

# CERN COURIER

VOLUME 46 NUMBER 8 OCTOBER 2006



## LHC dipoles – arrival on time

### NEUTRINOS

First beam from CERN  
to Gran Sasso p5

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Pinning down  $g$  for  
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CERN Courier is distributed to member-state governments, institutes and laboratories affiliated with CERN, and to their personnel. It is published monthly, except for January and August. The views expressed are not necessarily those of the CERN management.

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### Produced for CERN by Institute of Physics Publishing Ltd

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**General distribution** Courier Adressage, CERN, 1211 Geneva 23, Switzerland. E-mail: courrier-adressage@cern.ch  
In certain countries, to request copies or to make address changes, contact:

**China** Keqing Ma, Library, Institute of High Energy Physics, PO Box 918, Beijing 100049, People's Republic of China. E-mail: keqingma@mail.ihep.ac.cn

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**US/Canada** Published by Cern Courier, 6N246 Willow Drive, St Charles, IL 60175, US. Periodical postage paid in St Charles, IL, US. Fax: 630 377 1569. E-mail: vosses@aol.com  
POSTMASTER: send address changes to: Creative Mailing Services, PO Box 1147, St Charles, IL 60174, US

**Published by** European Organization for Nuclear Research, CERN, 1211 Geneva 23, Switzerland. Tel: +41 (0) 22 767 61 11  
Telefax: +41 (0) 22 767 65 55

**Printed by** Warners (Midlands) plc, Bourne, Lincolnshire, UK

© 2006 CERN ISSN 0304-288X

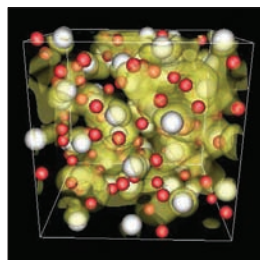


# CERN COURIER

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Proof for dark matter found p5



Accessing metallic water p11



Aronson takes over at BNL p39

## News

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**Cover:** Each day sees more dipoles installed in their positions underground in the tunnel of the Large Hadron Collider – the end of a journey that has involved hundreds of people in industry around Europe and worldwide (p28).

# 2007



## THE 11<sup>TH</sup> VIENNA CONFERENCE ON INSTRUMENTATION FEB 19-24, 2007



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- High Energy Physics and Nuclear Physics
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- Synchrotron Radiation and Neutron Scattering
- Applications in Biology and Medicine

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## NEUTRINOS

# OPERA experiment detects first neutrinos in beam from CERN

For the first time, on 18 August, the OPERA detector in the Gran Sasso Laboratory in Italy recorded the interactions of neutrinos sent from CERN, 732 km away. During the following 11 days, OPERA had about 120 hours of beam time and identified around 300 interactions correlated with the neutrino beam, in-line with predictions. This marked both a successful culmination for the beam-commissioning phase of the CERN Neutrinos to Gran Sasso (CNGS) project and a promising start to data-taking for OPERA. The ultimate aim is to observe oscillations from muon neutrinos into tau neutrinos.

The CNGS beam line incorporates a target to produce pions and kaons and a magnetic horn and reflector to focus them before they decay to muons and neutrinos in a 1 km vacuum pipe (CERN Courier October 2005 p6 and March 2006 p6). At the end of the decay pipe, a barrier of graphite and iron absorbs the remaining hadrons, leaving only muons, which are quickly absorbed downstream in the rock, and a beam of neutrinos travelling towards Gran Sasso.

The CNGS team began gradually to commission the installation at the start of 2006, beginning with tests without beam of some 200 items of equipment. Then, from 10 July, protons from CERN's Super Proton Synchrotron were sent step-by-step through the beam line to the target, using a beam 100 times less intense than the nominal beam. After analysis at the end of July, commissioning resumed at high intensity.

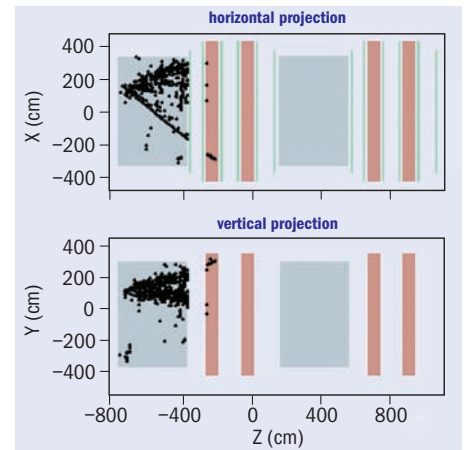
The OPERA Collaboration, comprising 170 physicists from 35 research institutes and



A view along the magnetic horn, prior to installation in the CNGS target chamber.

universities worldwide, began installing their detector in the underground laboratory at Gran Sasso in 2003 (CERN Courier April 2003 p6). The detector has two identical Super Modules, each containing a target section and a large-aperture spectrometer. The target consists of alternate walls of lead/emulsion bricks and modules of scintillator strips for the target tracker. The spectrometer, which detects muons emerging from neutrino interactions, consists of a precision drift-tube tracker, a 1.55 T magnet and resistive plate chambers (RPCs) inserted into the magnet.

During this first run, researchers verified the operation of the electronic detectors (4000 m<sup>2</sup> of RPCs, 6000 m<sup>2</sup> of scintillator strips and two magnets), checked the



A neutrino from CERN interacts in the first set of scintillator planes in OPERA, producing a hadron shower and a muon, which then penetrates the steel beyond.

synchronization of the OPERA and CNGS clocks and tested the algorithms governing the selection of interesting events. CNGS can send at most two bunches of neutrinos every 6 s, and to reduce the background noise, the experiment has to select events exactly as a bunch passes through. The two 10.5  $\mu$ s bunches are separated by 50 ms, and the design synchronization accuracy between CERN and OPERA is better than 100 ns.

OPERA is now ready to enter the next phase, aimed at observing neutrino interactions in the emulsions of the detector's 200 000 target bricks, which will be produced and installed over the coming months. The long search for tau neutrinos will start in earnest at the end of October and will last at least five years.

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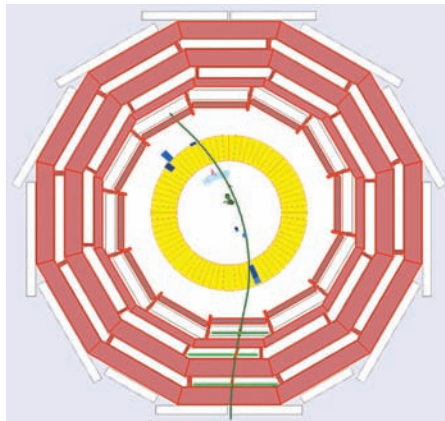
## LHC EXPERIMENTS

# CMS magnet reaches full field after eight years of construction

The world's largest superconducting solenoid magnet, built for the CMS experiment at the Large Hadron Collider (LHC), reached full field on 28 August. In addition, elements of the detector already in place within the magnet have been successfully recording the tracks of cosmic rays as part of the magnet test and cosmic challenge (MTCC).

The CMS magnet is a marvel of modern technology. Weighing in at more than 10 000 tonnes, the magnet is built around a 6 m diameter, 13 m long superconducting coil that generates a field of 4 T and stores 2.5 GJ of energy. When it was designed in the early 1990s, it was beyond the state-of-the-art. What makes it remarkable is not just its high magnetic field, but also the fact that the field is maintained with high uniformity over such a large volume. New techniques have had to be developed, allowing the solenoid coil to be more compact than 1990s technology could have achieved.

Construction of the magnet was approved in 1996, and began in earnest in 1998. By 2002, fabrication of the superconducting wire was complete. Winding the cable for the solenoid coil began in 2000 and took five years. By the end of 2005, the solenoid was ready for testing, and in February 2006, it was cooled to its operating temperature of



*A cosmic track recorded at full field in a "slice" of the CMS detector, with the tracker, hadron calorimeter (top and bottom), electromagnetic calorimeter and drift tubes (only bottom elements installed).*

4.5 K. Following the insertion of various particle detectors, the MTCC was ready to begin at the end of July (*CERN Courier* July/August 2006 p28).

During these tests, which lasted until the end of August, more than 25 million cosmic events were recorded at a trigger rate of around 200 Hz. It was a big task to provide the trigger, optimize the performance of the various detector systems and ensure the data integrity.

Highlights included data transfer to some Tier-1 centres of the LHC Computing Grid and fast off-line running at Fermilab. Now that the maximum field has been reached in this first phase of the MTCC, the next step is to map it with a precision of 1 in 10 000 in the space that will later be filled by the electromagnetic barrel calorimeter and tracking detectors.

- The magnet is a common project to which all 155 institutes of the CMS Collaboration have contributed financially. Major innovative and technical contributions have been made by the French Atomic Energy Commission in Saclay (CEA) for the original concept and general engineering; CERN for the project coordination, all ancillaries, and the magnet yoke and assembly; the Swiss Federal Institute of Technology (ETH Zurich) for the development and production of the compound superconductor and organization of major magnet procurement including the barrel yoke; the US Department of Energy's Fermi National Accelerator Laboratory near Chicago for the superconducting wire and field mapping; the Italian National Institute of Nuclear Physics (INFN) in Genoa for the design and execution of the winding operation; the Russian Institute for Theoretical and Experimental Physics (ITEP) in Moscow; and the University of Wisconsin for the endcap yoke.

## Two inner detectors move into place at the heart of ATLAS

After years of design, construction and commissioning, the two outer detectors – the transition radiation tracker (TRT) and the semiconductor tracker (SCT) – of the inner detector barrel were moved to the ATLAS cavern from the nearby cleanroom at the end of August. The journey was only about 100 m, but it required weeks of planning and a bit of luck concerning the weather. Special measures were in place to minimize shock and vibration during transportation. Accelerometers fitted to the barrel to provide real-time monitoring

recorded no values greater than 0.1 g, satisfying the transport specification for this extremely precise and fragile detector. Then, with only a few millimetres of clearance, the detector was inserted into the liquid-argon calorimeter cryostat.

The SCT and TRT are two of the three major parts of the ATLAS inner detector. The innermost layer (pixels) will be installed in 2007. The barrel part of the inner detector containing the two outer subsystems was assembled in February and passed through

complete characterization of its performance during tests in spring. An eighth of the TRT and a quarter of the SCT were equipped with complete readout chains, and during testing particular attention was paid to ensuring that the SCT did not generate noise in the TRT and vice versa. The results were a triumph for the designers – mechanical engineers, electronics engineers and physicists. The two detectors, which are completely independent, can operate at thresholds close to that defined by thermal noise.

## LHC EXPERIMENTS

# LHCb installs bridge and beampipe section...

The last large component of the Large Hadron Collider beauty (LHCb) experiment has descended into the cavern on the LHC ring, and the delicate installation of the important beryllium vacuum chambers has begun. LHCb will focus on the precision measurement of CP violation and rare decays of hadrons with b quarks, with a spectrometer covering only one side of the collisions in the LHC. Beryllium was chosen for 12 m of the 19 m long beampipe to minimize the level of background in the experiment.

The 10 tonne, 18 m long metal structure known as the bridge, which will support the LHCb tracking system, was lowered into the cavern in June. This was a challenge as there were only a few centimetres to spare as the structure was turned and moved into its final position. The bridge is made of stainless steel, which was chosen to avoid creating interference in the experiment as it is only



*A technician carefully inserts the wakefield suppressor into LHCb's beryllium beampipe.*

slightly magnetic. It has rails onto which will slide the three stations of the silicon inner tracker and the three stations of the outer tracker consisting of straw-tube detectors.

More recently, at the end of August, the first beryllium section of LHCb's beam vacuum chamber was installed. The three-day operation demanded patience and precision as the first

of four sections of the beampipe was connected to the vacuum vessel of the vertex locator (VeLo). This first section comprises a conical tube of 1 mm thick beryllium, nearly 2 m long, and an 800 mm diameter spherical window made from 2 mm thick aluminium alloy. The window is connected to the conical part of the beampipe through an aluminium alloy bellow, which allows mechanical alignment once the assembly is installed.

For installation, the beampipe was placed on a frame that slides over rails to move it gently into position. A wakefield suppressor was then inserted and connected electrically, and finally the spherical window was connected to the VeLo vessel using a metal seal. After installation was completed, the system was pumped down and a leak test conducted. The aim is to reach an average pressure of  $10^{-9}$  millibar with the beam passing through the beampipe.

## ...while ALICE installs the first detectors

In mid-July, the ALICE Collaboration reached important milestones with the installation of the trigger and tracking chambers of the muon spectrometer. They are the first detectors to be installed in their final position in the ALICE cavern of the Large Hadron Collider.

The role of the trigger detector is to select events containing a muon pair coming, for instance, from the decay of  $J/\psi$  or  $Y$  resonances. All of the eight half-planes of the resistive plate chambers (RPCs) are now in position behind the muon filter. The company General Tecnica fabricated the internal parts of the RPCs, which are made of bakelite, and groups from INFN Torino and Alessandria are constructing the readout chambers. The IN2P3 laboratory in Clermont-Ferrand has developed the front-end electronics and Subatech



*An ALICE trigger chamber is moved into position in front of the muon wall, with the dipole magnet in the background.*

Nantes has produced the readout electronics.

At the same time, workers at ALICE have installed the first half-station of the tracking system a few metres before the muon wall. The main task of this system is to sample the trajectory of muons with a resolution better than  $100\ \mu\text{m}$ . It is composed of cathode-pad/strip chambers, among the first of their kind, made from composite material. Extremely thin but still very rigid, the composite material helps to minimize the scattering of the muons. INFN Cagliari, the Petersburg Nuclear Physics Institute in Gatchina, Subatech Nantes and CEA Saclay constructed the big chambers, while the Institut de Physique Nucléaire at Orsay, and the Saha Laboratory in Kolkata, India, made the smaller ones.

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## FELS

## FLASH breaks more records and reaches the water window

Using the Free-electron LASer in Hamburg (FLASH), DESY has established a new world record, generating pulses of laser light at


wavelengths between 13.5 and 13.8 nm with an average power of 10 mW and energies of up to 170  $\mu$ J per pulse, all at repetition rates

of 150 times a second. The pulses have a duration of only around 10 fs, so the peak power per pulse can reach 10 GW, greater than is currently available at the biggest plasma X-ray laser facilities. In addition, a specific part of the radiation at 2.7 nm – the fifth harmonic – enables FLASH to reach deep into the “water window”, a wavelength range that is crucially important for the investigation of biological samples. The range around 13.5 nm is also important because laser radiation of this wavelength is required by the semiconductor industry to produce the next generation of microprocessors using extreme ultraviolet lithography.

FLASH is currently the only laser facility that can deliver ultra-short high-power X-ray laser pulses with a very high repetition rate. It currently generates laser radiation with fundamental wavelengths between 13.1 and 40 nm. Future development will see the repetition rate reach the multi-kilohertz range and the average power increase to more than 100 mW. FLASH also produced coherent radiation at the third and fifth harmonics of the 13.7 nm fundamental wavelength, that is, at around 4.6 and 2.7 nm with a pulse duration of less than 10 fs. The corresponding energies approach 1  $\mu$ J and 10 nJ per pulse for the third and fifth harmonics, respectively.

In 2007, the facility will be upgraded to allow it to generate radiation with a fundamental wavelength that is continuously tunable between 6 and 60 nm. At the higher harmonics, FLASH will thus provide ultra-short laser pulses with microjoule energies for which the wavelengths will be tunable within and across the edges of the water window. This will create unprecedented opportunities for high-resolution *in vitro* 2D and 3D imaging and spectroscopy of biological systems.

The record performance was achieved by the DESY FLASH team in collaboration with international partners, the characterization of the photon beams being performed in collaboration with researchers from the Laboratoire d'interaction du rayonnement X avec la matière (CNRS/Université Paris-Sud), the International Research Centre in Experimental Physics at Queen's University Belfast, and the National Centre for Plasma Science and Technology, Dublin City University.



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## ASTROPHYSICS

# US team finds direct proof for dark matter

The idea of dark matter in the universe dates back to the 1930s, with the observation that the gravitational force on the visible matter in clusters of galaxies could not fully account for their behaviour, implying some alteration to gravity, or the existence of non-luminous, invisible matter. Now a team in the US has used a combination of astronomical images to analyse gravitational lensing in a region where two clusters are merging. The researchers find that their observations cannot be explained by modified gravity.

While dark matter has become the focus of a range of research, from cosmology to particle physics, it has proved difficult to rule out the alternative scenario in which gravity is slightly altered from the standard  $1/r^2$  force law. The new study, however, has discovered a system in which the inferred dark matter is not coincident with the observable matter, and the difference in position is too great to be accounted for by modifying gravity. This, the team says, provides direct empirical proof for dark matter.

