the ALICE team at CERN, presented Paić with a sculpture of Sancho Panza, by Didier Anstett, artist and technician at CERN.

● A report by Alejandro Ayala on the "Guy fest" is available from ICN-UNAM.

Guy Paić in the ALICE cavern at CERN.

Art work by Didier Anstett: Sancho Panza.

INTERNATIONAL COLLABORATION

Remote system links Fermilab with CERN

Members of the CERN and CMS management in the CMS experiment's cavern participate remotely in the inauguration of Fermilab's Remote Operations Center (LHC@FNAL ROC) in the US.

On the other side of the Atlantic, representatives of Fermilab, the US Department of Energy and the National Science Foundation listen to Robert Aymar, the CERN director-general, give his speech for the inauguration. (Courtesy Fermilab Visual Media Services.)

Representatives from Fermilab and CERN inaugurated the Fermilab Remote Operations Center for the LHC (LHC@FNAL ROC) on 22 October. The ceremony took place on both sides of the Atlantic, with representatives from the US speaking in Fermilab, and those from CERN and the CMS collaboration in the cavern at Point 5 on the LHC ring.

The LHC@FNAL ROC, which is located on the ground floor of the Wilson Hall at Fermilab's main building, has been designed to allow teams at Fermilab to participate remotely in activities related to LHC commissioning and operation. For example, US accelerator experts are already carrying out monitoring operations at the ROC, particularly of components developed and built in the US. They will also take part in beam studies for the LHC.

The LHC@FNAL ROC will also play an important role in the operating and control system for CMS. The CMS collaboration is setting up a network consisting of several control centres, including remote centres such as the LHC@FNAL ROC. These remote centres will back up the main CMS control room at Point 5 by performing various tasks, such as data quality control, data analysis, and calibration and operation of the computer systems for data handling, storage and distribution.

The seven-hour time difference between Fermilab and CERN means that work done at the LHC@FNAL ROC will help to improve the efficiency and reactivity of the CMS team during data-taking. The ROC, which opened at the beginning of the year, has already allowed CMS groups to take part in the commissioning and cosmic-ray testing of sub-detectors for CMS. It is now playing its part in the commissioning of the experiment as a whole. With 600 scientists and 47 institutes, the US is the largest national group in the CMS collaboration.

AWARD

ALICE recognizes Hewlett-Packard's computing support

The ALICE Collaboration Board presented an award to Hewlett-Packard (HP) on 6 October for the company's role in enabling ALICE physicists to collect and process experimental data on the Grid. The ALICE data-acquisition and offline groups have collaborated with HP since 1993 in an annual programme of computing and Grid physics-data challenges. These are high-level exercises testing hardware and software frameworks for data acquisition and processing.

The award recognizes the special support given by HP, both in terms of hardware and access to expert help, well beyond the normal customer–provider relationship, testament to their commitment and interest in providing effective solutions for high-end and demanding scientific applications. HP hosted experts from ALICE in their "centre de compétences" in Grenoble, performing tests prepared with the help of HP experts and using a large HP cluster.

Jurgen Schukraft, ALICE spokesperson (left), presents the award to Michel Bénard, director of technology programmes and university relations at Hewlett-Packard.

Present data challenges involve not only real-time event generation and high-speed, high-volume transfer of data to mass storage – up to 1.5 GB/s and 130 TB/day – but also the subsequent offline data reconstruction on the WLCG. The offline group has deployed some 20 high-performance servers, and the cluster management and monitoring are built around the unique HP server remote management system, Integrated Lights-Out.

WORKSHOP

Fundamental physics re-explored in Patras

Participants gather at training workshop in Patras. (Courtesy University of Patras.)

More than 50 participants from around the world and from experiment and theory alike met in Patras for the 3rd Joint ILIAS–CERN–DESY Axion–WIMPs training workshop on 19–25 June. Josef Jochum of the University of Tübingen and Axel Lindner of DESY organized the meeting with Konstantin Zioutas of the University of Patras and CERN as chair. It provided stimulating talks with new results and much discussion.

A main focus was, naturally, on axions and other light particles coupled to photons. There were status reports and first results from the new generation of the "light shining through walls experiments" (ALPS, BMV, GammeV, LIPSS, OSQAR, PVLAS), which aim to detect such particles in the laboratory. These experiments direct a strong laser at an opaque wall and then search for photons on the other side. In the presence of a magnetic field, for instance, the laser photons could convert into axions which would pass through the walls before being reconverted into photons by the inverse process on the other side of the wall.

There were also results from the upgraded apparatus of the PVLAS collaboration, which last year seemed to have found indications for such a new particle in a polarization experiment. Now with an improved setup with better sensitivity and reduced systematic uncertainties, the collaboration is unable to confirm its earlier results. The CERN Axion Solar Telescope collaboration presented new bounds from searches for axion-like particles coming from the Sun. For the first time, these are better than constraints from the energy balance in helium-burning stars. Last, but not least, the meeting heard of progress in the Axion Dark Matter Experiment, which is searching for axions that could make up part or all of the dark matter in the universe.

Other dark matter candidates also featured prominently at the workshop. There was news from the searches for weakly interactive massive particles (CRESST II, EDELWEISS II and XENON 10) as well as from sky searches via X-ray and gamma-ray observations. Another way to gain new insights into fundamental physics is to test symmetries. On this front, there was a report on the cryoEDM experiment, which is searching for an electric dipole moment of the neutron; this would indicate a new source of CP violation.

On the theory side, participants heard about the wide variety of particles that can exist at low energies and that are predicted by extensions of the Standard Model, such as string theory and models with extra dimensions. Talks looked at what we can learn about the underlying fundamental theory by finding/constraining such particles, and what kinds of experiments are needed for the most efficient searches and how they can be improved. Although last year's results from PVLAS were the original motivation for many of the theoretical investigations, it became clear during the meeting that independent of this there is a huge discovery potential for new fundamental physics using low-energy experiments. In his talk just prior to the conference dinner, Dimitri Nanopoulos highlighted another important aspect of fundamental physics at low energies: the mystery of the dark energy that drives the accelerated expansion of the universe.

All in all it was an active meeting, with fundamental physics at low energies as an emerging theme. Searching for new particles and their interactions in small scale, low energy, high-precision experiments could prove to complement conventional accelerator physics in the search to discover the fundamental laws of nature.

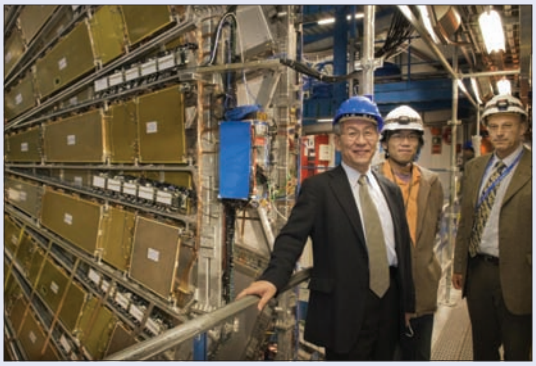
● The next workshop will be at DESY in June 2008. For more details about the meeting in Patras see http://axion-wimp.desy.de.

MEETING

The **10th International Conference on Instrumentation for Colliding Beam Physics** will take place in the Budker Institute of Nuclear Physics, Novosibirsk, Russia, on 28 February–5 March 2008. The programme covers various topics including tracking and vertex detectors, particle identification, calorimetry, electronics, trigger and data-acquisition systems, detector integration and instrumentation for astroparticle and neutrino physics. For more information see http://instr08.inp.nsk.su.

VISITS

Atsuto Suzuki, left, director-general for KEK in Japan, came to CERN on 2 July. He is seen here in the cavern of the ATLAS experiment with **Shuji Tanaka** from KEK, centre, and ATLAS spokesperson, **Peter Jenni**. His visit also included a tour of the LHC tunnel, the CLIC facility, the CERN Control Centre and the Computing Centre, followed by a meeting with Japanese physicists.