The team from the universities of Arizona and Florida, the Kavli Institute for Particle Astrophysics and Cosmology, and the Harvard-Smithsonian-Center for Astrophysics has combined observations from various telescopes to build a picture of what is happening in the galaxy cluster 1E0657-558. This cluster is particularly interesting because it shows evidence that a smaller cluster has at some stage ripped through a larger cluster, creating a bow-shaped shock wave.

Using images from the Hubble Space Telescope, the European Southern Observatory's Very Large Telescope and the Magellan telescope to provide information on gravitational lensing of more-distant galaxies, the team has created a map of the gravitational potential across the cluster 1E0657-558. This reveals two regions in which the mass is concentrated.

The team has also observed the cluster with NASA's Chandra X-ray Observatory to measure



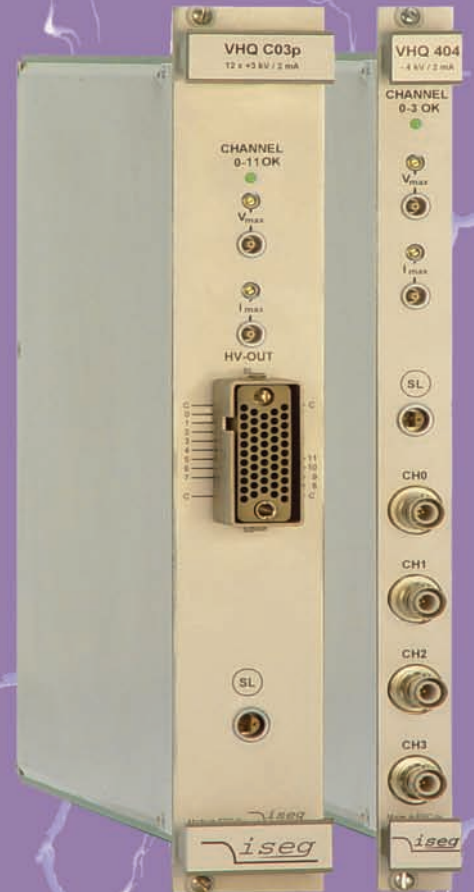
*Hot gas seen through X-ray emission (pink) contains most of the baryonic matter in two merging clusters in 1E0657-56, observed against an optical image of the overall cluster. Blue indicates the locations of the total mass as found in an analysis based on gravitational lensing. Most of this mass is clearly separate from the baryonic matter, indicating that it is mainly dark. The bow shape of the hot gas on the right suggests that this cluster has passed through the other. It seems that while the two gas clouds slowed on interacting, the dark matter did not, leading to the separation observed. (X-ray courtesy NASA/CXC/CfA/M Markevitch et al.; optical courtesy NASA/STScI; Magellan/U Arizona/D Clowe et al.; lensing map courtesy NASA/STScI; ESO WFI; Magellan/U Arizona/D Clowe et al.)*

the positions of the two clouds of hot gas that are associated with the merging galaxies. It finds that these two clouds of X-ray emitting plasma of normal baryonic matter are not coincident with the two central locations of the gravitational mass, which in fact are further apart. This suggests that the plasma clouds have slowed as they passed through each other and interacted, while dark matter in the two clusters has not interacted.

#### Further reading

D Clowe et. al. 2006 *Ap. J.* **648** L109.

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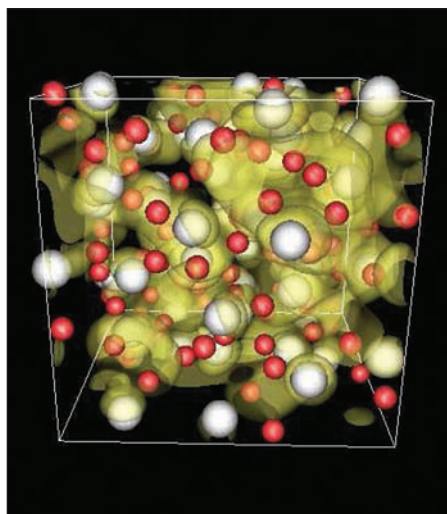
Compiled by Steve Reucroft and John Swain, Northeastern University

## Metallic water becomes even more accessible

Water is well known for its astonishing range of unusual properties, and now Thomas Mattsson and Michael Desjarlais of Sandia National Laboratories in New Mexico have suggested yet another one. They found that water should have a metallic phase at temperatures of 4000 K and pressures of 100 Gpa, which are a good deal more accessible than earlier calculations had indicated.

The two researchers used density functional theory to calculate from first principles the ionic and electronic conductivity of water across a temperature range of 2000–70 000 K and a density range of 1–3.7 g/cm<sup>3</sup>. Their calculations showed that as the pressure increases, molecular water turns into an ionic liquid, which at higher temperatures is electronically conducting, in particular above 4000 K and 100 GPa. This is in contrast to previous studies that indicated a transition to a metallic fluid above 7000 K and 250 GPa. Interestingly, this metallic phase is predicted to lie just next to insulating “superionic” ice, in which the oxygen atoms are locked into place but all the hydrogen atoms are free to move around.

Suitable conditions for metallic water should exist on the giant gas planets. In particular, the line of constant entropy (isentropes) on the planet Neptune is expected to lie in the region of temperature and



*The structure of metallic water at 4000 K and 2.5 g/cm<sup>3</sup> as found in the simulations by Mattsson and Desjarlais, with red hydrogen atoms and white oxygen atoms. A constant electron density surface for the electron state that is responsible for the conductivity is shown in gold.*

pressure suggested by these studies for the metallic liquid phase.

### Further reading

T R Mattsson and M P Desjarlais 2006 *Phys. Rev. Lett.* **97** 017801.

## Spherical salt less likely to stick around

Sometimes physics comes in handy for solving simple daily problems, like how to keep common salt from “caking” or clumping together. This problem, which arises in particular when salt is stored, is believed to be due to bridges forming between the crystals of sodium chloride. Amar Ballabh and colleagues from the Central Salt & Marine Chemicals Research Institute in Gujarat and the Hindustan Lever Research Centre and Unilever Research India in Bangalore have found that adding a small amount of the amino acid glycine to common salt makes the crystals come out as rhombic dodecahedrons instead of cubes.

The new shape is almost spherical and reduces the contact area between salt crystals. This not only makes caking less likely, but also improves the flow characteristics of the salt. The researchers say that their method can also be extended to the solar production of salt from natural brines, in a process in which the glycine can be recycled.

### Further reading

A Ballabh *et al.* 2006 *Crystal Growth & Design* **6** 1591.

## Star shades to help search for planets

Optical searches for distant planets are often hindered by the fact that the planets are faint, while the stars they orbit are bright – about 10<sup>10</sup> times brighter. This is a problem even for telescopes in orbit above the “twinkling” effects of Earth’s atmosphere. Now Webster Cash of the University of Colorado in Boulder has come up with a clever scheme to help.

Cash has designed specially shaped star shades, or occulting shields, attached to a spacecraft flown in formation with the telescope. The shields efficiently block starlight before it enters the telescope, so minimizing problems from diffraction and enhancing the possibility of seeing planets.

### Further reading

W Cash 2006 *Nature* **442** 51.

## Axion signature may be QED

Earlier this year the PVLAS collaboration announced the possible signature of the hypothesized particle known as the axion, in an experiment to measure light polarization rotation in a magnetic field (*CERN Courier* June p11 and July/August p19). Now a team of researchers in Lisbon has argued that what might have been detected is not an axion, but a new effect in quantum electrodynamics (QED).

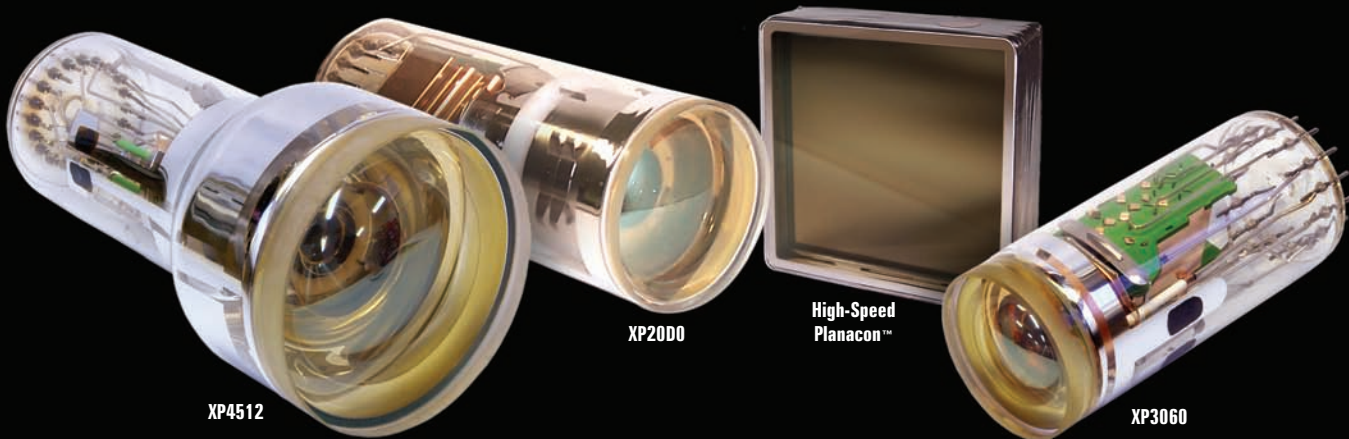
Tito Mendonça, Dias de Deus and Castelo Ferreira of the Instituto Superior Técnico in

Lisbon have argued that a beam of light propagating in a slowly rotating magnetic field can give rise to an infinite tower of frequency shifts proportional to the rotation frequency. The data from PVLAS may reflect a first measurement of this effect in pure QED, rather than evidence for an axion.

### Further reading

J T Mendonça, J Dias de Deus and P Castelo Ferreira 2006 <http://xxx.lanl.gov/abs/hep-ph/0606099>.

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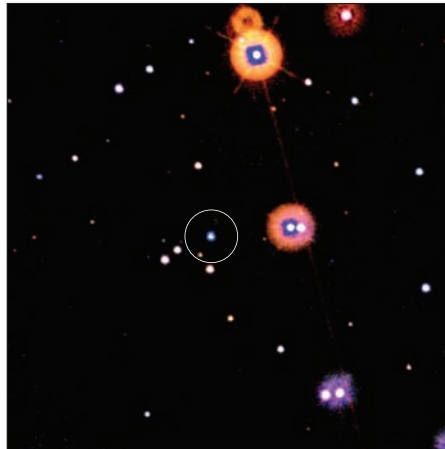
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## Supernova follows X-ray flash

Astronomers have reached another milestone in the understanding of gamma-ray bursts by observing a supernova at the location of an X-ray flash that was detected by NASA's Swift spacecraft. The supernova was caught from the start of the explosion thanks to the X-ray flash precursor, an observation that sheds light on the link between X-ray flashes, gamma-ray bursts and supernovae.

Swift, the first spacecraft dedicated to observing gamma-ray bursts, is again making the headlines. Being able to turn its X-ray and optical-ultraviolet telescopes within a minute or so to the location of a new gamma-ray burst, it provides key information on the position of the burst and on the evolution of its early afterglow (*CERN Courier* October 2005 p11). This has led to the identification of the host galaxies of a few short gamma-ray bursts, supporting the idea that short gamma-ray bursts arise from the merger of two neutron stars (*CERN Courier* December 2005 p20).

The recent observation of a supernova associated with the X-ray flash detected by Swift on 18 February is the subject of a series of four papers published in *Nature*. S Campana and colleagues link features of the X-ray flash to the shock wave from supernova SN 2006aj, while E Pian and collaborators report on the optical discovery of the supernova and its association with the X-ray flash. SN 2006aj is the fourth supernova to be clearly linked to an X-ray or gamma-ray burst event. While the previous associations established the link between long gamma-ray bursts and especially luminous and powerful type Ibc supernovae



Optical image of the supernova SN 2006aj (circled) associated with the X-ray flash XRF 060218 as seen by the Ultraviolet/Optical Telescope onboard NASA's Swift satellite. (Courtesy NASA/Swift/UVOT.)

(*CERN Courier* September 2003 p15 and September 2004 p13), this new observation shows that X-ray flashes are also produced in similar core-collapse explosions of stars stripped of their outer hydrogen and helium envelopes. The papers in *Nature* analyse the link between the physical properties of the X-ray flash XRF 060218 and its associated supernova compared with the three other similar stellar explosions so far observed.

The emission of XRF 060218 was seen to peak in the X-ray region, at a lower energy than for typical gamma-ray bursts. Moreover, although the event lasted for as long as around 2000 seconds, it was about

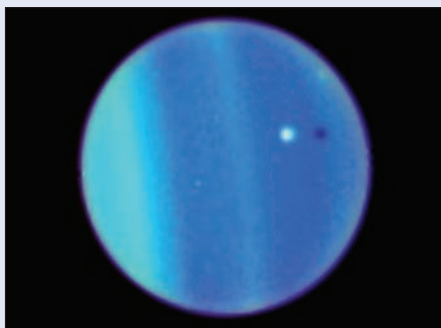
100 times less energetic than typical gamma-ray bursts. The associated supernova was also much less powerful for this X-ray flash than for the three gamma-ray bursts. The inferred initial mass of the dying star is only about 20 solar masses, which is believed to be too small to form a black hole through core collapse. P A Mazzali and collaborators therefore suggest that a magnetar – a strongly magnetized neutron star – is at the origin of the X-ray flash on 18 February. This peculiarity would explain the sub-energetic properties of this event compared with other gamma-ray bursts thought to be powered by black holes.

The observation thus extends gamma-ray burst phenomenology towards smaller stellar masses than expected. The supernova associated with XRF 060218 has properties between those of a normal supernova of type Ibc that does not produce a precursor event and those powering a gamma-ray burst. This should allow a better understanding of why only some dying stars produce an X-ray flash or a gamma-ray burst. The detection of this X-ray flash was only possible because it was relatively nearby. According to A M Soderberg and colleagues, X-ray flashes should be about 10 times more common than long gamma-ray bursts, but most of them are too far away to be detected by current instruments.

### Further reading

- S Campana *et al.* 2006 *Nature* **442** 1008.
- P A Mazzali *et al.* 2006 *Nature* **442** 1018.
- E Pian *et al.* 2006 *Nature* **442** 1011.
- A M Soderberg *et al.* 2006 *Nature* **442** 1014.

### Picture of the month



The Hubble Space Telescope captured for the first time a moon passing in front of Uranus. The large white dot on Uranus' blue-green disc is the icy moon Ariel and the nearby dark dot is its shadow. Uranus became the last but one planet of the solar system on 24 August 2006, when the general assembly of the International Astronomical Union classed Pluto as a "dwarf planet" and the prototype of a new class of trans-Neptunian objects. Uranus is the only planet with a spin axis lying nearly in its orbital plane. As the moons of Uranus orbit the planet above the equator, their paths align edge-on to the Sun only twice during the 84 year orbit of Uranus around the Sun. Additional transits by the large moons Umbriel, Titania and Oberon, will follow in the months to come. This could not have been seen 42 years ago with the limited telescopes of the 1960s. (Courtesy NASA; ESA; L Sromovsky, University of Wisconsin, Madison; H Hammel, Space Science Institute; and K Rages, SETI.)

# Goodfellow

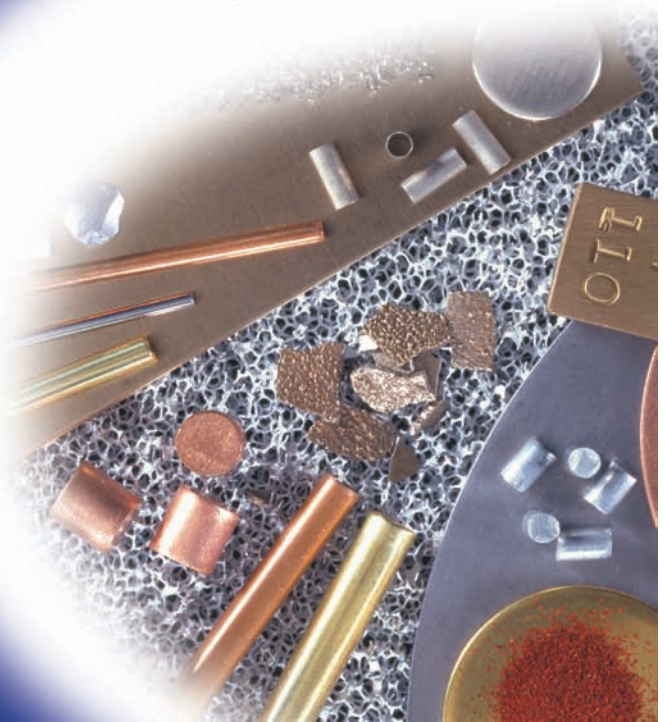
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## LAST MONTH AT CERN

# First results from neutrino experiment

From 27 June the neutrino experiment ran, for five or six days at a time, every other week until 17 September. Out of many hundreds of thousands of photographs, about 260 show neutrino interactions in the bubble chamber, and some 2500 show events occurring in the spark chamber.

The results presented in September at the Brookhaven "Conference on fundamental aspects of weak interactions", as well as the later ones given during the Sienna "International conference on elementary particles", were all of a preliminary nature and therefore subject to revision.

Even so, the results were impressive. First of all (as was apparent even from the first run in June) the discovery last year at Brookhaven of the existence of two types of neutrino (one associated with a muon and one with an electron) has been completely confirmed. In addition, the CERN experiment shows that similar neutrinos are produced in the decay of kaons – a muon neutrino when the kaon decays to a muon and an electron neutrino when (more rarely) it decays to an electron.

Another conclusion is that the results confirm the general theoretical belief that the number of "leptons" in the universe is constant, that is, either they are produced or destroyed as pairs of a particle and antiparticle, or when one disappears another takes its place. Thus, when positive pions were focused by the neutrino horn, their decay produced a positive muon (antiparticle) and a neutrino (particle) each time. The disappearance of the neutrino [by

interacting with a nucleus] then produced a negative muon (particle), which was recognized by its curvature in the magnetic field and lack of interaction. Previously the law had only been verified for electrons and electron neutrinos.

In the CERN experiment, too, it had been possible to use the neutrino as a probe to investigate the structure of nucleons (neutrons and protons) for the first time. The neutrino reactions that were observed have been separated for convenience into two classes: "elastic", when only a muon and a recoil nucleon are produced, and "inelastic", when other particles (pions, etc) are produced. It has been found that the cross-section (chance of happening) of elastic events at different neutrino energies is in excellent agreement with theory, but at the higher neutrino energies the number of inelastic events seems to be much greater than expected. It is an interesting discovery, which has made the final analysis of all the results more difficult and time consuming.

This particularly applies to the question of the existence of a new, really fundamental "particle", known as the intermediate boson or W particle. Such a particle has been postulated on theoretical grounds as being associated with the weak interaction in the same kind of way as the pion is associated with strong interactions and the photon with electromagnetic interactions. Because an elastic neutrino interaction is really weak, an investigation of such reactions was thought to give the best chance of finding the W particle. According to the theory, this weak

interaction between a neutrino and a nucleon is made up of two successive "not-so-weak" interactions between the neutrino and the intermediate boson and between the boson and the nucleon. Since only one such "semi-weak" interaction is required to produce the boson, it should be formed abundantly from neutrinos of energy sufficiently high to create its rest mass [ $\nu_{\mu} + \text{nucleon} \rightarrow \mu + \text{nucleon}^* + W$ ]. The W would disintegrate very quickly after formation, two of its important modes of decay being into a muon and a neutrino or into an electron and a neutrino. Bubble-chamber or spark-chamber photographs showing two muons, or an electron and a muon, proceeding from the same spot, with no other tracks, would thus indicate the existence of the W.

About 80 "candidates" for such an event were found among the spark-chamber photographs, and one rather dubious one was found among the bubble-chamber photographs. Such a low number shows that if the W particle does exist it has a relatively high mass, more than 1.4 times the mass of the proton. A major difficulty, however, exists in proving beyond doubt that the two tracks that were seen are really those of leptons and not of other particles – no easy task in a spark chamber, which gives no direct identification of tracks. Many of the 80 photographs undoubtedly show pions behaving by chance like muons. At the moment there is no proof that the W particle exists, only indications that have to be investigated further.

● Extracted from pp126–127.

## Keeping CERN clean

CERN has no less than 50 000 m<sup>2</sup> of glass, of all kinds, ranging from large bays measuring several square metres in area to reinforced glass cubes. All of this is kept clean by a team of six, and most of them can be seen in this photograph, which shows an unusual but nevertheless very useful aspect of work at CERN. The window-cleaning section also becomes involved with the accelerators, when it is



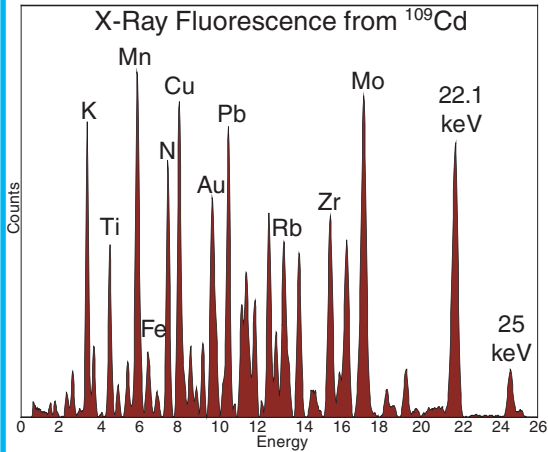
called upon to help the team cleaning the large electromagnets.

In the photograph, Robert Pelloux (at the bottom), Bernard Charvet, Pierre Boggio, Emile Brochu and Roger Paris are seen on the 12 m high tubular scaffolding, in position next to the facade of the Administration Building.

● From the article "Present layout of the CERN site", p133.

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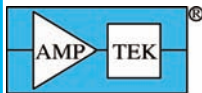
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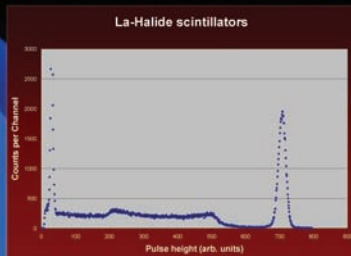
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# Trieste focuses on hadrons

A meeting at the ICTP in Trieste brought together participants from the hadronic-physics and heavy-ion communities.

The fifth Perspectives in Hadronic Physics conference was held on 22–26 May at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste. The latest in a series organized every second year by the ICTP and the Italian Istituto Nazionale di Fisica Nucleare (INFN), this year's conference was also sponsored by the Consorzio per la Fisica, Trieste, and the Department of Physics, University of Perugia. It brought together around 100 theorists and experimentalists for more than 60 plenary talks, focusing on present and future theoretical and experimental activities in hadronic physics and relativistic particle–nucleus and nucleus–nucleus scattering.

A major success of the conference was the joint participation of the hadronic and heavy-ion communities. This was reflected in the wide range of topics, from the structure of the hadron at low virtuality, to the investigation of the states of matter under extreme conditions and the possible formation of quark–gluon plasma in high-energy heavy-ion collisions. This article presents a summary of the broad range covered by the speakers.

## Hadrons, *in vacuo* and in the medium

The first part of the conference focused on the study through quantum chromodynamics (QCD) of free hadrons and the properties of hadrons in the medium – that is, in nuclear matter. It covered a broad spectrum of theoretical approaches and experimental investigations, including hadron structure and the quantities that describe it, namely form factors, structure functions and generalized parton distributions (GPDs). In this context there was much emphasis on the appreciable amount of experimental work undertaken at Jefferson Lab and at the Mainz Microtron (MAMI), for example, casting important light on the role of strange quarks in the nucleon.

MAMI has also obtained values of the masses and widths of mesons in the medium, which appear to differ appreciably from the free case. The possibility of a  $\omega$ -nucleus bound state was suggested. Scalar and axial vector mesons can be generated dynamically within a chiral dynamics approach, which was presented in detail.

Information from Jefferson Lab on the nucleon-spin structure function from almost real photon scattering to the deep-inelastic scattering (DIS) region was reviewed at the meeting, and recent results were reported on the use of semi-inclusive DIS on the proton and the deuteron as a tool for investigating the up and down quark densities. Quark–hadron duality was discussed both in its theoretical and experimental aspects, illustrating how recent data from Jefferson Lab can be used to extract the higher twist contributions to the moments of parton distribution functions, which are sensitive to the quark–gluon correlations in the nucleon. Several talks presented recent results on the calculations of hadron form factors and cross-



At the meeting Nobel laureate Roy Glauber described his work on quantum optics and its relationship to heavy-ion physics.

sections in terms of relativized quark models. These included the consideration of higher Fock components in the hadron wave functions.

Exclusive hard processes were discussed in terms of a new non-perturbative quantity that describes the hadron-to-photon transition, for instance in virtual Compton scattering in the backward region. The usefulness of this approach was illustrated in forward exclusive meson-pair production in  $\gamma\gamma^*$  scattering.

GPDs were the subject of detailed discussion at the meeting, with a report on the impressive experimental results from Hall A and the Deeply Virtual Compton Scattering Collaboration at Jefferson Lab. These experiments have accessed the twist-2 term in the proton, which is a linear combination of GPDs, and they find almost no dependence on momentum-transfer squared,  $Q^2$ . This is in good agreement with the theoretical expectation where the process described by the so-called “handbag” diagram dominates.

Turning to the calculation of GPDs, a meson-cloud model allows their computation at the hadronic scale, while GPDs for a nuclear target have been calculated in a constituent quark model, which shows that nuclear effects prove to be much larger than expected. Theoretical results for Compton scattering and two-photon annihilation into pairs of hadrons within the handbag approach were compared with data from Jefferson Lab and from the Belle experiment at the KEKB facility. The meeting presented indications for the presence and role of two different non-perturbative scales in hadronic structure, while showing that complementary information on the 3D parton structure of the hadron was accessible by measuring multiple parton distributions in hadron–nucleus reactions.

Cold nuclear matter figured in several talks, which presented new experimental and theoretical results. These clearly demonstrated that nowadays our knowledge on nuclei has reached the stage of a quantitative access to nucleon–nucleon correlations.

Mechanisms for quark hadronization and hadron formation in the medium were another important topic. The HERMES collaboration at DESY reported a clear attenuation of various leading hadrons in heavy targets compared with the DIS process on deuterium. Theoretical interpretations of these nuclear effects are based either ▷

in terms of inelastic hadron interactions or in terms of quark energy loss. Successful interpretations of the data provide information on the time needed to produce a colour-neutral precursor, which eventually fragments into a leading hadron. Preliminary data at a lower photon energy from the CEBAF Large Acceptance Spectrometer at Jefferson Lab, particularly on the transverse-momentum broadening, are expected to shed new light on these effects owing to the finite formation time of hadrons.

Several presentations showed that eventually it will be possible to explore QCD where the strength of nonlinearities is substantially higher than at DESY's HERA electron-proton collider. The meeting also discussed ultraperipheral collisions, which will allow the study of structure functions at low  $Q^2$ , and diffraction at very high energies.

### From hadrons to quark-gluon plasma

The heavy-ion part of the conference began with an overview of saturation physics from the Relativistic Heavy Ion Collider (RHIC) to the Large Hadron Collider (LHC). Here emphasis was on experimental signals for the so-called colour glass condensate, followed by the theoretical aspects of saturation and shadowing physics at small values of the variable, Bjorken  $x$ .

The modification of the jet shapes in the jet-quenching phenomenon at RHIC seems to provide an efficient tool for probing the soft gluon radiation induced by the produced medium. At both RHIC and the LHC, the ratios of heavy to light mesons at large transverse momentum offer solid possibilities for checking the formalisms for energy loss. Photon-tagged correlations have also been proved to be efficient tools for extracting both the vacuum and the medium-modified fragmentation functions, in proton-proton and nucleus-nucleus scattering. The strength of the jet-quenching process depends on the medium transport coefficient  $\hat{q}$ , but this dependence is weakened by the geometrical bias that favours the production of the hard parton at the periphery of the medium. Nonetheless, its precise value is of considerable importance to interpret the present RHIC data and to foresee the amount of quenching in lead-lead collisions at the LHC. A recent non-perturbative estimate of this quantity, using the anti-de Sitter space/conformal field theory correspondence, was presented.

Recent measurements of  $J/\psi$  production in deuteron-gold and gold-gold collisions by the PHENIX collaboration at RHIC seem to be consistent with a weak shadowing effect together with the possible inelastic interaction of the  $J/\psi$  meson in cold nuclear matter. In the heavy-ion collisions, the  $J/\psi$  suppression at RHIC is remarkably similar to that observed at CERN's Super Proton Synchrotron (SPS), despite the much larger energy density reached at RHIC. The reason for this is not yet clear and could be owing to the formation of  $J/\psi$  states from the statistical recombination of charm quarks in the medium.

The soft-physics side reported recent numerical calculations on plasma instabilities, which attempt to determine the behaviour of an anisotropic non-abelian medium on long time scales. Observables measured in two-pion (Hanbury-Brown/Twiss) interferometry and in pion spectra at RHIC are consistent with the emission of pions from a system that has a restored chiral symmetry. The recent preliminary data from the NA60 experiment on  $\rho$ -meson production in indium-indium collisions at SPS energies were discussed. While the measurements compare well with expectations for the broadening of the  $\rho$  width, these data tend to exclude the drop in mass expected from Brown-Rho scaling, which predicts the in-medium mass to be pro-

portional to the  $\bar{q}q$  condensate. More detailed presentations complemented overviews of heavy-ion collisions at intermediate energies and the physics programme for the ALICE experiment at the LHC.

The conference then focused on spectroscopic studies and the production of exotic states. The new exotic states discovered at 4 GeV by Belle and the BaBar experiment at SLAC can be understood as diquark-antidiquark ( $qq-\bar{q}\bar{q}$ ) states. The meeting also covered various problems related to dense hadronic matter – in particular, the high-temperature phase of QCD, bifurcations in the physics of strong gluon fields, and the topological structure of dense hadronic matter, and the possibility of measuring the production of “strangelets” at the LHC using the Centauro And Strange Object Research (CASTOR) detector at the CMS detector.

The conference also discussed the formation and properties of ultra-dense quark matter in the stars, from several different aspects. These included the colour-superconducting quark matter that can be formed in the core of compact stars, the various many-body approaches to the treatment of the equation of state of nuclear matter at baryon densities exceeding the density of normal nuclei by several times, and the quark-deconfinement model of gamma-ray bursts.

The last part of the meeting focused on the presentation of the most relevant plans for future experimental facilities. These included overviews on the future Facility for Antiproton and Ion Research (FAIR) at GSI and the broad programme of physics at the Japan Proton Accelerator Research Complex (J-PARC), as well as physics at Jefferson Lab with the CLAS detector. The possibilities offered by a high-luminosity electron-ion collider were also discussed.

The conference closed with a talk from the 2005 physics Nobel prize winner, Roy Glauber from Harvard, who described his pioneering work on quantum optics and its relationship to heavy-ion physics. The hadronic and heavy-ion communities are now looking forward to the sixth Perspectives in Hadronic Physics ICTP conference.

### Further reading

The proceedings of the conference will appear in *Nuclear Physics A*. Presentation slides are available at [www.pg.infn.it/hadronic06/](http://www.pg.infn.it/hadronic06/).

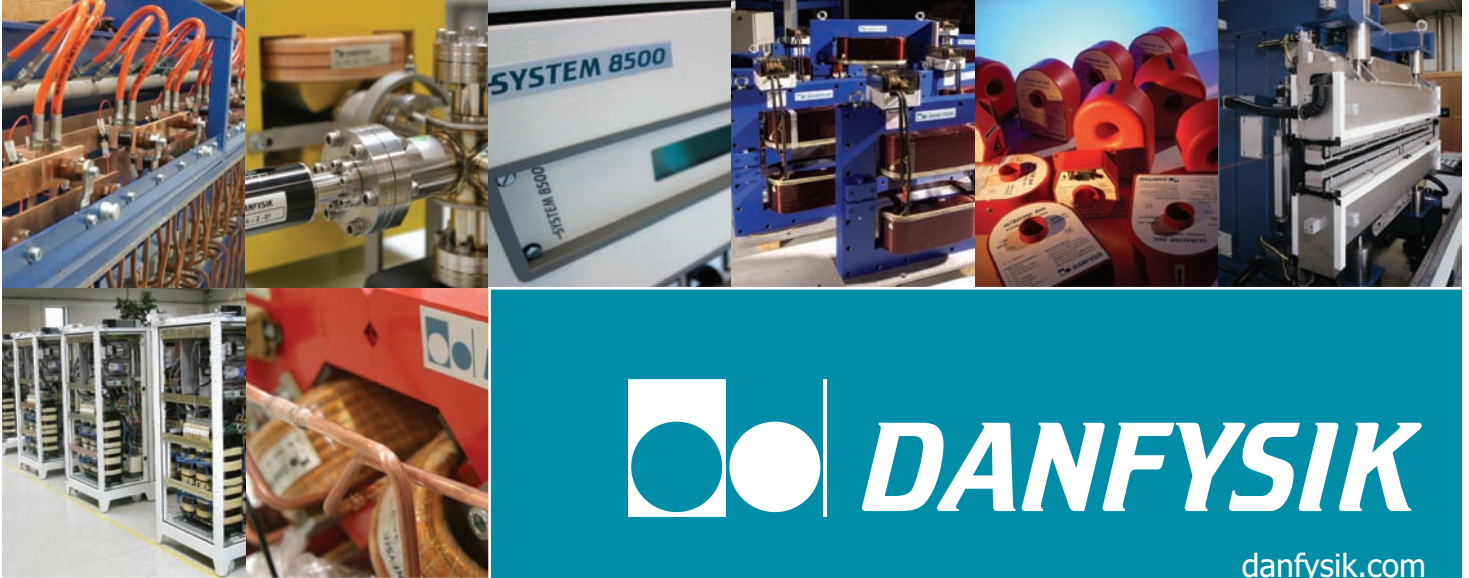
### Résumé

*De la physique des hadrons au plasma quark-gluon*

*La cinquième Conférence “Perspectives in Hadronic Physics” a eu lieu en mai à l’ICTP de Trieste. Elle a rassemblé une centaine de théoriciens et d’expérimentateurs pour des séances consacrées aux activités théoriques et expérimentales présentes et futures en matière de physique des hadrons et de diffusion relativiste particule-noyau et noyau-noyau. Un des grands intérêts de cette conférence était de réunir des spécialistes de deux domaines, la physique des hadrons et la physique des ions lourds. De ce fait, les thèmes abordés étaient extrêmement variés, allant de la structure du hadron à faible virtualité à l’étude des états de la matière dans des conditions extrêmes et la possibilité de formation du plasma quark-gluon dans les collisions d’ions lourds à haute énergie. L’article résume les différents sujets traités par les intervenants.*

**François Arleo**, CERN, **Claudio Ciofi degli Atti**, University of Perugia and INFN, and **Daniele Treleani**, University of Trieste and INFN.