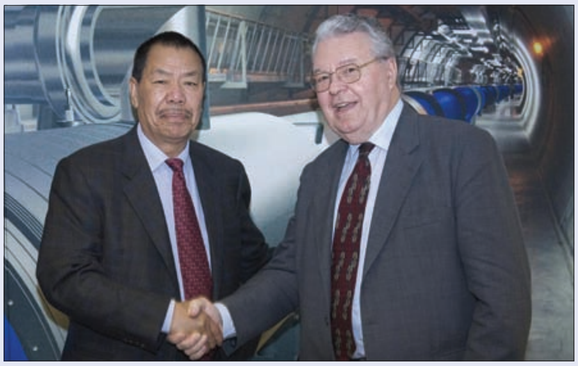


Israeli minister of science, culture and sport, **Galeb Majadle**, visited CERN on 26 July, and toured the ATLAS muon chamber assembly hall, where he installed the final thin-gap muon chambers for the big muon detector wheel. He also visited the ATLAS experimental cavern, the LHC tunnel and the Computing Centre. The day ended with a meeting with Herwig Schopper, former director-general of CERN and chair of the SESAME council, and Hafeez Hoorani, SESAME's chief scientific officer, regarding the project in Jordan for a synchrotron light source.

On 23 July, the Hellenic Republic vice-minister, minister of development, **Giannis Papathanasiou**, right, visited CERN. He toured the ATLAS cavern and the CERN Axion Solar Telescope (CAST), where he is seen with the general secretary for research and technology, **Giannis Tsoukalas**, left, and CAST spokesperson, **Konstantin Zioutas**, centre.

Samuel Aronson, director of the US Department of Energy's Brookhaven National Laboratory (BNL), left, and BNL Physics department chair, **Thomas Ludlam**, centre, came to CERN on 24 September. They were given a tour of the ATLAS experiment by spokesperson, **Peter Jenni** (right), and also saw the LHC tunnel, the ALICE experiment and the CLIC facility.

On 12 October, **Horst Stöcker**, right, who has recently taken over as scientific managing director of GSI (see p40), visited CERN. He toured the ISOLDE facility and the Antiproton Decelerator, and met with his counterpart at CERN, director-general **Robert Aymar**, left.



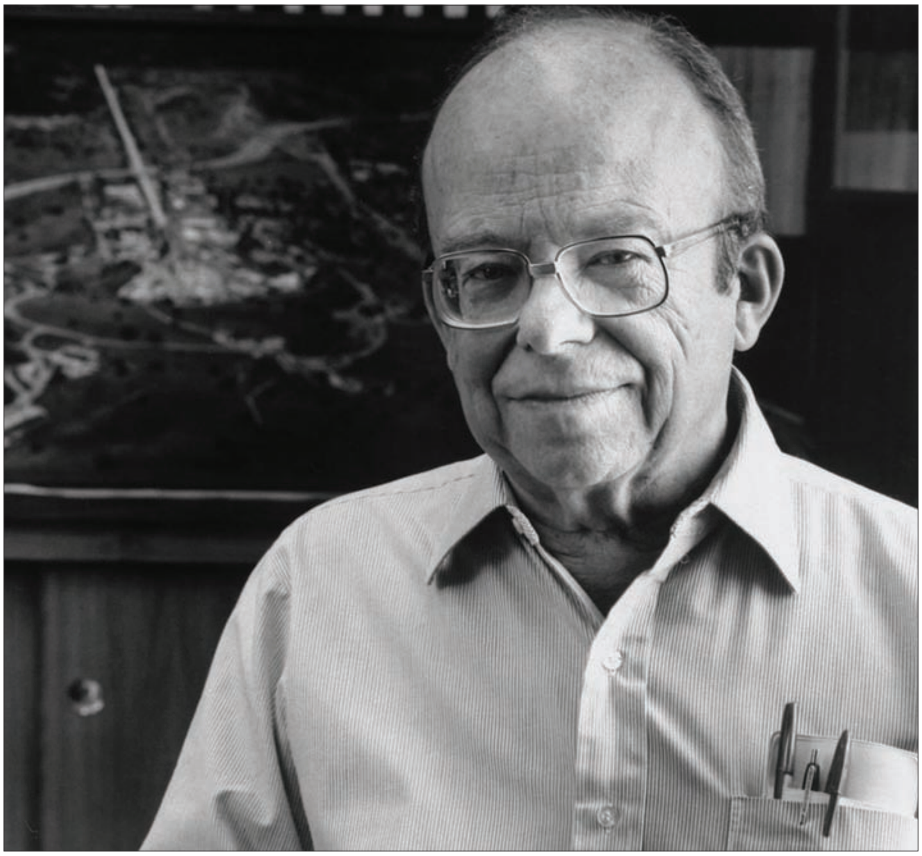
Minister of information and communications, **Lyonpo Leki Dorji**, left, from the Kingdom of Bhutan, shakes hands with CERN's director-general, **Robert Aymar**, in front of a montage of the LHC tunnel on his visit to CERN on 18 October. After signing the guest book he toured the real location and visited the ATLAS experiment.

OBITUARY

Wolfgang KH (Pief) Panofsky 1919–2007

Wolfgang (Pief) Panofsky, one of the outstanding contributors to the remarkable progress in the field of particle physics, passed away on 24 September, aged 88.

Pief's family emigrated from Germany to the US in 1934 to escape the Nazi regime, which came to power in 1933. His father, Erwin Panofsky, a world-renowned art historian who had previously served in the US as visiting professor, had accepted a professorship at Princeton University. Pief, then 15, never entered US high school, but immediately went to the university, where he graduated with a Bachelor's degree in 1938. In a spirit of adventure, and attracted by a letter from Robert Millikan, he went on to Caltech and worked on his PhD in the X-ray laboratory of Jesse DuMond, who had been impressed with his know-how in electronics. Pief also taught, and, together with Carl Anderson, even wrote a textbook on electricity and optics. In 1942 he obtained his PhD with DuMond and also married his mentor's daughter Adele. By this time the US was at war, and Pief worked on various military projects, one on the detection and localization of targets, another, in collaboration with Los Alamos, on the measurement of the yield of a nuclear explosion. He observed "Trinity", the first nuclear explosion, from a B-29 bomber at a distance of 3 km.



Pief in his office at SLAC, with an aerial view of the laboratory with the famous linac behind him. His family came to the US from Germany in 1934. (Courtesy SLAC Photo.)

After the war, Pief went to Berkeley at the invitation of Luis Alvarez, and collaborated with him in the design of proton linear accelerators. He also participated in some very interesting experiments. In 1947 the π-meson was discovered, and Berkeley, with Ernest Lawrence's 340 MeV proton synchrocyclotron and the 300 MeV electron synchrotron invented by Edwin McMillan, was the only laboratory in the world in which these interesting particles could be produced. I had the privilege of collaborating with Pief in one of the experiments with pions, the first observation of the decay of the π^0 into two gamma rays. The π^0 had been anticipated for theoretical reasons, and clear indications of gamma rays that could be attributed to its decay had been observed, but this experiment demonstrated the existence of the particle and also permitted a measurement of its mass, which is close to that of its charged partner. Another, very beautiful experiment showed that when negative pions are captured in hydrogen, about half of the time (this "half" was called the "Panofsky ratio") π^0-mesons are produced. This permitted a more accurate measurement of the π^0 mass, and turned out to be a very useful means of producing π^0-mesons in future studies of their properties. During this period Pief also taught, and together with Melba Phillips, wrote a widely used textbook on classical electrodynamics.

In 1951, the Regents of the University of California required of its faculties that they sign the politically repressive "non-communist oath". Pief signed it although he disapproved of it, but then left Berkeley to join the physics faculty of Stanford University, across the San Francisco Bay. W W Hansen had started an electron linear accelerator project at Stanford some years previously and the "Mark III" had begun to work. Unfortunately, Hansen had died prematurely, and in 1949, with the help of his experience in linear accelerator design, Pief was able to inject new life into a somewhat faltering programme. Together with Edward Ginzton he took over the direction of the project. By 1953, Mark III was 70 m long, with an energy of 400 MeV, and it served Robert Hofstadter in the very important first measurements of the nucleon form factors.

In 1956, Panofsky and Ginzton began to develop plans for Project M – M for monster – a two-mile electron linear accelerator, with 30 times the energy of Mark III. Because of its size, the project required federal funding by the Atomic Energy Commission (AEC), and Pief was instrumental not only in getting AEC support, but also in getting it to agree that, contrary to its policies at other national laboratories, it would not require any security clearances at the new laboratory. He also needed to convince the Stanford faculty that physicists from other laboratories would be equally welcome. In 1961 agreement and approval for the construction of the Stanford Linear Accelerator Centre, SLAC, had been reached and Panofsky became its director. In the meantime Ginzton had left to become director of the microwave development company, Varian Associates. Ground for SLAC was "broken" in 1962, and the first full-length beams were achieved in 1966. The qualities of Pief's leadership in this very large and successful effort were universally admired and acknowledged: his patience and energy, his ability to resolve conflict constructively, and his creative contributions to both the accelerator design and experimental physics questions.

Pief remained director of SLAC until 1983, and the laboratory's contributions to progress in particle physics in these 23 years were truly remarkable. He led in the conception and design of the spectrometers of the deep inelastic-scattering experiments of Jerome Friedman, Henry Kendall and Richard Taylor, which in 1968–69 discovered the composite nature of the nucleons, that is, they are made of "partons", later shown to be the quarks and gluons of the Standard Model. In 1973 the newly built SPEAR electron–positron storage ring at SLAC discovered the charm quark as the constituent of the Ψ resonance, called the J by Sam Ting *et al.*, who saw the resonance simultaneously at Brookhaven Laboratory. A few months later, in the same SPEAR data, Martin Perl discovered the τ, and hence the existence of a third family of particles. Analysing the shapes of the hadronic events in SPEAR, Gail Hanson discovered the jet nature of the hadronic materialization of the partons. In 1989, SLAC anticipated the more powerful LEP collider at CERN. With collisions of electrons and positrons accelerated in the two-mile linac, it was the first to see the shape of the Z resonance, and so catch a glimpse of the number of neutrino families. These remarkable successes all profited very much from Pief's technical vision and his ability to foster productive collaboration in the experimental teams.

Pief was also motivated by a deep consciousness of the responsibility of the scientist to society, as well as concern about the danger posed by the arsenals of nuclear weapons. He served over many years as advisor to the US government. He was member of the Scientific Policy Committees in the Eisenhower, Kennedy, Johnson and Carter administrations, and contributed to the achievement of two very important US–USSR nuclear weapons treaties: the atmospheric test-ban treaty of 1963 as well as the antiballistic missile treaty of 1972. He also served as consultant to the Defence Department in the context of the Jason group of scientists. In 1970, Pief and Sidney Drell founded the Stanford Center for International Security and Arms Control, and for several years Pief served as chair of the Committee on International Security and Arms Control of the National Academy of Science.

In summary, Pief made beautiful experimental contributions to our understanding of particles, was instrumental in the conception and leadership of highly successful laboratories in this field, and gave much of his energy and wisdom to help our society to try to rid itself of the menace of nuclear weapons. His list of awards, prizes and degrees is the longest ever. Thank you for what you have done in one lifetime, Pief.

Jack Steinberger, CERN.

NEW PRODUCTS

Lake Shore Cryotronics Inc has introduced a low vibration, cryogen-free micro-manipulated probe station. The new CCR-based probe station provides efficient temperature operation and control with a 4 K cryogen-free closed-cycle refrigerator. It operates over 4.5–350 K, providing a stability of 10 mK. Control heaters provide the probe station with fast thermal response and rapid warm-up for a sample exchange of 3.5 hours. Six ultra-stable probe arms allow precise three-axis control of the probe position. For more information tel +1 614 891 2244; fax +1 614 818 1600; e-mail info@lakeshore.com or see www.lakeshore.com/crps.html.

McPherson's new Spectral Test Station (STS) provides a 100 mm diameter collimated and wavelength-variable monochromatic light beam to illuminate, spectrally calibrate and document the radiometric sensitivity and response characteristics of spectral and hyper-spectral sensors. The STS delivers discrete bands of monochromatic light and/or scans selected spectral regions from < 200 nm to 14 μm. The system is useful for QC testing of multiple detector chips, CCDs or focal plane arrays. Chips on substrates up to four inches in size can be reliably tested. For further details tel +1 978 256 4512; fax +1 978 250 8625; e-mail mcp@mcphersonInc.com or see www.mcphersoninc.com.

Physik Instruments (PI) LP has announced the new P-876 line of piezo composite patch transducers, which are highly bendable and tolerate bending radii as low as 20 mm. The rugged design ensures reliability, high resistance to damage and a lifetime of more than 10^9 cycles. PI also now offers a new family of ultrasonic piezo-motor-driven linear stages, including models M-663, M-664 and M-682, which provide travel ranges to 50 mm. A direct metrology linear encoder with 0.1 μm resolution provides high linearity and positioning accuracy. The integrated ceramic linear motors can generate push–pull forces up to 7 N, at speeds to 400 mm/s. For more information tel +1 508 832 3456 or +1 949 679 9191; fax +1 508 832 0506 or +1 949 679 9292; or e-mail info@pi-usa.us.

UltraVolt Inc has announced the development of a line of precision, enhanced power supplies, called the "E" Series, which operates from 0–1 kV to 0–15 kV at 4 W, 15–20 W, or 30 W. The "E" Series modules offer a high-resolution, programmable, high-voltage DC output optimized for bias or power applications. Target specifications include a tight temperature coefficient of < 10 ppm for the + 10 VDC reference, output voltage monitor, and HV output. Each model also has output current calibrated to < ± 0.01%. For further information tel +1 800 948 7693; or see www.ultravolt.com.

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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

The Strategic Helmholtz Alliance “Physics at the Terascale“ (http://www.terascale.de) is a research network supported by the Helmholtz Association and comprises the research centres DESY and FZ Karlsruhe, 17 German Universities and the Max-Planck-Institute for Physics. Within the framework of the worldwide investigation of the fundamental properties of matter using accelerators at the highest energies, the Alliance will sustainably concentrate and advance the expertise and strengths of the participating institutes.

The Strategic Helmholtz Alliance “Physics at the Terascale” invites applications for several postdoctoral fellowships in particle physics theory, experimental particle physics and detector development. The Alliance Fellowships are intended to further the careers of individuals of outstanding potential and offer the opportunity to pursue research for a period of up to five years. Applicants must have a Ph.D. and have proved their ability as an individual and independent researcher.

Particle Physics Theory

with a focus on the research areas

a) Phenomenology beyond the Standard Model (in SUSY and non-SUSY theories, including also aspects of model building)
b) Precision calculations and the development of dedicated higher-order Monte Carlo programs (Standard Model predictions, field-theoretical and calculational methods)
c) Monte Carlo generators (multi-purpose Monte Carlo programs, including parton showering, hadronisation etc.)