# Accelerating Technology

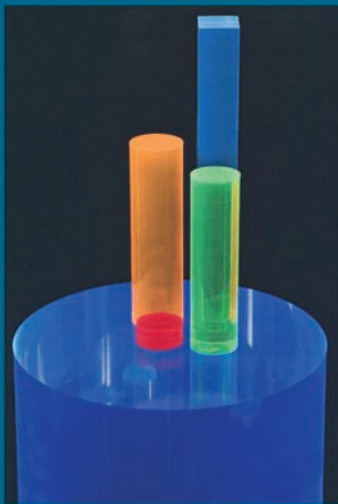


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# EPAC'06 showcases the latest in accelerators

The Scottish city of Edinburgh provided a beautiful and historic setting for the major accelerator conference of 2006.

The 10th European Particle Accelerator Conference, EPAC'06, took place in Edinburgh on 26–29 June. Attended by more than 1000 participants from 33 countries on six continents, it offered a wide scientific programme, covering all aspects of accelerators and their technology. In particular, the meeting showed that the future of high-energy physics looks bright, thanks to a community that is generating innovative ideas, which are being studied in worldwide collaborations. All-in-all, EPAC'06 was a bumper edition, and this article reports only briefly on the highlights.

The packed programme included some special sessions, during which the three European Physical Society Accelerator Prizes for 2006 were awarded. These went to Axel Winter of DESY and Hamburg University, to Lutz Lilje of DESY, and to Vladimir Tepljakov of IHEP, Protvino, who was unable to attend. The conference also featured a talk by Roger Penrose from Oxford, with the intriguing title “Big Bang: An Outrageous New Perspective, and its Implications for Particle Physics”, and Stefano Chiochio from Garching, a leading member of the ITER fusion project team, gave an inspiring closing presentation on “ITER and International Scientific Collaboration”.

## The high-energy frontier

The imminent operation of the Large Hadron Collider (LHC) at CERN was one of the major issues at the conference and was covered during the sessions devoted to circular colliders. Speakers described the challenges of construction, installation, the first test beams and the future upgrades, which are already foreseen. A good proportion of the talks and posters about the LHC were the work of an enlarged world community, reflecting the trend of increased co-operation among the particle-physics laboratories.

Existing colliders, the Tevatron at Fermilab and HERA at DESY, will pass the baton for the high-energy frontier to the LHC. Talks described the recent successful runs at the Tevatron and the technical challenges during operation of HERA, in both cases emphasizing possible lessons for the LHC.

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven is currently in a very active phase. In six years of operation, there have been collisions between various ion species; now a long future is envisaged, with runs with enhanced luminosity, new ion species and e-RHIC, which will become HERA's heir with a programme of electron–proton collisions. The high-luminosity frontier at colliders



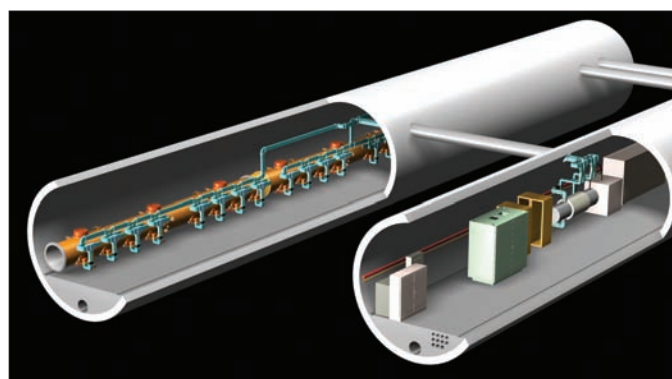
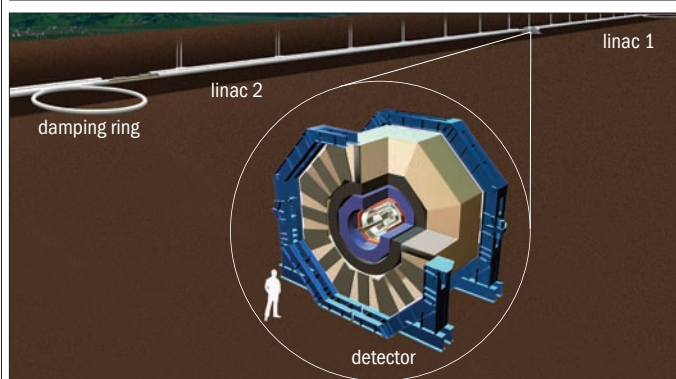
*This year's major accelerator conference, EPAC'06, took place in the historic city of Edinburgh. (Courtesy Michaela Marx, DESY.)*

featured in presentations on the success of the programmes at the B and  $\varphi$  factories, for which there are new and innovative ideas for increasing luminosity.

With the LHC on the horizon, the accelerator community is already preparing the next steps to push the high-energy frontier even further in work on linear colliders, lepton acceleration and new acceleration techniques. Innovative ideas and novel techniques are being developed, which require technologies beyond the state of the art, and ambitious and challenging R&D programmes are being pursued often by fruitful worldwide collaborations.

The importance of these developments was highlighted in the opening presentation at EPAC'06, by Barry Barish, director of the Global Design Effort (GDE) for an International Linear Collider (ILC). He emphasized the worldwide consensus that has emerged for an electron–positron linear collider as the favoured next high-energy physics facility, to complement the LHC and to study the properties of the particles that the LHC should discover. Barish presented the technological challenges of the ILC based on superconducting accelerating cavities, and described the GDE by a worldwide collaboration to optimize the design, do the R&D and prepare the technology transfer to industry. The aim is to have a 500 GeV linear collider ready to build from 2010, possibly extendable to 1 TeV.

Ambitious test facilities are planned in the US and Japan to develop superconducting radio-frequency (RF) technology beyond the state of the art as developed by the DESY-based TESLA



The Global Design Effort for an International Linear Collider envisages opposing linacs with two detectors (left) and two tunnels, one for accelerator units and one for services and RF power. (Left: courtesy KEK/Rey. Hori, and Norman Graf/Michael Hyde; right: Fermilab.)

collaboration. The Compact Linear Collider (CLIC) study is pushing linear-collider technology even further into the collision energy range of multi-tera-electron-volts by using a novel scheme of two-beam acceleration at high frequency. The ambitious CLIC Test Facility is being developed at CERN to demonstrate the feasibility of the concept in a multi-lateral collaboration.

The key to high luminosity in linear colliders is very small beam dimensions (a few nanometres) at the collision point. This requires beams that are cooled to extremely small emittances in damping rings and very strong focusing in beam delivery systems. Large collaborations are developing these techniques and setting up test facilities.

More exotic technologies could extend the high-energy frontier even further in the future. The conference heard about the concept of acceleration using plasma wake-fields induced by lasers able to produce accelerating fields of several tera-electron-volts a metre. A recent demonstration showed quasi-mono-energetic beam acceleration, thus opening the door to multi-giga-electron-volt applications in a variety of domains by taking advantage of progress in lasers. The meeting also reported impressive post-acceleration in plasma excited by beam.

Another avenue for continuing the quest for higher energies could involve muons, which have all the advantages of electrons without the intrinsic limitations owing to synchrotron radiation. They could be ideal for future high-energy research if successful cooling can be achieved. A Muon Ionisation Cooling Experiment is being built at the Rutherford Appleton Laboratory (RAL) in the UK to demonstrate the feasibility of the novel technique of ionization cooling, with a first beam expected in October 2007. Research with neutrinos, which are produced naturally in the decay of muons, could also benefit from this technique. The conference heard of various methods being studied for a possible neutrino factory. They range from using muon decay in storage rings to the innovative techniques of “beta beams”, involving the decay of unstable ions produced by a high-power proton beam hitting a target or ionization in a dedicated ring.

### Light sources and hadron rings

Covering storage rings, linacs and energy-recovery linac-based sources, the presentations on synchrotron light sources and free-electron lasers (FELs) began with a flash rather than a bang. FLASH, the FEL facility at DESY, was reported to be delivering 13 nm and has achieved a peak brilliance that exceeds all other sources by orders of magnitude. There were several reports of R&D programmes

in the US, the UK and Japan into injector and superconducting RF systems that would meet the challenges of future advanced energy-recovery sources such as the fourth-generation light source (4GLS) proposed for the UK.

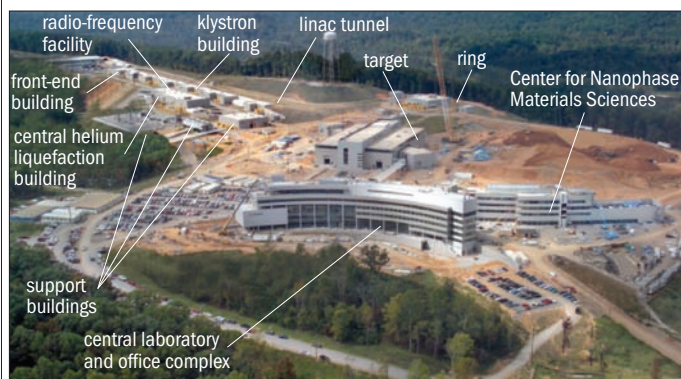
Turning to new third-generation storage rings, the old adage that you wait for one and then three come along together has proved true. The Australian Light Source has just announced first beam in the storage ring, and the SOLEIL and Diamond projects in France and the UK, respectively, have both seen beam commissioning activities this year. Talks on the two European projects illustrated the power of modern digitally based diagnostic systems in beam commissioning and, coincidentally, reported delays caused by cooling water – not a glamorous system but a vital component of any large accelerator.

The growing role for conventional laser systems within single-pass FEL facilities was reported in a talk that reviewed a diversity of applications. One such application, highlighted separately, was synchronization, a critical aspect in achieving and exploiting short-pulse sources. Other highlights included the successful lasing of the SPring-8 Compact SASE Source test accelerator in Japan, a report on injector systems for FELs, and a review of single-pass FELs, which reported that these devices are now relatively mature drivers of user facilities and also discussed the challenges of extending this technique to shorter wavelengths.

The session on hadron accelerators featured several commissioning reports, as well as new projects and developments. The Spallation Neutron Source (SNS) at Oak Ridge has recently gone through its initial commissioning stage with the first high-energy beam pulses on the target producing spallation neutrons. Norbert Holtkamp, the SNS director of the Accelerator Systems, who is soon to take up a position as principal deputy director-general of ITER, presented some of the highlights from the commissioning.

The very large Facility for Antiproton and Ion Research being prepared at GSI will provide antiprotons and ions of all charge states with intensities that are orders of magnitude higher than are available today. Presentations on other high-intensity machines and their operation included status reports on the accelerators of the Japan Proton Accelerator Research Complex, the upgrade to 1.8 MW of the proton facility at PSI, and the upgrades to the ISIS pulsed neutron source at RAL.

More novel topics included the ideas of an Energy Recovery Linac to be used as a high-energy electron cooler for RHIC; the use of crystals and channelling of beams in accelerator extraction, deflection and ▷



Oak Ridge's Spallation Neutron Source is now at 1 GeV, with three instruments installed. (Courtesy Oak Ridge National Laboratory.)

collimation; and the ideas and first tests with a circular RF quadrupole. At CERN, the Low Energy Antiproton Ring – a cooler storage ring – has recently been rejuvenated as the Low Energy Ion Ring for use as a lead-ion cooler and accumulator ring for the LHC.

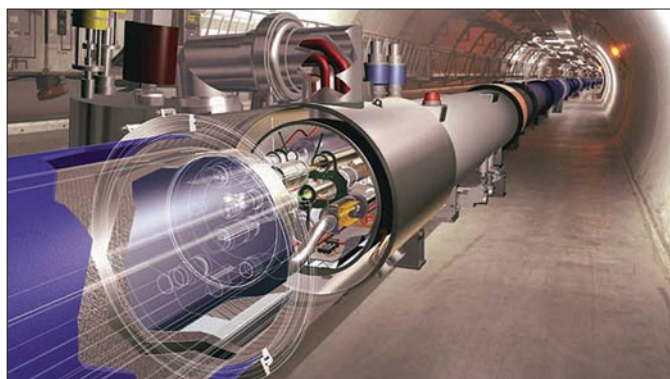
### Beam dynamics and control

As at previous conferences, beam dynamics and electromagnetic fields received the largest number of contributions. Almost 300 papers were presented in this category, underlining the extremely high level of activity and continuous interest that the accelerator community has in this area. Eleven talks and the poster sessions covered a broad spectrum, ranging from beam optics and single-particle dynamics, through collective effects and instabilities, to developments in computer code and simulation studies.

Speakers reviewed the well developed art of electromagnetic field computation, stressing the benefits of an interdisciplinary approach involving computer science and applied mathematics along with accelerator physics. One impressive example concerned a complex 3D model of a complete superconducting accelerator module of the type that was developed by the TESLA collaboration at DESY. Another overview focused on modelling the effects of space charge and coherent synchrotron radiation in bunch compressor systems – a topic of the highest relevance for FEL projects operating with high peak-current electron bunches. The electron cloud instability, a potential performance limitation in both positron and proton storage rings, retains high activity in both experimental and simulation studies. A great deal of effort has gone into refining computer modelling of the effect, for example, to include aspects of surface science and the magnetic fields of quadrupole and wiggler magnets.

Further presentations concerned space-charge driven resonances and halo formation in high-intensity hadron beams; improvement of collimation systems by non-linear optics insertions; single-particle dynamics near the half-integer resonance in the KEKB facility in Japan and in the presence of betatron coupling in RHIC; suppression of longitudinal coupled bunch instabilities by phase modulation; local bunch shortening by strong RF focusing in the DAFNE machine at Frascati; and analysis of a fast beam-ion instability occurring in a small gap undulator at the Pohang Light Source.

The session on beam instrumentation and feedback featured numerous contributions on R&D for the ILC and FEL facilities. For the ILC these included new developments in cavity and re-entrant-cavity beam-position monitors with sub-micrometre resolution, high-resolution



The LHC's cryogenic system will cool 24 km of superconducting magnets to operate at 1.8 K and generate fields of 8.33 T.

beam-size monitoring systems based on laser wires and Fresnel zone plates, and fast beam-based feedback. Higher-order-mode (HOM) signals induced in superconducting cavities have been used to measure the position of the cavity centres, the beam phase relative to the phase of the accelerating frequency, the beam position, and in a HOM-based feedback to minimize the HOM power in a module.

Talks related to FELs presented new developments and challenges in measuring ultrashort longitudinal bunch profiles, including the intrabunch structure, together with recent experimental data. New applications with ultrafast laser diagnostics, which achieve resolutions approaching 10 fs, were also described, as well as a bunch arrival-time monitor system that has yielded a precision of about 30 fs and could be applied to measure the beam position with an error of only about 3  $\mu\text{m}$ . The future developments discussed included, for example, the combination of ultrafast lasers and light emitted in FELs.

Other highlights in this session included recent measurements of the transverse profiles of the counter-rotating beams at the Tevatron, which have been achieved using ionization profile monitors with new fast electronics. There was also a report on progress on developments for a test of the CPT theorem, whereby the depolarization frequency of two electron bunches was measured with record accuracy.