Applicants are encouraged to provide a preference list of up to three host institutes chosen from

RWTH Aachen (a, b)
University Bonn (a, c)
University Dortmund (a)
University Freiburg (a, b, c)
University Hamburg (a, b)
University Karlsruhe (a, b)
University Mainz (a, b)
University Würzburg (a, b)

where the corresponding research fields are indicated in parentheses. Applicants should arrange for two letters of recommendation to be sent to the address below. Preference will be given to applications received by **15 December 2007.**

Experimental Particle Physics

with a focus on analyses of data from the Large Hadron Collider LHC in the research areas

a) Precision measurements of the top quark
b) Search for the Higgs Boson at LHC
c) Search for extensions of the Standard Model such as supersymmetry or large extra dimensions
d) Development of experimental analysis techniques such as high-level graphical analysis tools, statistical tools and novel techniques for detector calibration
e) Contributions to the development of Monte Carlo generators

Applicants are invited to provide a preference list of up to three host institutes chosen from

RWTH Aachen (a, d)
DESY (a)
University Freiburg (b, c)
University Hamburg (c, d)
University Karlsruhe (c)
University Mainz (c, d)
LMU München (b, c)
University Siegen (b, e)

where the corresponding research fields are indicated in parentheses. Please give the names of two persons who can provide further information about the candidate. Closing date for applications is **31 December 2007.**

Detector Development

with a focus on the research areas

RWTH Aachen: Research and development for the sLHC upgrade of the CMS tracker with a focus on electronics system design, in particular improved powering schemes. The fellow will work in the RWTH Aachen CMS group which played a key role in the development and construction of the CMS tracker.

University Göttingen: The fellow is expected to take a leading role in the development of modern particle physics detectors with an emphasis on the upgrade of the ATLAS pixel detector.

University Heidelberg: The Kirchhoff-Institute for Physics is seeking a research fellow to work on the upgrade of the ATLAS level-1 calorimeter trigger to cope with the conditions imposed by a possible LHC luminosity upgrade. Experience in trigger related studies is required.

Applicants are encouraged to indicate their preferred institute.

Please give the names of two persons who can provide further information about the candidate. Closing date for applications is **31 December 2007.**

Applications should include a letter of application, CV, academic records as well as a list of publications and should be addressed to Prof. Ian Brock (Scientific Manager of the HGF Alliance) DESY, Notkestr. 85, D-22607 Hamburg (Ian.Brock@desy.de).

The particle theory group of the Department of Physics at the University of Siegen has an opening for a

Helmholtz Research Fellow (Tenure Track) for Particle Physics Phenomenology

We are looking for a theoretical physicist with substantial postdoctoral expertise in high-energy collider physics, in particular in the phenomenology of electroweak interactions or of new physics beyond the Standard Model. The position is funded by the Helmholtz Alliance “Physics at the Terascale” until June 2012 and remunerated according to the TVL regulations for public sector employees. Based on an evaluation of the candidate’s scientific record which is scheduled after three years, the position may subsequently become that of a permanent scientific employee of the University of Siegen.

The particle theory group at Siegen has interests in the areas of collider phenomenology, flavour physics, QCD and Monte Carlo development. The experimental particle physics group is involved in ATLAS and ILC. The university intends to increase the number of female scientists and encourages applications from women. Handicapped persons will be favoured in case of equal qualification.

Interested candidates should arrange for two letters of recommendation and submit their application including CV, list of publications, and a statement on past and future research, no later than **31 December 2007** to Prof. Ian Brock (Scientific Manager of the Helmholtz Alliance) DESY, Notkestr. 85, D-22607 Hamburg (Ian.Brock@desy.de).

For further information, please contact:
Prof. Wolfgang Kilian (kilian@hep.physik.uni-siegen.de)

The theoretical and experimental particle physics groups at the University of Wuppertal have an opening for a

Helmholtz Research Fellow for Monte Carlo Development

The candidate should participate in the development and verification of Monte Carlo generators for accelerator-based high-energy physics experiments. He/She should play a leading role in the planned Monte Carlo network in Germany and should have a thorough understanding of the theoretical basis of event generators as well as the experimental applications and demands. Significant experience in the use of Monte Carlo generators in particle physics is required. Demonstrated collaborations with experimental as well as theoretical physicists would be very welcome.

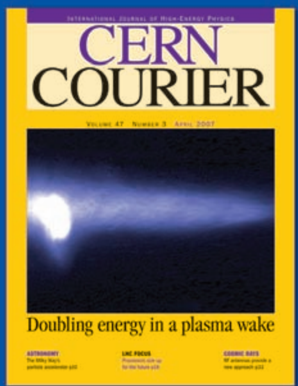
The salary will follow that of the TVL regulations for public sector employees at the level of E13. The candidate may be offered a permanent position after four years.

Interested candidates should arrange for two letters of recommendation and submit their application including CV, list of publications, and a statement on past and future research, no later than **31 December 2007** to Prof. Ian Brock (Scientific Manager of the Helmholtz Alliance) DESY, Notkestr. 85, D-22607 Hamburg (Ian.Brock@desy.de).

For further information, please contact:
Prof. Peter Mättig (peter.mattig@cern.ch) or
Prof. Robert Harlander (Robert.Harlander@physik.uni-wuppertal.de)

Detailed descriptions of the positions are available at http://www.terascale.de or from the Scientific Manager of the Helmholtz Alliance.

Essential reading for the worldwide physics community



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The Science and Technology Facilities Council will bring strategic leadership and an integrated approach to UK investments in large national and international research facilities, whilst continuing to deliver world-class science, technology and people for the UK. The Council is involved in some of the world's most exciting research projects – like the Diamond Light Source Synchrotron and the Large Hadron Collider – and will develop new areas of science and technology – with your help.

Experimental Particle Physics Research Associate (SPBU062)

Rutherford Appleton Laboratory, Oxfordshire, UK

£24,638 to £27,998 per annum, dependent on skill set

Applications are invited for a post-doctoral research associate within the STFC Particle Physics Department at RAL. The appointee will be expected to take a prominent role in one of the on-going analysis activities within the ATLAS group providing an opportunity for an ambitious physicist who feels that they can contribute to the physics output from the LHC, with opportunities to influence its direction. In addition they will participate in physics bench mark studies and detector R&D aimed at a future linear collider detector.

Applicants should be self-motivated, dynamic team players with good communication skills. They should have a strong interest in physics analysis with PhD-level experience in experimental particle physics. Experience with (or an interest) in silicon detector systems would be valuable although applications from qualified and enthusiastic candidates with other relevant experience are also encouraged.

The post will be based at RAL in the particle physics department (PPD) with opportunities to spend time at the CERN facility and international travel.

For an informal discussion about this post, please contact Professor Mike Tyndel on 01235 445246 or email m.tyndel@rl.ac.uk

To apply online please go to http://www.scitech.ac.uk/About/Vacs/Contents.aspx or for further information about the recruitment process, please contact Mandy Spelzini on telephone number 01235 445872 or e-mail recruit-spbu@rl.ac.uk

Closing date for applications: 16 January 2008.

Interview date: 24 January 2008.

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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

The Strategic Helmholtz Alliance "Physics at the Terascale" (http://www.terascale.de) is a research network supported by the Helmholtz Association and comprises the research centres DESY and FZ Karlsruhe, 17 German Universities, and the Max-Planck-Institute for Physics. Within the framework of the worldwide investigation of the fundamental properties of matter using accelerators at the highest energies, the Alliance will sustainably concentrate and advance the expertise and strengths of the participating institutes.

BERGISCHE UNIVERSITÄT WUPPERTAL

As part of the Alliance the University of Wuppertal has a position open for a

Helmholtz Junior Professorship

for Particle Physics at High-Energy Accelerators

with the tenure-track option for a full professorship at the level of W2 or W3

to be filled as soon as possible. Salary will be according to the level W1 (BbesG gem. § 36 HG).

The candidate should be able to demonstrate excellent research results in the framework of large accelerator-based experiments and should have taken significant responsibilities within the experiment. He/She should strengthen the activities of the University of Wuppertal in experimental physics at the terascale, complement them through his/her own projects and participate in the planning of future particle physics experiments. Collaboration with the existing experimental and theoretical particle physics groups in Wuppertal is expected.

Currently the particle physics group at the University of Wuppertal is involved in the ATLAS and D0 experiments, the development and running of the LHC computing grid and the development of detectors for the sLHC and ILC.

The position will be financed as a junior professorship (W1) by the Helmholtz Alliance including some funds for personnel and investment. Following a positive evaluation after three years, the position will be extended for a further three years. A decision will be taken on the appointment as a full professor (W2 or W3) at the latest in the last year of the junior professorship.

Required qualifications are a university degree, teaching aptitude as well as a high degree of competence in scientific research, usually demonstrated through the quality of the doctorate (minimum level "magna cum laude"). The candidate should not be older than 35 years and have worked for at least two years outside of the University of Wuppertal.

Applications including CV, copies of certificates, list of publications as well as teaching experience should be submitted to the Dekan des Fachbereichs C, Univ.-Prof. Dr. rer. nat. Reint Eujen, Bergische Universität Wuppertal, D-42097 Wuppertal.

Applications from women are encouraged. In the case of equal qualifications, ability and scientific achievements women will be preferred, unless outweighed by the personal qualities of another applicant. The rights of handicapped persons to be favoured in case of equal qualification remain valid.

Closing date for applications: 31 December 2007

RICE

Faculty Position in Experimental Nuclear Physics

Rice University

The Department of Physics and Astronomy at Rice University invites applications for a tenure-track Assistant Professor position in Experimental Nuclear Physics. Rice has been active in the STAR experiment at RHIC and with preparations for heavy ions at the CMS experiment at the LHC. In addition to participating in all phases of these experiments the Rice Medium Energy Group is traditionally involved in the design and construction of the hardware. Applicants should send a dossier that includes curriculum vitae, a statement of research and teaching interests, a list of publications, and arrange for at least three letters of recommendation to be sent to B. E. Bonner, Co-Chair, Faculty Search Committee, Physics and Astronomy Department – MS 61, Rice University, 6100 Main Street, Houston, TX 77005. Applications may be considered until the position is filled, but those received by January 15 will receive full consideration. The appointment is expected to begin July, 2008.

Rice University is an affirmative action/equal opportunity employer; women and under-represented minorities are strongly encouraged to apply.

The ESRF (European Synchrotron Radiation Facility) is a multinational research institute, employing 600 staff, located in Grenoble. The ESRF is financed by 18 countries and carries out fundamental and applied research with synchrotron (X-ray) light.

We are currently seeking for the Accelerator and Source Division:

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for the development of permanent magnet undulator and wiggler - Ref. 4128

For further information please consult:
http://www.esrf.fr/Jobs/Technical/4128

A post-doctoral fellow m/f

for the development of a cryogenic permanent magnet undulator - Ref. PDAS02

For further information please consult:
http://www.esrf.fr/Jobs/Research/PDAS02

An engineer/physicist m/f

for the Beam Diagnostics experienced in electron beam diagnostic - Ref. 4122

For further information please consult:
http://www.esrf.fr/Jobs/Technical/4122

To apply, send a letter and CV before 15/01/08, with the adequate reference, to recruitment@esrf.fr or ESRF, Personnel Service, 6 rue Jules Horowitz BP 220, 38043 Grenoble cedex 09, France.

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Foundation for Fundamental Research on Matter

The Foundation for Fundamental Research on Matter (FOM) promotes, co-ordinates and finances fundamental and applied physics research of international standard/ calibre in The Netherlands. It is an autonomous foundation responsible to the physics division of the national research council NWO. FOM employs about 1000 people, primarily scientists (including PhD students) and technicians, who work at FOM research institutes and research groups at universities. FOM is chiefly financed by the NWO (Netherlands Organisation for Scientific Research) Governing Board and NWO Physics and can be considered as the Physics Division of NWO. In addition to the government funds of NWO, FOM acquires financial means from the European Union and through collaboration with the industry and universities. For additional information see http://www.fom.nl

FOM

Nikhef is the national institute for subatomic physics in the Netherlands with ca. 250 employees of which about 120 physicists. It is a collaboration between four universities and the funding agency FOM. The institute coordinates and supports major activities in experimental subatomic physics in the Netherlands, such as the preparation of experiments at the Large Hadron Collider at CERN, notably Atlas, LHCb and Alice. Furthermore astroparticle physics is part of Nikhef's scientific programme, in particular through participation in the Antares project.

Nikhef has three openings for

Postdoctoral research associates
(two + one years)

in the Atlas programme

The group is responsible for part of the construction and installation of the Semi Conductor Tracker, the Monitored Drift Tubes chambers of the muon spectrometer and for several aspects of data acquisition. Our research activities concentrate around track reconstruction, top quark physics and searches for the Higgs boson and supersymmetry.

We have positions available for excellent postdoctoral researchers. These are expected to take a leading role in physics analyses in the area of top quark studies and super-symmetry searches as well as to assist in optimizing the data taking performance of Atlas. Development of new initiatives will be encouraged. Successful candidates will be based at CERN, with regular visits to Nikhef.

Requirements
You have a PhD in particle physics and extensive experience in both data analysis and software development for particle physics experiments; familiarity with algorithm development, OO design and programming in C++ is an asset. You are expected to have good communication skills and be able to work in an international team.

Information
Further information can be obtained from prof. dr. Stan Bentvelsen (Stan.Bentvelsen@nikhef.nl).

Applications
Interested candidates are invited to submit a curriculum vitae and a statement of their research interests before December 15th, 2007. Applications should be accompanied by the names of three persons that can provide letters of reference.
Applications should be sent to:
Nikhef, att. Mr. T. van Egdom,
P.O. Box 41882, NL-1009 DB Amsterdam,
or by email to pz@nikhef.nl
Please quote vacancy: PZ-070832.

All qualified individuals are encouraged to apply.

NIKHEF

Max Planck Institute for Physics

(Werner Heisenberg Institute)

MAX-PLANCK-GESELLSCHAFT

ATLAS Postdoctoral Position

The *Max-Planck-Institut für Physik* is one of the leading research institutes in the field of particle and astroparticle physics. One main research activity is the participation in the ATLAS experiment at the Large Hadron Collider (LHC) at CERN. The *Max-Planck-Institut für Physik* has contributed to the design, construction and commissioning of the Semiconductor Tracker, the Hadronic Endcap Calorimeter and the Muon Spectrometer of the ATLAS detector.

We invite applications for a postdoctoral position in experimental particle physics within our ATLAS Muon Detector Group. Candidates are expected to contribute to our activities in the commissioning and operation of the ATLAS Muon Spectrometer, to reconstruction or analysis software development and to ATLAS data analysis. The group operates a dedicated calibration and alignment computing center for the Muon Spectrometer in Munich, is engaged in a research program for searches for the Higgs boson and for supersymmetric particles and also started detector and electronics development for future upgrades of the ATLAS detector.

Salary and benefits are according to the German public service pay scale (TVöD Bund). The contract is initially limited to three years with the possibility of extension within the frame of the German *Hochschulrahmengesetz.* The Max Planck Society is an equal opportunity employer committed to increasing the participation of women wherever they are underrepresented. Applications from women are, therefore, particularly encouraged. The Max Planck Society is committed to employing more handicapped individuals and especially encourages them to apply.

For questions concerning the position please contact Dr. Hubert Kroha (kroha@mppmu.mpg.de). Interested applicants should send an application letter including curriculum vitae, list of publications and statement of research interests and arrange for three letters of recommendation to arrive no later than December 21, 2007 at the following address:

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)
Ms. A. Schielke
Föhringer Ring 6
D-80805 München

HUMBOLDT-UNIVERSITÄT ZU BERLIN

The Faculty of Mathematics and Natural Sciences I, Institute of Physics invites for

Postdoctoral Position Salary: - Vgr. IIa - BAT-O nach AnwTV HU (limited to max. 6 years), box number: **AN/115/07**

We search for an experimental physicist with a PhD degree in particle physics to work in a postdoctoral position for the ATLAS experiment at the Large Hadron Collider LHC at CERN. The focus of activities will be data acquisition and data analysis at ATLAS, e.g. the search for new phenomena beyond the Standard Model. In parallel there will be the opportunity to work on hardware developments for future experiments. The position includes the participation in teaching within the limits of 4 hours per week and per semester. Experience in the fields of data analysis, object-oriented programming or detector development are very welcome.