### Technology and applications

The session on accelerator technology covered three aspects at the forefront of developments in different areas of accelerators: RF systems for linear and circular machines, insertion devices for synchrotron radiation facilities, and gantry designs for the latest accelerators for proton and carbon cancer therapy. In addition, there was a report on the unique experience of building a 27 km cryogenic installation at CERN for the LHC.

Superconducting cavities are now the preferred choice for RF for new accelerators, with various designs and applications. There are different options for producing the RF power to feed the cavities: klystrons, inductive output tubes and solid-state amplifiers all have their place, depending on the final power that is needed. To control and regulate these systems digital electronics is the choice everywhere.

Synchrotron-radiation facilities depend on the quality of the synchrotron light that they produce; better quality comes from installing insertion devices. The conference introduced the latest developments in this area: superconducting and in-vacuum undulators and wigglers, cryocooled magnetic structures, and so on.

As usual, a good proportion of the posters and talks on the applications of accelerators was devoted to medicine, in particular protons and light-ion therapy. Hadron accelerators have been used experimentally for cancer treatment for more than a decade, and new projects are now being built to provide general and regular treatment. One of the most demanding aspects in terms of fulfilling the strict safety regulations is the stability and precision of the gantry that delivers the particle beam. There are now designs for gantries weighing 650 tonnes, with a precision of 0.5 mm.

While more than a dozen hospital-based facilities for proton therapy are in operation or under construction around the world, Japan has the only two dedicated centres for cancer therapy with light ions, namely, carbon ions. However, two new centres are being built in Europe, and these will offer beams of both protons and ions. One is located in Heidelberg and the other at the Centro Nazionale Adroterapia Oncologica in Italy. Several others are in advanced stages of planning, and in Japan, the construction of a third carbon-therapy facility has started at Gunma University.

This session also heard about fixed-field alternating-gradient accelerators and their potential use, for example, in accelerator-driven systems (subcritical nuclear reactors), muon acceleration or the production of neutrons for boron neutron capture therapy. In the latter case, neutrons would be produced by 10 MeV protons in an internal beryllium target, and the energy loss and emittance increase of the stored beam caused by scattering in the target would be counteracted by a process similar to the one that is used in ionization cooling.

- The next conference will take place in Genoa, Italy, in June 2008.

#### Further reading

The proceedings, published less than a month after the conference, are available open-access from the Joint Accelerator Conferences Website (JACoW) at [www.jacow.org](http://www.jacow.org).

#### Résumé

*EPAC'06: une vitrine pour les accélérateurs*

*La belle ville historique d'Edimbourg, en Écosse, a constitué le cadre de la dixième conférence européenne sur les accélérateurs de particules (EPAC'06), qui s'est tenue en juin et a rassemblé plus de 1000 participants venant de 33 pays. Le programme scientifique couvrait tous les aspects des accélérateurs et des technologies annexes, depuis les très hautes énergies du Grand collisionneur de hadrons et du projet de Collisionneur linéaire international jusqu'aux moindres détails de la commande des faisceaux et des contraintes techniques de l'hadrothérapie. Cette manifestation a montré en particulier combien l'avenir de la physique des hautes énergies est prometteur, grâce aux physiciens qui proposent une multitude d'idées innovantes, lesquelles sont à l'étude dans des collaborations internationales.*

**Caterina Biscari**, LNF/INFN, and **Christine Petit-Jean-Genaz**, CERN, on behalf of the EPAC'06 Scientific Programme Committee.

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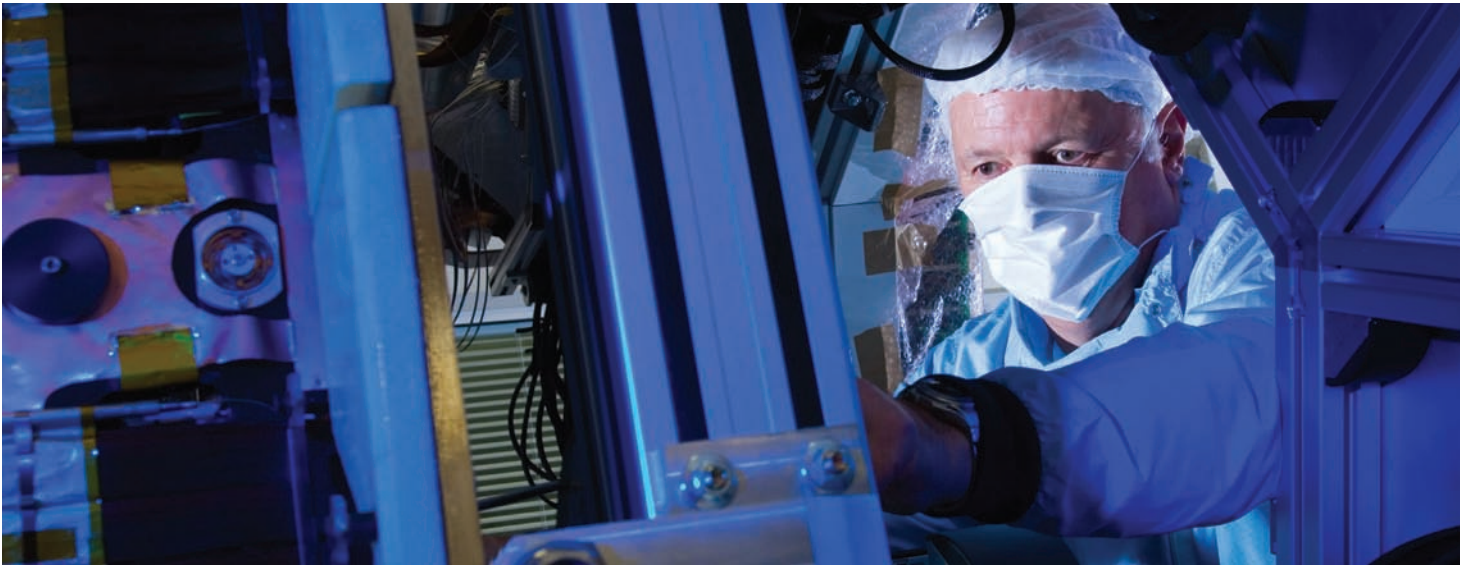
"I must confess - your Libera electronics have turned me into a believer! This is the first time in my (too long!) career that I've seen a BPM system work on day one!"

commented Alan Jackson, Technical Director at Australian Light Source, after the successful storage ring commissioning.



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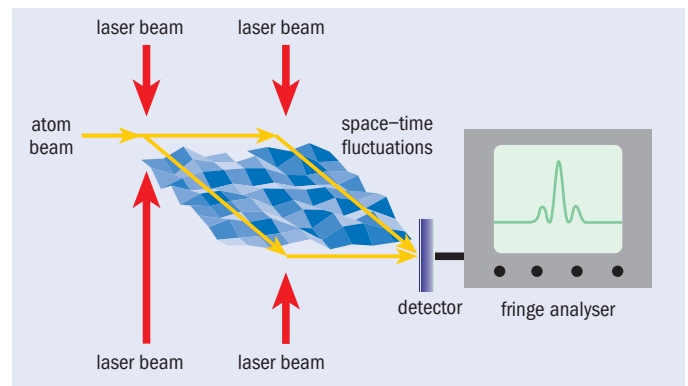
# Can experiment access Planck-scale physics?

A gravitational analogue of Brownian motion could now make it possible to investigate Planck-scale physics using the latest quantum technology.

Physics on the large scale is based on Einstein's theory of general relativity, which interprets gravity as the curvature of space-time. Despite its tremendous success as an isolated theory of gravity, general relativity has proved problematic in its integration with physics as a whole, and in particular with the physics of the very small, which is governed by quantum mechanics. There can be no unification of physics that does not include both general relativity and quantum mechanics. Superstring theory and its recent extension to the more general theory of branes is a popular candidate for a unified theory, but the links with experiment are very tenuous. The approach known as loop quantum gravity attempts to quantize general relativity without unification, and has so far received no obvious experimental verification. The lack of experimental guidance has made the issue extremely hard to pin down.

One hundred years ago, when Max Planck introduced the constant named after him, he also introduced the Planck scales, which combined his constant with the velocity of light and Isaac Newton's gravitational constant to give the fundamental Planck time around  $10^{-43}$  s, the Planck length around  $10^{-35}$  m and the Planck mass around  $10^{-8}$  kg. Experiments on quantum gravity require access to these scales, but direct access using accelerators would require machines that reach an energy of  $10^{19}$  GeV, well beyond the reach of any experiments currently conceivable.

For almost a century it has been widely perceived that the lack of experimental evidence for quantum gravity presents a major barrier to a breakthrough. One possible way of investigating physics at the Planck scale, however, is to use the kind of approach developed by Albert Einstein in his study of thermal fluctuations of small particles through Brownian motion, where he showed that the visible motion provided a window onto the invisible world of molecules and atoms. The idea is to access the Planck scale by observing decoherence in matter waves caused by quantum fluctuations, as first proposed using neutrons more than 20 years ago by CERN's John Ellis and colleagues (Ellis *et al.* 1984). Since then, ultra-cold atom technologies have advanced considerably, and armed with the sensitivity of modern atomic matter-wave interferometry we are now in a position to consider using "macroscopic" instruments to access the Planck scales, a possibility that William Power and Ian Percival outlined



*In an atom interferometer, an atomic wavepacket is split into two wavepackets that follow different paths before recombining. The phase change of each wavepacket is proportional to the proper time along its path, resulting in an interference pattern when the wavepackets recombine. The detection of the decoherence by observing the fuzziness of this pattern due to space-time fluctuations on the Planck scale would provide experimental access to quantum-gravity effects analogous to the access to atomic scales provided by Brownian motion.*

more recently (Power and Percival 2000).

Our recent work represents a new approach to gravitationally produced decoherence near the Planck scale (Wang *et al.* 2006). It has been made possible by the recent discovery by one of us of the conformal structure – the scaling property of geometry – of canonical gravity, one of the earliest important approaches to quantum gravity. This leads to a theoretical framework in which the conformal field interacts with gravity waves at zero-point energy using a conformally decomposed Hamiltonian formulation of general relativity (Wang 2005). Working in this framework, we have found that the effects of ground-state gravitons on the geometry of space-time can lead to observable effects by causing quantum matter waves to lose coherence.

The basic scenario is that near the Planck scale, ground-state gravitons constantly stretch and squash the geometry of space-time causing conformal fluctuations in space-time. This process is analogous to the Brownian motion of a pollen particle interacting with ambient molecules of much smaller sizes. It means that information on gravitons near the Planck scale can be extracted by observing the conformal fluctuations of space-time, which can be done by analysing their blurring effects on coherent matter waves.

The curvature of space-time produces changes in proper time, the time measured by moving clocks. For sufficiently short time inter- ▷

vals, near the Planck time, proper time fluctuates strongly owing to quantum fluctuations. For longer time intervals, proper time is dominated by a steady drift due to smooth space–time. Proper time is therefore made up of the quantum fluctuations plus the steady drift. The boundary separating the shorter time-scale fluctuations from the longer time-scale drifts is marked by a cut-off time,  $\tau_{\text{cut-off}}$ , which defines the borderline between semi-classical and fully quantum regimes of gravity. It is given by  $\tau_{\text{cut-off}} = \lambda T_{\text{Planck}}$ , for quantum-gravity theories, where  $T_{\text{Planck}}$  is the Planck time, and  $\lambda$  is a theory-dependent parameter determined by the amplitude of zero-point gravitational fluctuations. A lower limit on  $\lambda$  is given by noting that the quantum-to-classical transition should occur at length scales  $\lambda L_{\text{Planck}}$  that are greater than the Planck length  $L_{\text{Planck}}$  by a few orders of magnitude, so we can expect  $\lambda > 10^2$ .

A matter-wave interferometer can be used to measure quantum decoherence due to fluctuations in space–time, and hence provide experimental guidance to the value of  $\lambda$ . In an atom interferometer an atomic wavepacket is split into two wavepackets, which follow different paths before recombining (see figure p25). The phase change of each wavepacket is proportional to the proper time along its path, resulting in an interference pattern when the wavepackets recombine. The detection of the decoherence due to space–time fluctuations on the Planck scale would provide experimental access to quantum-gravity effects analogous to accessing to atomic scales provided by Brownian motion.

In our analysis we find that  $\lambda$  is given by:

$$\lambda \sim \left( \frac{M^2 c^4 T_{\text{Planck}} T}{\hbar^2 \Delta} \right)^{1/3}$$

where  $M$  is the mass of the quantum particle;  $T$  is the separation time before two wavepackets recombine; and  $\Delta$  denotes the loss of contrast of the matter wave and is a measure of the decoherence (Wang *et al.* 2006). Existing matter-wave experiments set limits on the size of  $\lambda$ , their sensitivity depending on both  $\Delta$  and  $M$ . Results using caesium atom interferometers (Chu *et al.* 1997) and also from a fullerene  $C_{70}$  molecule interferometer (Hackermueller *et al.* 2004) with its larger value of  $M$ , both set a lower bound for  $\lambda$  of the order of  $10^4$ , well within the theoretical limits of  $\lambda > 10^2$ . This suggests that the sensitivities of advanced matter-wave interferometers may well be approaching the fundamental level due to quantum space–time fluctuations. Investigating Planck-scale physics using matter-wave interferometry may therefore become a reality in the near future.

Further improved measurements will confirm and refine this bound on  $\lambda$ , pushing it to higher values. An atom interferometer in space, such as the proposed HYPER mission, could provide such improvements. However, the lower bound of  $\lambda$  calculated using current experimental data is already within the expected range. This is a very good sign and strongly suggests that the measured decoherence effects are converging towards the fundamental decoherence due to quantum gravity. Therefore, a space mission flying an atom-wave interferometer with significantly improved accuracy will

be able to investigate Planck-scale physics.

As well as causing quantum matter waves to lose coherence at small scales, the conformal gravitational field is responsible for cosmic acceleration linked to inflation and the problem of the cosmological constant. Our formula, which relates the measured decoherence of matter waves to space–time fluctuations, is “minimum” in the sense that ground-state matter fields have not been taken on board. Their inclusion may further increase the estimated conformal fluctuations and result in an improved “form factor” in our formula. In this sense, the implications go beyond quantum gravity to more generic physics at the Planck scale. Furthermore, it opens up new perspectives of the interplay between the conformal dynamics of space–time and vacuum energy due to gravitons, as well as elementary particles. (A well known example of vacuum energy is provided by the Casimir effect.) These may have important consequences on cosmological problems such as inflation and dark energy.

### Further reading

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### Résumé

*Peut-on atteindre l'échelle de Planck par l'expérience?*

*Malgré le triomphe de la relativité générale comme théorie isolée de la gravitation, il s'est avéré difficile de l'intégrer dans l'ensemble de la physique, et en particulier de la concilier avec la mécanique quantique. Faute de pouvoir s'appuyer sur des données expérimentales, le domaine de la gravité quantique est resté mal défini. Les expériences devraient pouvoir aller jusqu'à l'échelle de Planck; or, pour y arriver directement au moyen d'accélérateurs, il faudrait des machines atteignant une énergie de  $10^{19}$  GeV. Toutefois, il est possible qu'à proximité de l'échelle de Planck les gravitons à l'état fondamental étirent et écrasent la géométrie de l'espace-temps, ce qui entraînerait la décohérence des ondes de matière quantique. Grâce à cet effet, on pourrait peut-être faire des expériences de physique à l'échelle de Planck au moyen d'un interféromètre atomique, par un procédé analogue, dans le domaine de la gravité, à l'étude du mouvement brownien.*

**Robert Bingham**, Centre for Fundamental Physics CCLRC Rutherford Appleton Laboratory and University of Strathclyde,  
**Tito Mendonça**, Instituto Superior Tecnico, and **Charles Wang**, University of Aberdeen.



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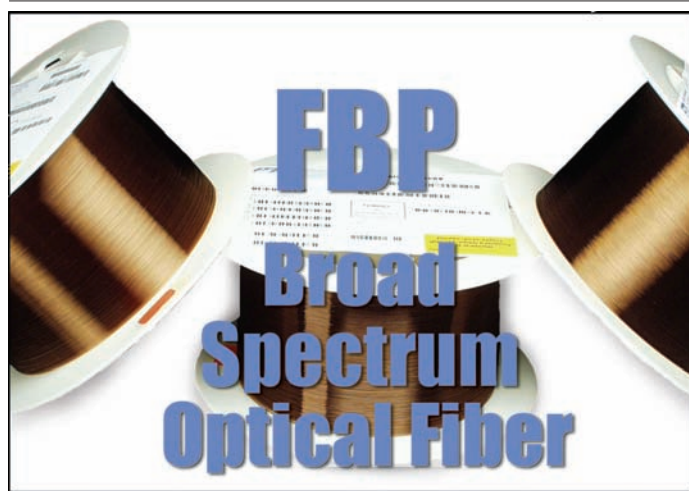
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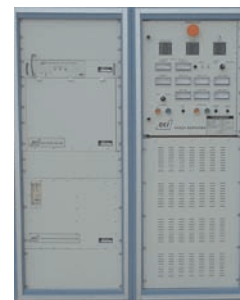
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# The longest journey: the L

The 1232 superconducting dipole magnets are the key element of the LHC. The suppliers involved a bold contractual procedure, which has

Nearly three years ago we celebrated the lift-off of the industrial production of the superconducting dipole magnets for CERN's Large Hadron Collider (LHC), marked by the delivery of the first octant on 3 December 2003 (*CERN Courier* January/February 2004 p30). It had taken about 10 years of R&D, models and prototyping to launch the first large call for tender, and a further five years of model refinement, industrialization and pre-series construction (the first 90 dipoles) to surpass a production rate of 10 dipoles a month in summer 2003. In contrast, it took only three years at the maximum rate to produce the remaining 90% of the dipoles. Indeed, since December 2005, the production has begun to slow and will finish well before the end of 2006, in perfect time for installation in the LHC ring.