Position for a PhD student Salary: Part time (50%) - Vgr. IIa - BAT-O nach AnwTV HU (limited to max. 6 years), box number: **AN/116/07**

We search for a physicist with a diploma or master thesis in the field of experimental nuclear, astroparticle or particle physics. The position allows to participate in the data acquisition and data analysis of the ATLAS experiment within the project of a PhD thesis. Experience in the fields of data analysis, object-oriented programming or detector development are welcome.

Applications (c.v., statement of research interest and 2 letters of reference) should be sent till 22 Dec. 2007 to: Humboldt-Universität zu Berlin, Mathematisch-Naturwissenschaftliche Fakultät I, Institut für Physik, Prof. Dr. Heiko Lacker, Newtonstraße 15, D-12489 Berlin. In the letter of application the box number for the application should be given. Applications arriving later will be considered as long as the position is not filled. Women and minorities are encouraged to apply. Applications of disabled candidates will be considered with preference under the condition of equal aptitude.

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BOOKSHELF

Winter Bookshelf

During the year *CERN Courier* receives many books, most of which cover the usual specializations in particle physics. Among them, nevertheless, are books that deal with a broader range of topics or that are intended for a wider audience. In this festive season, "Bookshelf" reviews some of these for more relaxed, broader reading, whether at home or on journeys to visit family and friends.

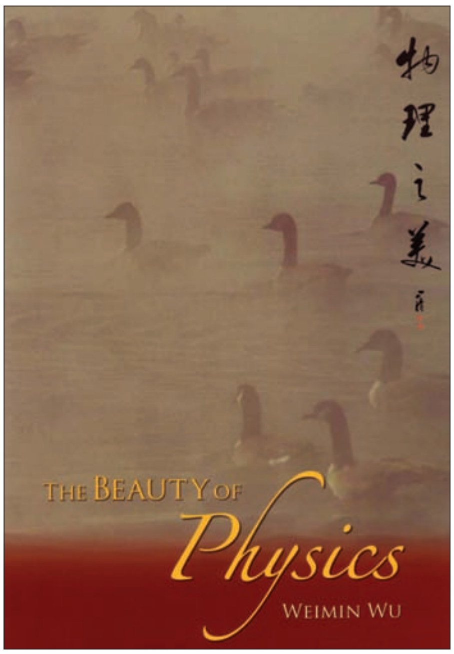
The Beauty of Physics by Weimin Wu, World Scientific Publishing. Hardback ISBN 9812705600 £29 ($54).

Weimin Wu has led an extraordinary life. Arriving at Fudan University in 1960 at age 17, he was inducted into a special "Section Zero" – by day he studied nuclear physics, in the evenings he helped with research into uranium-enrichment techniques for China's atomic bomb.

In 1965 he moved to Lanzhou University as a graduate student, but a year later the Great Proletarian Cultural Revolution burst over China and graduate students were a major target. Wu was packed off to an arid mountain region, where he worked as a shepherd, lived in a cave and survived on potatoes, wild plants, rainwater and melted snow. When he was allowed back to Lanzhou, he found that his supervisor had been accused of reactionary scholarship and landlordism, and assigned to clean toilets. Wu himself was soon sent to be a labourer. A commissar rescued him in 1969 and employed his skills to help develop the launch control system of China's first artificial satellite.

After the end of the Cultural Revolution in 1976, the Chinese government discovered that intellectuals were "part of the working class". But as Wu writes, "the era that destroyed the talents of many also had cast a dark shadow over them for a lifetime".

In 1978 Wu joined the group tasked with building China's first particle accelerator and in 1980 he came to CERN for two years, joining Jack Steinberger's CDHS neutrino group. Back in Beijing he led the Chinese group involved in ALEPH's muon detectors, and in June 1989 he observed the first J/Ψ particle to be seen at BES, the Beijing spectrometer. Three weeks earlier he had participated in pro-democracy demonstrations and witnessed the army's repression in Tiananmen Square. Shortly afterwards he left China and found sanctuary at Fermilab, where he now works on the CMS experiment.



Of the two achievements closest to his heart, one occurred on 25 August 1986 when, despite technical and political obstacles, he sent the first e-mail from China (to Jack Steinberger at CERN). The other achievement was this book of photographs.

Wu has been taking photographs since he was 12. His takes his subjects mostly from nature and from the places and people in his life. Many of his photographs are romantic images of flowers, sunsets, rainbows and landscapes. Several are more mysterious, such as a green swimming pool, lit from within, in a city at night. "To me," Wu writes, "physics and photography are like a pair of twin sisters." Both require elegance, conciseness and the good luck that "is granted only to those who are prepared".

The book includes 12 pages of episodes from Wu's life, 12 pages by him about his photography, and more than 100 pages of his photographs divided into "Flowers", "Landscape", "People" and "The Beauty of Physics" – a selection of photos that remind him of physical concepts, with titles such as *Latticework* and *Multidimensional Space*, including the cover, which shows *Birds of a Feather Flock Together*.

Michael Marten, Science Photo Library.

Das Schicksal des Universums: Eine Reise vom Anfang zum Ende by Günther Hasinger, C H Beck. Hardback ISBN 9783406562037 €22.90.

In *Das Schicksal des Universums*, Günther Hasinger, managing director of the Max Planck Institute for Extraterrestrial Physics in Garching near Munich, presents a comprehensive compilation of today's knowledge on cosmology, meeting well the needs of the interested lay reader. Although there are no formulae in the book, the author explains up-to-date knowledge in astrophysics, with many colour illustrations.

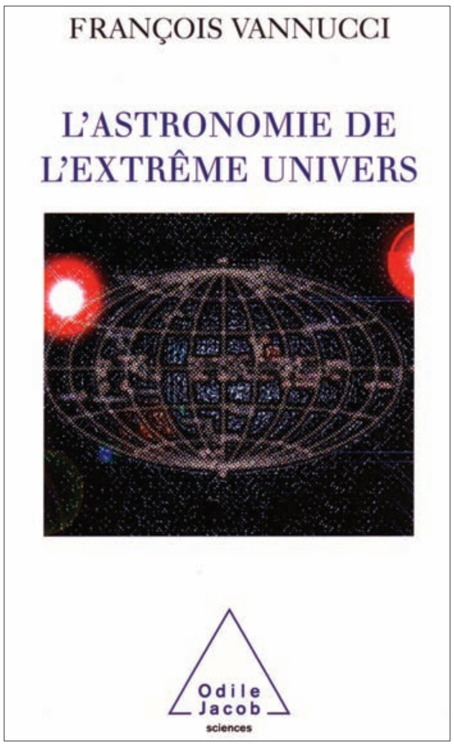
After mentioning Galileo's observations from the beginning of the 17th century, the story begins to take off when Einstein published his theory of general relativity in 1915, as there was no solution to his equations for a universe that is static and limited in space. What follows is a century of discoveries in theoretical and experimental particle physics, quantum mechanics, astrophysics and astronomy. Hasinger explains all of the relevant results obtained in these fields, keeping the balance between what is already confirmed and accepted by the scientific community and what still needs confirmation or is only at the level of hypothesis. He also describes experimental facilities, so that the reader understands how great is the scientific endeavour in this field.

In the final chapter, "Und wo bleibt Gott?" ("And what about God?"), Hasinger tackles a question that he has presumably had to answer many times after his public lectures. His response reflects his ample experience in dealing with public interest in natural sciences. It also makes *Das Schicksal des Universums* an authentic piece of literature.

I highly recommended this book to people who want to find out more of what we know about our universe, without being bothered with the mathematics used by all scientists working in this field. Despite the lack of mathematics, many physicists will also enjoy reading the book for its completeness and for Hasinger's writing style.
Christoph Ilgner, Technische Universität Dortmund.

L'astronomie de l'extrême Univers par François Vannucci, Odile Jacob. Broché ISBN 2738119131 €23.90.

À l'heure où l'observatoire Pierre Auger annonce avoir identifié les noyaux actifs de galaxies comme sources des rayons cosmiques à très haute énergie (p5), voici un livre à lire absolument, qui permet de mieux appréhender les enjeux et les techniques de l'astroparticule. Cette discipline qui marrie l'infiniment grand et l'infiniment petit, l'astrophysique et la physique des particules, est en plein essor, et les découvertes que l'on en attend devraient complètement changer notre conception de l'Univers.



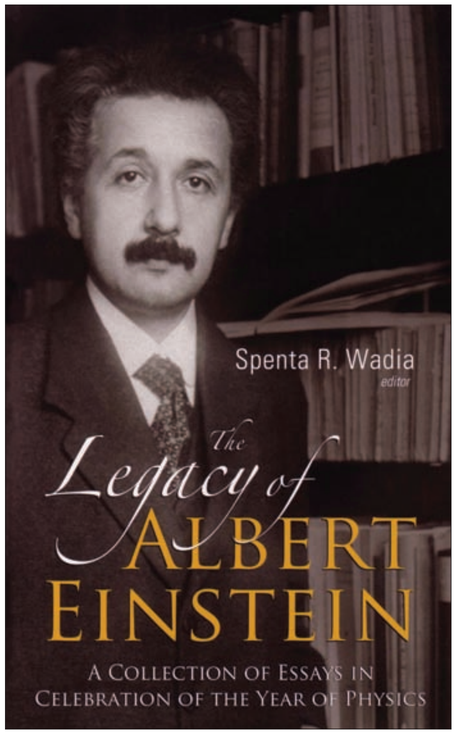
L'auteur donne dans les premiers chapitres de son ouvrage les points de repère scientifiques et historiques essentiels pour permettre à chacun de comprendre le contexte et les grandes questions auxquelles sont confrontés les physiciens des astroparticules. Aucune connaissance préalable n'est donc requise pour pénétrer dans *L'astronomie de l'extrême Univers* qui constitue un vrai effort de vulgarisation pour ce domaine souvent considéré comme ardu. On regrettera néanmoins l'absence d'illustrations et de schémas qui auraient rendu plus concrets les sujets abordés, l'auteur se contentant de renvoyer vers quelques sites internet.

Rayons cosmiques, neutrinos, ondes gravitationnelles... L'ouvrage passe en revue l'ensemble de ces nouveaux messagers de l'Univers et évoque quelques-unes des expériences les plus prometteuses pour détecter ces particules presque insaisissables. Si l'astroparticule n'en est qu'à ses balbutiements, l'ambition n'en est pas moins de dresser la carte de l'Univers dans les plus hautes énergies, traquant dans ses moindres recoins les phénomènes les plus violents qui puissent exister, comme les trous noirs super massifs ou les restes de supernovae. L'auteur aborde également les nouvelles grandes quêtes de la physique que sont notamment les énigmatiques matière sombre et énergie noire.

Le questionnement philosophique du dernier chapitre aurait sans doute pu être évité et laissera perplexes certains lecteurs. Mais on comprend comme la tentation est forte dès lors que l'on aborde des thématiques aussi excitantes, aux frontières de l'Univers et de la connaissance.
Arnaud Marsollier, CERN.

The Legacy of Albert Einstein: A Collection of Essays in Celebration of the World Year of Physics by Spenta R Wadia (ed.), World Scientific. Hardback ISBN 9789812700490 £54 ($98). Paperback ISBN 9789812704801 £29 ($54).

Like most physicists, I have been intrigued by the personality and work of Albert Einstein since my school days. This book, certainly to me, gives a global overview of the work done by Einstein including



highlights of his persona as a radical pacifist and a democrat. It provides a broad, clear and precise overview of how his five famous papers sowed the seeds of revolution of 20th-century physics. For many, including the authors of this book, he was certainly a hero and a model.

To a large extent modern physics can be viewed as an elucidation of the meaning and relationship between the three fundamental constants of nature: the speed of light, Planck's constant and Newton's gravitational constant. Einstein, more than any single individual in the history of physics, has profoundly transformed the way that we think about these constants. His words on the goal of a physicist – "The supreme test of the physicist is to arrive at those universal laws of nature from which the cosmos can be built up by pure deduction" – clearly show his passion towards the fundamental laws of nature in a simple, powerful and beautiful manner.

The book begins with contributions regarding Einstein's zeal for the search for unification of general relativity with electromagnetism, which he hoped would explain the existence and properties of particles of matter and allow them to be calculated. (Electrons and protons were the only elementary particles known in the 1920s). Here David Gross notes that although Einstein recognized the implicit global symmetry (which regulates the laws of motion) in Maxwell's equations and elevated it to space–time itself, he did not follow the route towards local (gauge) symmetry. If he had, says Gross, he might very well have discovered non-Abelian gauge theory or supersymmetry. Michael Atiyah takes up Einstein's geometrized approach towards a unified theory. Geometry has long played a significant role in explaining the fundamental forces of nature – from Newton's three-dimensional *Principia*, to Einstein's profound extension to four-dimensional space–time for general relativity, to recent 10-dimensional space–time string theory.

Ashoke Sen beautifully extends Einstein's realization that space–time is curved and not flat into string theory, which attempts to provide an all-encompassing description of nature both at large (gravitationally dominated) and small (quantum mechanical) distances. String theory postulates that the elementary constituents of matter are not point-like particles, but rather one-dimensional objects (strings). To experimentalists these strings may appear as particles, given the distance that the most energetic accelerators can probe. However, the different oscillation modes of a fundamental string could represent different elementary particles including the graviton – the mediator of gravitational force.

The chapter by Atish Dabholkar further elaborates on how string theory could contribute to explaining the black hole – a solution to Einstein's gravitational-field equations in the absence of matter that describes the space–time around a gravitationally collapsed star. Abhay Ashtekar then moves towards quantum gravity, by extending the one-dimensional string to the higher-dimensional objects known as "branes".

One of the interesting topics in the book was also the subject of Einstein's doctoral dissertation on molecular dimensions. Through Einstein's statistical approach to the motion of suspended particles, Brownian motion had a broad impact not only on the natural sciences, but also on "man made" subjects such as economics and computer science, as Satya Majumdar describes. N Kumar then outlines the dramatic relationship between Bose's route towards quantum statistics in an attempt to derive Planck's law of black-body radiation and Einstein's generalization of the approach, leading to the famous Bose–Einstein condensation. This phase transition below a critical temperature, which arises from inter-particle interactions that are not normally expected, was finally observed in 1995.

Einstein's legacy for relativistic cosmology is very nicely described by Jayant Narlikar, one of the leading experts and defenders of steady-state cosmology. He reviews the historical account of how cosmology has developed since Einstein's famous 1917 paper. The current observational status that cosmologists face with its serious puzzles linking fundamental physics and cosmology is clearly visible in this and the subsequent chapter on dark energy by Subir Sarkar.

Towards the end, T Jayaraman sheds light on Einstein's personal life, which spanned some of the most tumultuous years of a turbulent century. From the question of world peace to the crisis of the individual's relation to society under capitalism, many of the political and social issues that he sought to address continue to be important today.

Overall the book focuses on various aspect of Einstein's work and thoughts with a general sense that string theory is the answer to his dream of unification. I certainly enjoyed the elegant approach of explaining abstract concepts and their future implications through the words of some of the renowned experts in the field.
Sanjay Padhi, University of Wisconsin-Madison.