Only four years ago success was far from certain. The preparation time for the largest and most complex hi-tech production ever tried in particle physics had been so long that scepticism was palpable. Moreover, the scheme devised by the LHC management – that CERN would supply the magnet manufacturers with all of the main components – seemed to many to be doomed to fail. One component or another would cause delays and/or technical problems, which would be charged to CERN. Now this story looks set to have a happy ending, and we should know for sure by November 2006.

## The route to success

There have been five key ingredients for this success. First, we ensured adequate preparation and training of the companies during the industrialization phase. This was set up through pilot orders and technology transfer in the CERN Magnet Assembly Facility in Building 181, where about 25 dipole “cold masses” went through the final stages of assembly. It was preceded by a fairly long period of careful preparation and prototyping.

This first stage allowed detailed technical specifications to be produced. The dipoles were “build to print” and “build to process”, with only minor degrees of freedom left to the companies in certain areas, notably in the coil winding and pole assembly. This reflected a change in strategy from the start of the project, when CERN management was inclined to buy an almost turnkey product, where the supplier takes responsibility for how production is implemented. In the end, CERN retained a kind of intellectual property in the dipole project.

A third important point was that CERN procured all the main components for the magnet assembly (figure 1 and box). This put an additional burden on CERN's shoulders, involving managing and taking responsibility for the interfaces; liability for delays, such that the famous just-in-time curves of the LHC “dashboard” might have been (and almost were in a few cases) a nightmare; additional workloads that were difficult to cope with; and transport, storage and logistics:

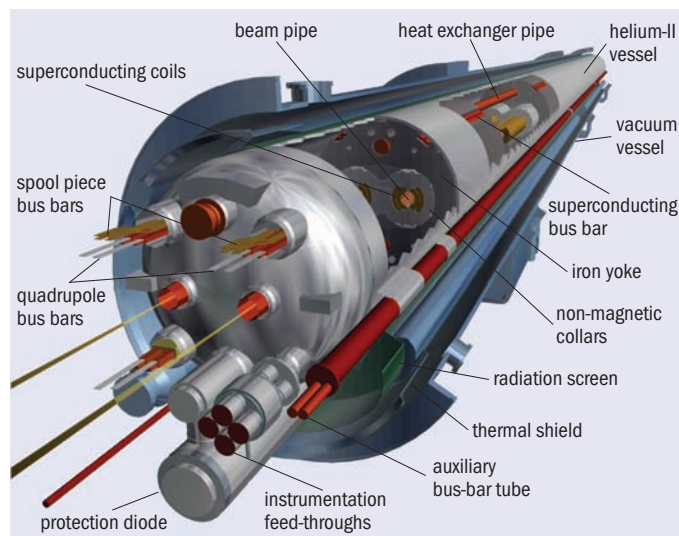


Fig. 1. Many of the major components of one of the 15 m long superconducting dipole magnets for the LHC at CERN.

we moved 120 000 tonnes of material around Europe, with five international road transport operations a day for more than four years.

Despite these difficulties, this procurement policy has proved to be to CERN's advantage, and has probably been the cornerstone of our success. It meant that technical homogeneity was assured with contracts issued by one client. Quality assurance (QA) was guaranteed, with follow-up by the final client, that is, by the body most interested in the final product and the only one qualified to balance quality against realism as dictated by the schedule. The procurement policy also enabled economy of scale, through large contracts and the possibility of placing them ahead of the magnet-assembly contracts, which was critical for items requiring long lead times and technical uniformity, such as the superconducting cables and the low-carbon steel for the yoke. In addition, the procurement by CERN of many of the components has helped a balanced industrial return, a goal set by the CERN Council that has been met thanks to the Purchasing Service.

A fourth ingredient for success has been the continuous supervision by a team of CERN physicists, engineers and technicians, reinforced by external professional QA inspectors, who have been resident on the manufacturing sites. Many people in CERN's Accelerator Technology (AT) department, as well as in the Accelerator Beams (AB) and Technical Support (TS) departments, have played key roles in measurement, analysis and validation of the work undertaken by industry.

Lastly, most of the major tooling for construction and monitoring

# HC dipoles arrive on time

ments for the LHC. Their production by three different industry suppliers proved to be highly successful, as **Lucio Rossi** explains.

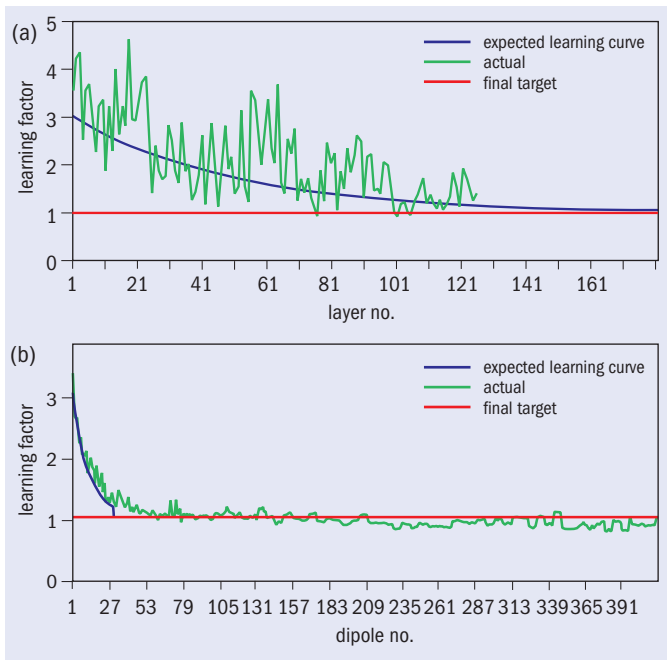


Fig. 2. Production curve for each coil winding of 30 pre-series magnets (a) and for the whole magnet production (b) for Babcock Noell. The predicted rates were very close to the rates achieved.

was supplied under CERN's responsibility. This allowed tooling development and procurement to carry on in parallel with development of the optimal assembly procedure for the dipoles. This constituted a risk, especially in the case of the big welding presses. However, this strategy, devised as early as 1998, allowed us to gain at least two years, allowing the LHC schedule to be met.

## Industrial organization

CERN awarded the contract for manufacturing the LHC dipole magnets – or more precisely, what we call the cold masses, before they are installed in their cryostats at CERN and completed with other items, such as the beam screen – to three firms or consortia. These suppliers were the French Alstom MSA–Jeumont Areva consortium, the Italian company AS-G (previously Ansaldo Superconduttori Genova) and the German firm Babcock Noell (previously BNN). The tender process was difficult and lasted about three years (1999–2001). Eventually, the companies agreed to lower substantially the tendered price, with no compromise on the technical quality. In exchange CERN had to take most of the risk and responsibility, except for manufacturing errors. The price reduction meant that there was no margin for big errors or for delays, which inevitably incur extra costs.

## The incredible supply chain

All the components of a main LHC superconducting dipole magnet shown in figure 1, and indeed a few more, have been priced by CERN; they constitute more than half of the value of the entire magnet. Additional components were procured for the pre-series production, that is, the first 90 magnets.

For a few critical components – namely the superconducting cable that generates the magnetic field, the austenitic (non-magnetic) steel collars that preserve the geometry of the coils against the magnetic forces of 400 tonnes per metre, and the magnetic steel laminations of the flux-return yoke – CERN procured the raw material, supplied it to the companies producing the finished components, and eventually supplied the components to the magnet manufacturers. This was a supply chain in which logistics, QA, traceability in real time and weekly evaluation of the near- and long-term needs, with consequences also for storage, were far from simple. In total, CERN moved about 120 000 tonnes of material all around Europe, equivalent to three times the total mass that will be cooled down to 1.9 K in the LHC. On average 10 heavy trucks a day were cruising Europe for the dipole project during the three years at the full production rate.

The three suppliers structured the work-flow, the production process and the logistics in different ways. These all worked well and led to no major difference in production flow.

The French consortium has taken care of cable insulation, coil fabrication and pole assembly on one site, Jeumont Areva, the pride of the French nuclear industry near the Belgian border. The poles are then shipped about 500 km south to Belfort in the historical Alstom factory where the French TGV high-speed train was born. Here, where Alstom also successfully produced about 40% of the precious LHC cable, the poles are put together in dipole assemblies and collared. The collared coils then have to pass critical tests based on HV electric integrity and magnetic measurements. The assembly of the cold mass is eventually completed on the same site with yoking, welding of the shells and curvature formation, corrector magnet mounting, finishing of the extremities with electrical connections among coils and bus bars, closure with the endcap, “collarete” and various flange welding, and final assessment of the curvature and geometry at the extremities. Once the final vacuum test has been passed, the cold mass is transported by special lorries – developed by TCT, winner of the 2002 “truck of the year” in France – along the 250 km route to CERN.

With the Italian company Ansaldo Superconduttori, cable insu- ▷

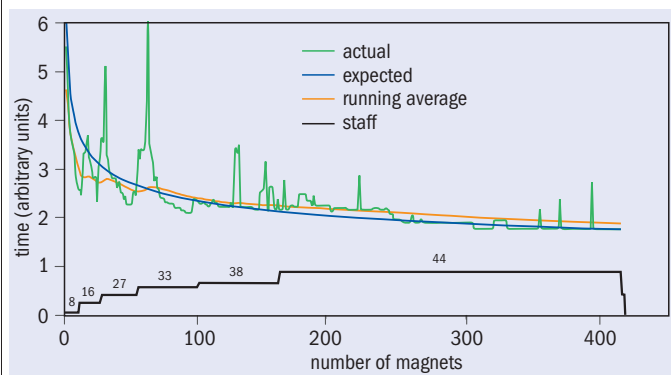


Fig. 3. Production, or learning, curve for the pole production (winding, curing and pole formation) done at Jeumont.

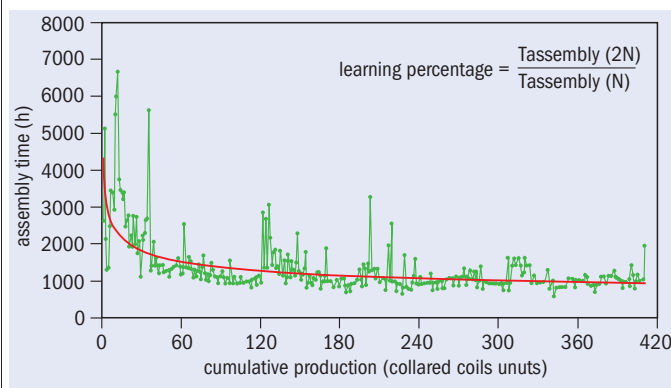


Fig. 4. Analysis of the production by single dipole and the fit with a learning model for industrial production at Babcock Noell.

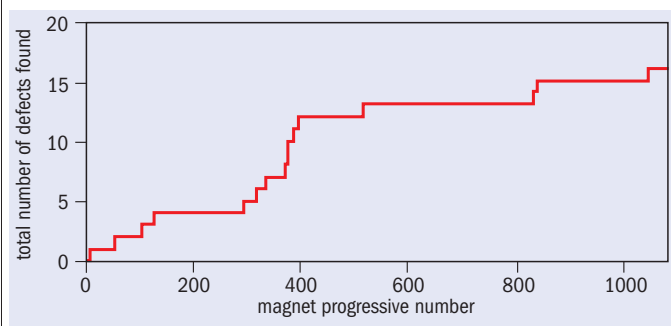


Fig. 5. Cumulative collared-coil defects that were detected during magnet production by means of magnetic measurements.

lation is done by a subcontractor, and then everything else is produced on site at Genoa. This is where the huge superconducting coils of the barrel toroid magnet for the ATLAS detector and the giant solenoid for the CMS detector were also manufactured. For the LHC cold masses, every step takes place from coil winding to the last geometrical laser track control, before the cold mass is shipped to CERN, about 400 km away. In total half of the magnetic energy that will be stored in the LHC tunnel and in the detectors will come from magnets constructed in Genoa.

The German company Babcock Noell split production between two sites. The first stage, up to the production of the collared coil and magnetic measurements, took place in Würzburg, near the headquarters, while the cold-mass assembly was done some 300 km east in Zeitz, near Leipzig, in a renovated building previ-

ously used for tank repair and maintenance for the Soviet Union army in the former East Germany. The finished cold masses travel 1000 km across Germany and part of France to CERN.

### Industrial production

It is interesting to analyse the industrial approach to managing the production, in particular as applied by Babcock Noell, which had already finished its supply of cold masses in November 2005. This company, in principle less experienced than the other two suppliers in such production techniques, first conducted a careful study, in collaboration with the University of Hanover, to evaluate the whole sequence of operations that are necessary to manufacture a dipole cold mass. The study indicated the number of assembly lines and people needed for each operation (or post) on the base of two shifts, five days a week, as a function of production rate. This work allowed the sensitivity of each working post to be assessed with respect to tooling failure or the necessity to ramp up beyond the nominal rate to recover from a stoppage. Not surprisingly, it singled out the winding stage as the ultimate bottleneck in the overall production.

Taking advantage of the fact that in Germany workers can be hired for projects for up to five years, while avoiding high social payments on laying off after the project, Babcock Noell also decided to take on about 30–40% more employees than the other two firms, which allowed them to carry out the production less time than the other suppliers. The company has consistently delivered 3.5–4 dipoles a week, while a rate of 3–3.3 would have been enough to meet the contractual obligation. In this way the firm lowered its general expenses and used tooling and manpower more intensively. From CERN's point of view this helped to compensate for a general delay in the pre-series production. However, we could not have sustained such an advanced schedule from all three producers; we would have become short of components, with the serious risk of having to pay extra costs for work stoppages: in 2005, at the maximum production rate, we had more than 400 people working at the three suppliers.

Figure 2 (p29) shows the “learning” curves for the production at Babcock Noell. It is remarkable how close to the forecast the actual production rate was. The small margin gained with respect to the target was used to correct inevitable errors and mistakes that were generated by manufacturing or by faulty components. Figure 2a highlights the most critical part, the coil winding and curing for the pre-series of 30 magnets; the singularities are clearly shown, while they are hardly visible in the global production plot in figure 2b. Reaching the goal is satisfying for the companies and also for CERN. It confirms that such a technically complex object can be made ready for industrial production.

Figure 3 shows the learning curves of another producer, Jeumont, in coil winding, curing and assembly. In this case the company continues learning and at each injection of new personnel there is a “need” for learning. For all three suppliers, although to different degrees, the earliest part of the production process proved to be the most critical and more subject to mistakes and unexpected events.

CERN has also carried out a study to compare the dipole production with other projects in terms of industrial learning curves. Based on well known industrial production theory, the data can be fitted with certain models (typically based on power curves) and used to determine the learning percentage, as in figure 4 for the dipole production. Compared with other production processes, the learning

percentage for the LHC dipole production lies, not surprisingly, between shipbuilding and aerospace production.

**Production and QA**

In considering QA, we can take the example of the collared coils and the detection of hidden defects, in which magnetic measurements at the suppliers at room temperature (with a current of only 8 A, that is, at a 5 mT field) played a primary role. CERN provided the tooling and the know-how and, once the pre-series was completed, passed the job of measuring to industry for the series production. Each measurement has been analysed almost online at CERN, with a commitment to giving an answer normally within two hours, exceptionally within a day, if the magnet is good. If an anomaly is detected, a thorough analysis is carried out to establish if the magnet can proceed or if it must be disassembled, a decision that is costly and painful because of the interruption to the tight production cycle.

Figure 5 show the total number of collared coils that have been disassembled versus the magnet fabrication number. At the start of production, as expected, there were a number of rejects. Then after a period of good production, a defective series appeared when production was almost stable. After investigation these defects were traced to small details and procedures that did not have sufficient margin to accommodate small mistakes once the slow and strictly monitored early production gave way to mass production, which also involved huge recruitment and training of new staff. Indeed in the mass production the experienced technicians, trained for years during the prototyping period, became the supervisors of newly trained colleagues; the reality is that in series production the best workers are not active players.