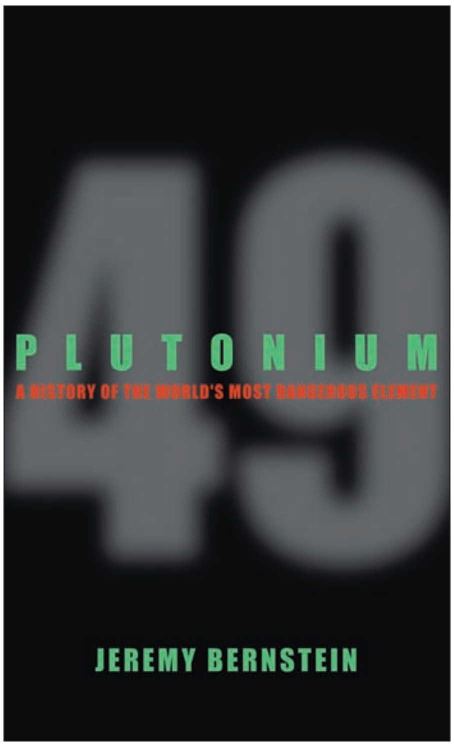
Plutonium – A History of the World's Most Dangerous Element by Jeremy Bernstein, Joseph Henry Press. Hardback ISBN 0309102960 $27.95.

Plutonium is dangerous for two reasons: ingesting milligram quantities can make you very ill indeed; and larger quantities, when appropriately primed, make nasty fission bombs. The problem with plutonium, Jeremy Bernstein points out, is that the world has now accumulated about 2000 tonnes of the stuff, and is still making it at the rate of about 70 tonnes each year. What to do with so much noxious evil?

Bernstein's book spans about 170 pages, of which the first 75 or so are a primer in nuclear physics, setting the scene for plutonium's appearance. After such a long wait, the saga could have been fleshed out more, for example with the heroic microscopic chemistry used by Glenn Seaborg's team at Berkeley, using Lilliputian equipment made of tiny quartz fibres and capillary straws. (It is described in Richard Rhodes' classic *The Making of the Atomic Bomb*.) Bernstein says that Seaborg "performed an experiment on half a microgram" to show that plutonium was more fissile than uranium.

The motivation for his book, Bernstein explains, was Rainer Karlsch's 2005 book *Hitlers Bombe*, which claimed that German scientists achieved nuclear explosions on German soil. Bernstein sets out to refute this. Nevertheless the knowledge that German scientists had discovered fission spurred the wartime US to outbuild the world, taking engineering to a new level for the huge production plants needed to furnish fissile material. The Hanford reactors, built from scratch by Du Pont in about 18 months, eventually housed some 50 000 workers. Bernstein refers to "some rowdy behaviour"; read Rhodes to learn that workers were not allowed to carry guns, that bodies were found regularly in rubbish bins, and that saloons were built with hinged windows so that tear-gas canisters could be lobbed in.

As momentum increased, wartime



plutonium production moved from the milligram level of the initial Berkeley experiments using cyclotrons, to samples of about a gram at pioneer reactors, before the gigantic Hanford plant began to supply the quantities that were needed to make fission bombs. Rhodes describes how world history was governed by the rate at which fissile material could be produced and manufactured into bombs.

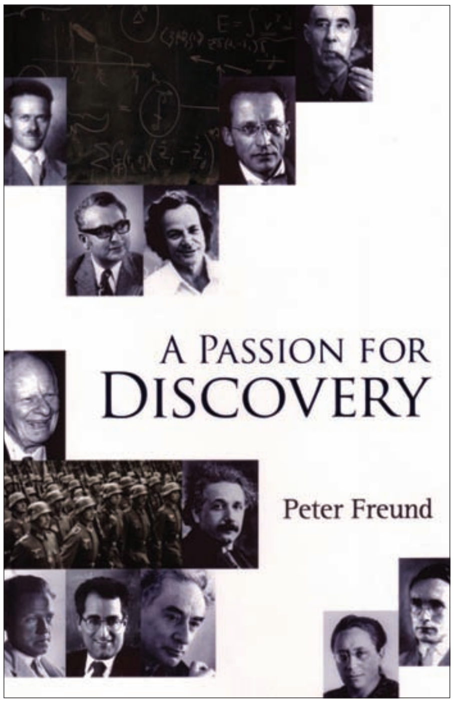
At the central Los Alamos laboratory there were accidents in which workers using primitive apparatus breathed in, swallowed or wounded themselves with plutonium – and lived. Bernstein goes into a lot of detail on the 1974 Silkwood case, in which a plutonium worker who had been accidentally contaminated was killed in a car accident. He could have made more of the earlier episodes, which are also documented.

In 1945, unsure of the exact danger of the new element, Los Alamos wanted to know more, but initially there was not enough plutonium to spare for medical physics experiments. After first using animals, Los Alamos commissioned trials in which 18 "volunteers" were given transuranic doses. Survival times ranged from six days to 44 years. The study was hushed up and only revealed half a century later by Eileen Welsome's Pulitzer Prize exposé in the *Albuquerque Tribune*. Bernstein prefers the underlying science of the diabolic element, a subject on which he is well qualified to write.
Gordon Fraser, Divonne-les-Bains.

A Passion for Discovery by Peter Freund, World Scientific. Hardback ISBN 9789812706461 £19 ($35). Paperback ISBN 9789812772145 £14 ($25).

In the preface to his book, author and theoretical physicist Peter Freund expresses his desire to "put a human face on the grand story" of the pursuit of physics, and to give readers an idea of the beautiful goal of the physicist's work, while avoiding technical means. A grand goal, especially as Freund hopes to do this for non-physicists, but one that he falls short of achieving.

The book is essentially a series of anecdotes about physicists and mathematicians, often collected around grand themes in history and science. In the 28 short chapters, one encounters lesser known stories about well known scientists – Einstein, Feynman, Dirac, Oppenheimer – along with



vignettes about those who are more obscure, but who are sometimes more interesting.

Freund is at his best when he focuses on one, perhaps two, scientists in each chapter, such as those devoted to Ernst Stueckelberg de Breidenbach, Wolfgang Pauli and Subrahmanyan Chandrasekhar. Much of the book, however, reveals his tendency to jump from one person and idea to another in a way that can make for difficult and disjointed reading. The chapters devoted to grand scientific themes, with few of the anecdotes that keep the book lively, can be especially tough going. Freund also introduces people and scientific and mathematical concepts – sometimes complex – without explanation or reference, so presenting large roadblocks for potential non-scientist readers.

Throughout his long career, Freund has obviously met many influential scientists and collected many fascinating stories about them and their colleagues. I can easily believe that, as he states in the preface, his students are riveted when he recounts them in person. But in trying to collect them all in one place and bind them together in a series of grand themes, many of the individual stories lose much of their impact.

If you're already familiar with the history of physics and its greatest players, and you're searching for some lesser known stories about them, this book is for you. But be prepared to hunt for the gems.
Katie Yurkewicz, CERN.

Que cache l'électron? de Jean-Louis Bobin, Le Pommier. Broché ISBN 9782746503038 €4.50.

Soixante petites pages et une très grande police pour parcourir toute l'histoire de l'électron, la particule à la base des phénomènes électromagnétiques ainsi que de tous les liens chimiques qui font la matière et les matériaux. Le défi était effectivement énorme. Jean-Louis Bobin a réussi à condenser plus de 100 ans de physique (d'abord atomique, puis corpusculaire et enfin quantique) en très peu d'espace. Le prix à payer est l'effet «survol». Rien n'est vraiment expliqué, tout est simplement mentionné.

La collection *Le Petites Pommes du Savoir*, dont ce livre fait partie, s'adresse à un public non averti mais malheureusement je crois qu'un tel public ne pourrait rien retenir du livre sauf, peut-être, l'idée que rien n'est «fondamental», même pas l'électron. L'idée de parcourir l'histoire de la physique en suivant les recherches menées sur l'électron et ses propriétés, est très appréciable mais elle aurait mérité beaucoup plus de place.
Antonella del Rosso Vite, CERN.