A project like this requires pragmatism to focus on the main objective: producing a magnet of sufficient quality in the given time, rather than continuously improving. As stated in the first external review of superconducting cable and magnet production, instituted in autumn 2001 and composed by a panel of international scientists and engineers, “the best is the enemy of the good”. We made this the guiding star of the whole production process. Following other good advice from the review, a thorough audit of QA was carried out on the manufacturing sites; the very low rate of mistakes in the later production (see figure 5) is also a result of these high-quality audits.

**Delivery and performance**

It is worth remembering that at the call for tender for the series in 2001 – 386 dipole cold masses for each of the three producers – the bidders offered their minimum price, reduced by more than 20%, with a delivery for November 2006, even if the contract demanded it for June 2006 to provide some contingency. Even then, November 2006 was already considered the latest date to respect the LHC schedule. This goal has not shifted, showing that the project, despite the problems encountered in other areas, has not been delayed significantly since the end of 2001. Babcock Noell has completed production seven months early and the other two suppliers are projected to have delivered the dipoles for the tunnel (1232 in total) by October 2006, in line with the LHC schedule.

The performances of the magnets can be qualified to a good extent by three parameters. The first is quench behaviour, that is, the irreversible loss of the superconducting state. Figure 6 shows the number of quenches that are needed to pass the nominal field of 8.3T at >

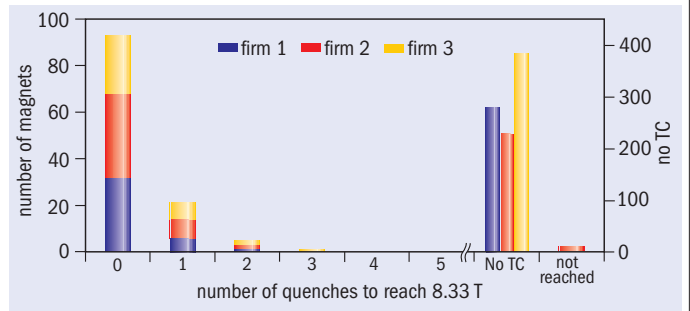


Fig. 6. Number of quenches to reach nominal field for dipoles on second thermal cycle, i.e. the less good magnets – most dipoles were accepted without a second cycle (no TC). Out of 1122 tested by 15 August 2006, only 14 were rejected owing to their quench performance, most of which have since been repaired.

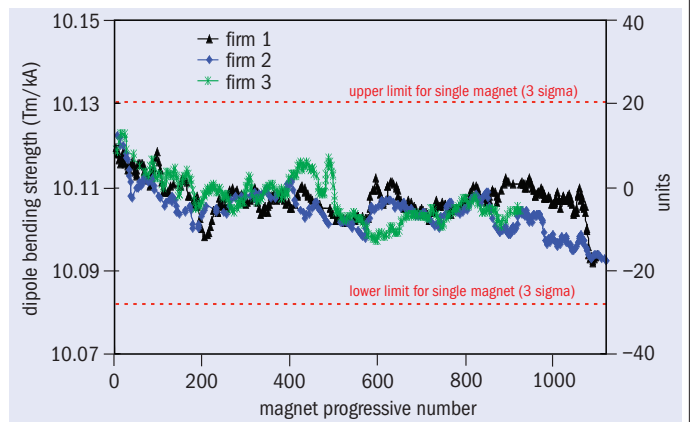


Fig. 7. Bending strength for 95% of the cold-mass production. The uniformity is impressive and is much better than the expectations that were based on previous projects.

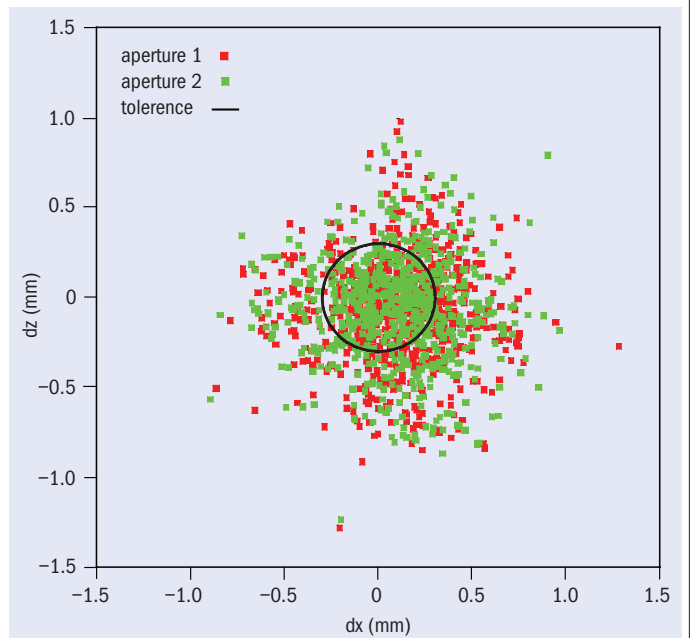
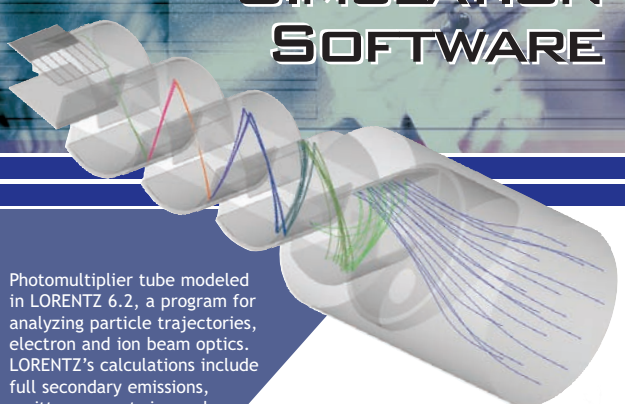


Fig. 8. Position of the sextupole corrector as measured before installation. The circle is the tolerance for the average value, and the the whole diagram ( $\pm 1.5$  mm) is the  $3\sigma$  tolerance. Thus all corrector magnets are well within the requirements.

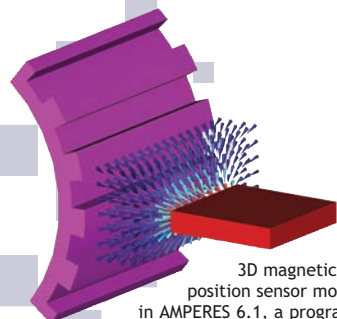
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the second thermal cycle. (The magnets will see at least three thermal cycles before they see particle beams.) The number passing is very encouraging; based on this and on the results for a few weak magnets that were tested three or four times, we anticipate that dipole quenches will take up only around 10–15 days during the hardware commissioning, and a negligible time during beam operation.

Regarding the magnetic field, the most important quantity to monitor is the uniformity of bending strength between dipoles, as all of the magnets in a sector of the LHC will be powered in series. Figure 7 (p31) shows the exceptionally satisfactory results for the coils already measured (95% of the whole production). Based on these results, magnets from different manufacturers can be mixed, allowing us to drop a constraint that would have made installation even more difficult than it is today.

A third important check concerns the geometry of the magnets. The dipoles are bent to follow the beam trajectory and minimize coil aperture and cost. Each dipole cold mass has a sagitta of 9 mm over its 15 m length and must be very precise at the extremities, where corrector magnets are positioned. This is not easy on equipment that weighs 30 tonnes, has a laminated construction, and the shape of which is determined by friction and welding shrinkage. It required a great deal of supervision in industry and at CERN (where the cold masses are inserted in their cryostats and many other operations preformed), and good collaboration among different teams in the AT, AB and TS departments. Figure 8 (p31) shows the actual positions of the sextupole corrector magnets.

### Acknowledgements

The production of the LHC dipoles involved hundreds of people at CERN and about 1200 people in industry all around Europe and worldwide. It has been a hi-tech achievement that has shown the capacity of high-energy physics and of CERN in particular to achieve large and difficult industrial projects on time.

- The dipole delivery, as well as the delivery of other numerous components of the LHC, can be followed at the LHC dashboard at <http://lhc.web.cern.ch/lhc/>.

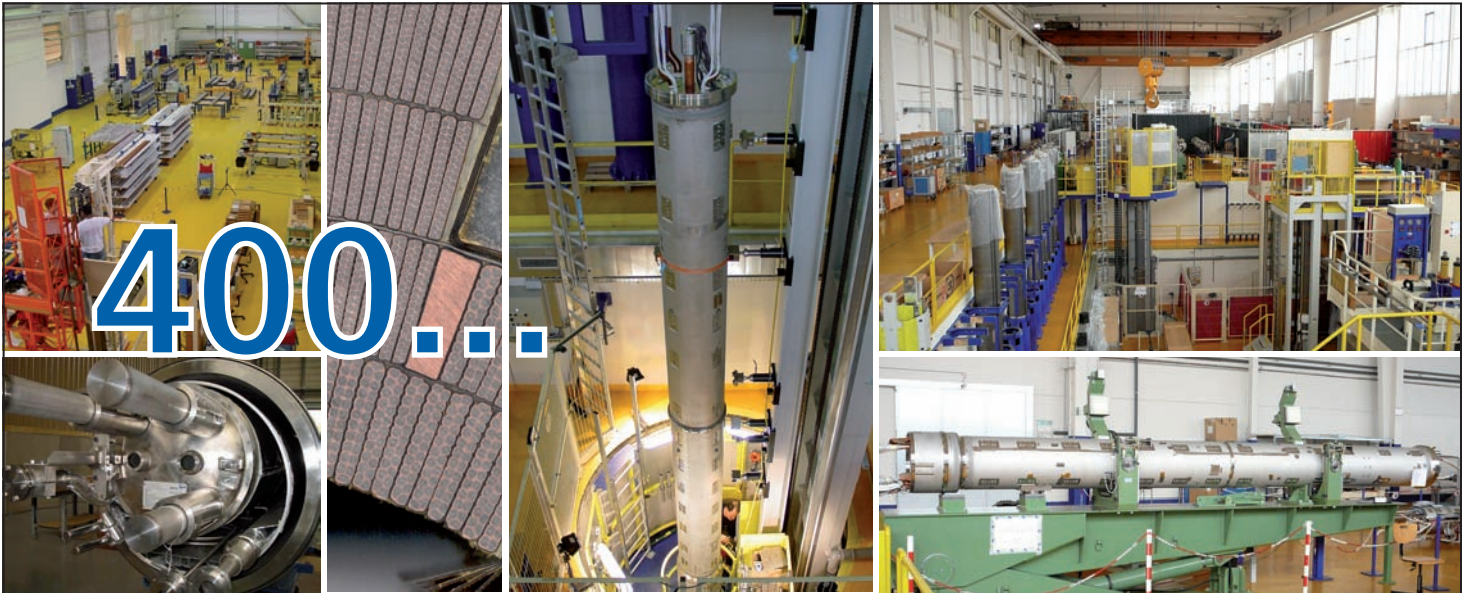
### Résumé

*Un long voyage: les dipôles du LHC arrivent à temps*

*La production des 1232 aimants supraconducteurs pour le Grand collisionneur de hadrons est presque achevée, à temps pour que l'installation puisse se faire avant le démarrage de la machine en 2007. Il y a quatre ans seulement, cela ne semblait pas si sûr. Le temps de préparation pour cette opération, la plus complexe et la plus vaste réalisation de haute technologie jamais entreprise, a été si long que le scepticisme était palpable. De plus, certains considéraient que la formule imaginée par l'équipe responsable du LHC, qui prévoyait que le CERN devait fournir aux fabricants d'aimants l'ensemble des éléments principaux, vouait le projet à l'échec. Toutefois, la production des dipôles s'est finalement très bien passée, en partie grâce à une procédure d'achat innovante, et a montré que le monde de la physique des hautes énergies pouvait mener à bien des projets industriels vastes et complexes.*

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A measurement of the electron magnetic moment using the combination of several leading-edge techniques has achieved new levels of accuracy, yielding a more precise value for the fine structure constant.

**Gerald Gabrielse** and **David Hanneke** describe this remarkable experiment.

The electron's magnetic moment has recently been measured to an accuracy of 7.6 parts in  $10^{13}$  (Odom *et al.* 2006). As figure 1a (p36) indicates, this is a six-fold improvement on the last measurement of this moment made nearly 20 years ago (Van Dyck *et al.* 1987). The new measurement and the theory of quantum electrodynamics (QED) together determine the fine structure constant to 0.70 parts per billion (Gabrielse *et al.* 2006). This is nearly 10 times more accurate than has so far been possible with any rival method (figure 1b). Higher accuracies are expected, based upon convergence of many new techniques – the subject of a number of Harvard PhD theses during the past 20 years. A one-electron quantum cyclotron, cavity-inhibited spontaneous emission, a self-excited oscillator and a cylindrical Penning trap contribute to the extremely small uncertainty. For the first time, researchers have achieved spectroscopy with the lowest cyclotron and spin levels of a single electron fully resolved via quantum non-demolition measurements, and a cavity shift of  $g$  has been directly observed.

## Unusual features

A circular storage ring is the key to these greatly improved measurements, but the accelerator is unusual compared with those at CERN, say. To begin with the storage ring uses only one electron, stored and reused for months at a time. The radius of the storage ring is much less than  $0.1 \mu\text{m}$ , and the electron energy is so low that we use temperature units to describe it – 100 mK. Furthermore, the electron does not orbit in a familiar circular orbit even though it is in a magnetic field; instead, it makes quantum jumps between only the ground state and the first excited states of its cyclotron motion – non-orbiting stationary states. It also makes quantum jumps between spin up and spin down states. Blackbody photons stimulate transitions between the two cyclotron ground states until we cool our storage ring to 100 mK to essentially eliminate them. The spontaneous emission of synchrotron radiation is suppressed because

Dear Gerald... As one of the inventors [of QED], I remember that we thought of QED in 1949 as a temporary and jerry-built structure, with mathematical inconsistencies and renormalized infinities swept under the rug. We did not expect it to last more than 10 years before some more solidly built theory would replace it... Now, 57 years have gone by and that ramshackle structure still stands... It is amazing that you can measure her dance to one part per trillion and find her still following our beat. With congratulations and good wishes for more such beautiful experiments, yours ever, Freeman Dyson. (Dyson 2006).

of its low energy and by locating the electron in the centre of a microwave cavity. The damping time is typically about 10 seconds, about  $10^{24}$  times slower than for a 104 GeV electron in the Large Electron-Positron collider (LEP). To confine the electron weakly we add an electrostatic quadrupole potential to the magnetic field by applying appropriate potentials to the surrounding electrodes of a Penning trap, which is also a microwave cavity (figure 2a p36).

The lowest cyclotron and spin energy levels for an electron in a magnetic field are shown in figure 2b. (Very small changes to these levels from the electrostatic quadrupole and special relativity are well understood and measured, though they cannot be described in this short report.) Microwave photons introduced into our trap cavity stimulate cyclotron transitions from the ground state to the first excited state. The long cyclotron lifetime allows us to turn on a detector to count the number of quantum jumps for each attempt as a function of cyclotron frequency  $\nu_c$  (figure 3d p37). A similar quantum jump spectroscopy is carried out as a function of the frequency of a radiofrequency drive at a frequency  $\nu_a = \nu_s - \nu_c$ , which stimulates a simultaneous spin flip and cyclotron excitation, where  $\nu_s$  is the spin precession frequency (figure 3c). The lineshapes are understood theoretically. One-quantum cyclotron transitions (figure 3b) and spin flips (figure 3a) are detected with good signal-to-noise from the small shifts that they cause to an orthogonal, classical electron oscillation that is self-excited.

The dimensionless electron magnetic moment is the magnetic moment in units of the Bohr magneton,  $e\hbar/2m$ , where the electron has charge  $-e$  and mass  $m$ . The value of  $g$  is determined by a ratio of the frequencies that we measure,  $g/2 = 1 + \nu_a/\nu_c$ , with the result that  $g/2 = 1.00115965218085(76)$  [0.76 ppt]. The uncertainty is nearly six times smaller than in the past, and  $g$  is shifted downwards by 1.7 standard deviations (Odom *et al.* 2006).

What can be learned from the more accurate electron  $g$ ? The first result beyond  $g$  itself is the fine structure constant,  $\alpha = e^2/4\pi\epsilon_0\hbar c \triangleright$

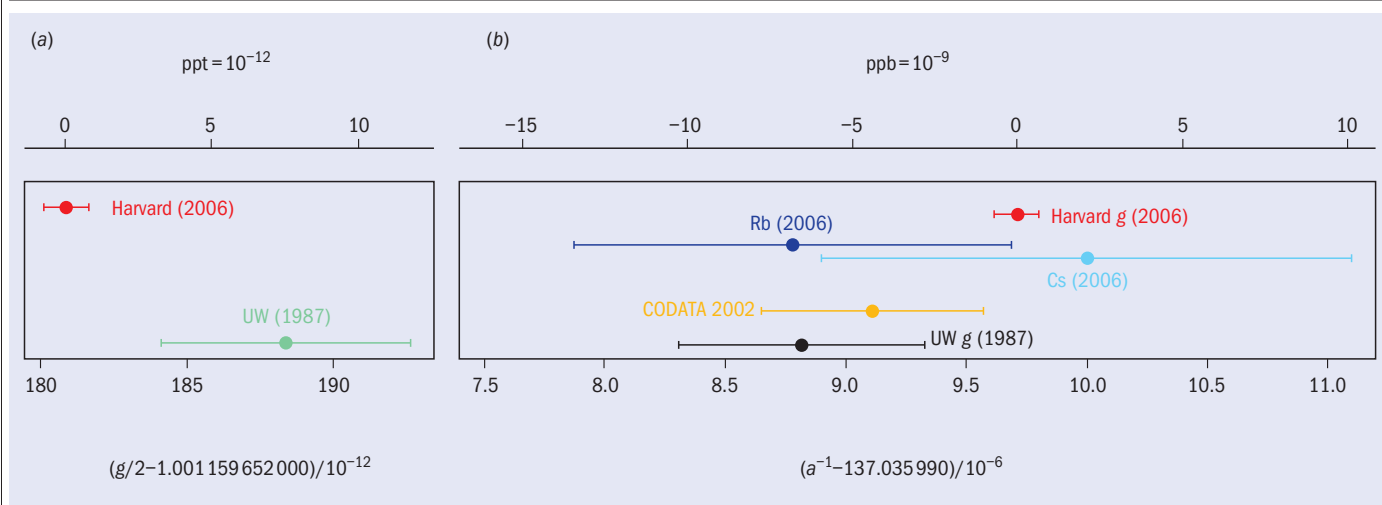


Fig. 1. (a) The latest measurements of the electron g value, showing a six-fold improvement on the measurement made in 1987. (b) Determinations of  $\alpha$ , and the current CODATA value. The measured g values are converted to  $\alpha$  with current QED theory.

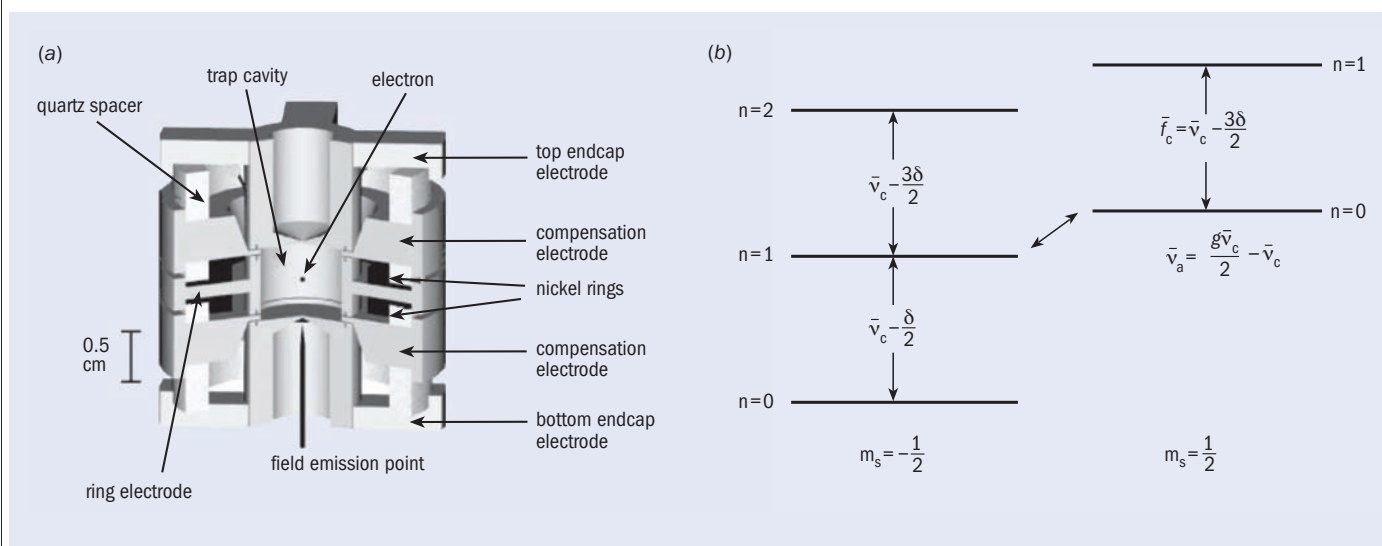


Fig. 2. (a) The cylindrical Penning trap cavity used to confine a single electron and inhibit spontaneous emission. (b) The cyclotron and spin levels of an electron confined within the trap. The experimental set-up has allowed a spectroscopy of these levels for the first time.

– the fundamental measure of the strength of the electromagnetic interaction, and also a crucial ingredient in our system of fundamental constants. A Dirac point particle has  $g = 2$ . QED predicts that vacuum fluctuations and polarization slightly increase this value. The result is an asymptotic series that relates g and  $\alpha$ :

$$g/2 = 1 + C_2(\alpha/\pi) + C_4(\alpha/\pi)^2 + C_6(\alpha/\pi)^3 + C_8(\alpha/\pi)^4 + \dots a_{\mu\tau} + a_{\text{hadronic}} + a_{\text{weak}} \quad (\text{Eq. 1})$$

According to the Standard Model, hadronic and weak contributions are very small and believed to be well understood at the accuracy needed. Impressive QED calculations give exact  $C_2$ ,  $C_4$  and  $C_6$ , a numerical value and uncertainty for  $C_8$ , and a small  $a_{\mu\tau}$ . Using the newly measured g in equation 1 gives  $\alpha^{-1} = 137.035999710(96)$  [0.70 ppb] (Gabrielse *et al.* 2006). The total uncertainty of 0.70 ppb is 10 times smaller than for the next most precise methods (figure 1b), which determine  $\alpha$  from measured mass ratios, optical frequencies, together with rubidium (Rb) or caesium (Cs) recoil velocities.

The second use of the newly measured electron g is in testing QED. The most stringent test of QED – which is one of the most demanding comparisons of any calculation and experiment – continues to come from comparing measured and calculated g-values, the latter using an independently measured  $\alpha$  as an input. The new g, compared with equation 1 with  $\alpha(\text{Cs})$  or  $\alpha(\text{Rb})$ , gives a difference  $\delta g/2 < 15 \times 10^{-12}$  (see Gabrielse 2006 for details and a discussion.) The small uncertainties in g/2 will allow a 10 times more demanding test if ever the large uncertainties in the independent  $\alpha$  values can be reduced. The prototype of modern physics theories is thus tested far more stringently than its inventors ever envisioned – as Freeman Dyson remarks in his letter at the beginning of the article – with better tests to come.

The third use of the measured g is in probing the internal structure of the electron – limiting the electron to constituents with a mass  $m^* > m\sqrt{(\delta g/2)} = 130 \text{ GeV}/c^2$ , corresponding to an electron radius  $R < 1 \times 10^{-18} \text{ m}$ . If this test was limited only by our experimental uncertainty in g, then we could set a limit  $m^* > 600 \text{ GeV}$ . This is not as strin-

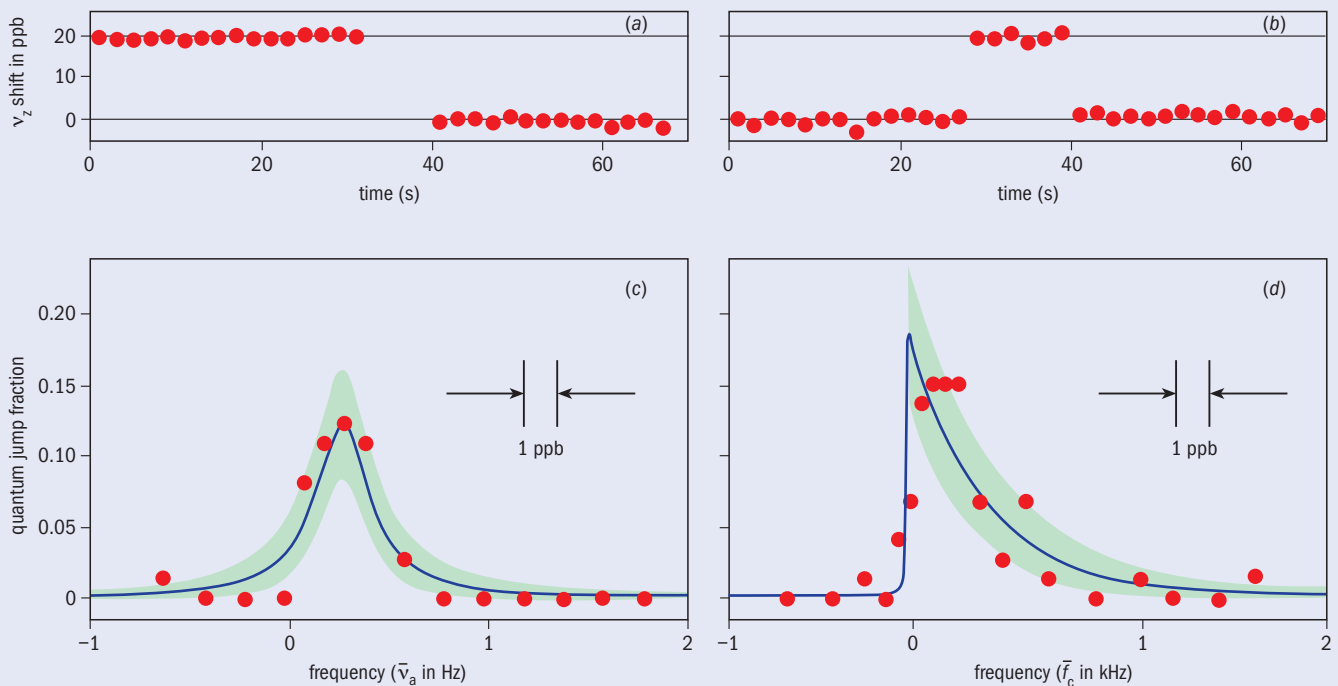


Fig. 3. Sample shifts in frequency  $\bar{\nu}_z$  for (a) a spin flip and (b) a one-quantum cyclotron excitation. The measured quantum jump spectroscopy lineshapes are shown for (c) anomaly and (d) cyclotron transitions, with a maximum likelihood fit to the calculated lineshapes (solid line). The bands indicate 68% confidence limits for distributions of measurements about the fit values.

gent as the related limit set by LEP, which probes for a contact interaction at 10.3 TeV. However, the limit is obtained quite differently, and is somewhat remarkable for an experiment carried out at 100 mK.

The fourth use of the new electron  $g$  concerns measurements of the muon  $g - 2$  as a way to search for physics beyond the Standard Model. Even though the muon  $g$  values have nearly 1000 times larger uncertainties than the new electron  $g$ , heavy particles – possibly unknown in the Standard Model – are expected to make a contribution that is much larger for the muon. However, this contribution would still be very small compared with the calculated QED contribution, which depends on  $\alpha$  and must be subtracted out. The electron  $g$  provides  $\alpha$  and a confidence-building test of the QED, both needed for the large subtraction.

CERN has long embraced particle physics at whatever energy scales are most appropriate for learning about fundamental reality. It is impressive that CERN is replacing the highest energy electron–proton collider, LEP, with the world’s highest energy proton collider, the Large Hadron Collider. Also at CERN, however, the lowest energy antiproton storage rings are also operating. One antiproton cooled to 4.2 K was used to show that the magnitudes of  $q/m$  for the proton and antiproton were the same to better than nine parts in  $10^{13}$  – the most stringent test of CPT invariance with a baryon system.

Now, these low-energy antiproton techniques are being used to make the coldest possible antihydrogen atoms, to be used for higher-precision tests of fundamental symmetries. It is fitting that the new measurement of the electron magnetic moment and the fine structure constant were carried out in the lab of a long-time CERN researcher, since they illustrate the power of low-energy techniques of the sort that we are applying to antihydrogen studies at CERN’s Antiproton

Decelerator facility, the unique source of low-energy antiprotons.

#### Further reading

- F Dyson 2006 *Letter to G Gabrielse*.  
 G Gabrielse *et al.* 2006 *Phys. Rev. Lett.* **97** 030802.  
 B Odom *et al.* 2006 *Phys. Rev. Lett.* **97** 030801.  
 S Peil and G Gabrielse 1999 *Phys. Rev. Lett.* **83** 1287.  
 R S Van Dyck, Jr *et al.* 1987 *Phys. Rev. Lett.* **59** 26.

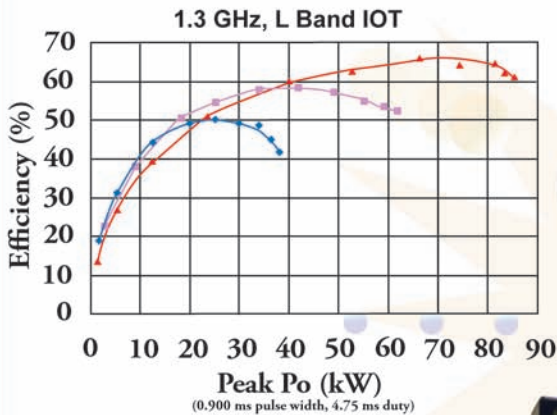
#### Résumé

*Mesure de précision du magnétisme de l'électron*

*Grâce à l'association de plusieurs techniques de pointe, une nouvelle précision a été atteinte dans la mesure du moment magnétique de l'électron,  $g$ , en réduisant l'incertitude d'un facteur six. Cette mesure plus précise permet de calculer la constante de structure fine avec une incertitude dix fois moindre que dans les mesures précédentes les plus précises. Elle constitue un moyen de vérification de la théorie de l'électrodynamique quantique et impose des limites quant aux structures internes de l'électron. Ces résultats améliorés ont été rendus possibles par un cyclotron quantique à un électron. L'électron est confiné dans un piège de Penning cylindrique, qui est également une cavité micro-onde, ce qui permet d'éliminer le rayonnement synchrotron. Les mesures se font sur la base de la spectroscopie des niveaux d'énergie les plus bas de l'électron confiné.*

**Gerald Gabrielse** and **David Hanneke**, Harvard University.  
 Gabrielse is spokesperson of CERN's ATRAP Collaboration.

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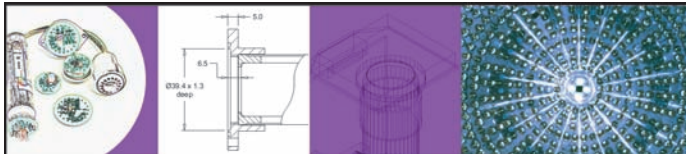


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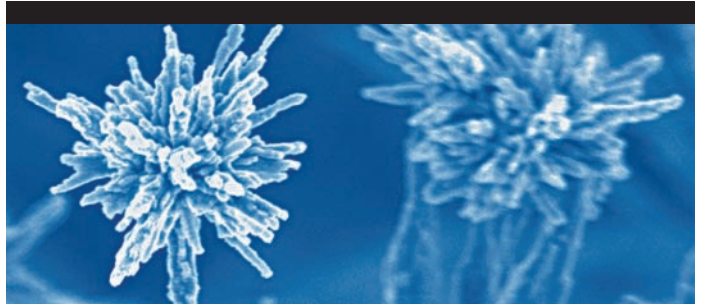
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# FACES AND PLACES

## APPOINTMENTS

# Aronson takes over the reins at Brookhaven National Laboratory

Samuel Aronson has become the new director of Brookhaven National Laboratory, having been the interim director since Praveen Chaudhari stood down in April. Aronson was chosen after a search by a committee set up by the board of directors of Brookhaven Science Associates, which manages the laboratory for the US Department of Energy. He previously served as Brookhaven's associate laboratory director for high-energy and nuclear physics, overseeing the operation of the Relativistic Heavy Ion Collider (RHIC) and the Physics Department.

Aronson earned his PhD in physics from Princeton University in 1968 and worked as a



Samuel Aronson takes the helm as director. (Courtesy Brookhaven National Laboratory.)

research associate at the University of Chicago's Enrico Fermi Institute for Nuclear Studies until 1972. He then moved to the University of Wisconsin, where he was a faculty member until 1977. He joined Brookhaven's Accelerator Department in 1978 and moved to the Physics Department in 1982, becoming deputy chair in 1988. In 1991, as a senior physicist, he served as the head of the PHENIX detector project during the construction of RHIC, a challenge he completed before he became chair of physics in 2001. He was appointed as Brookhaven's associate laboratory director for high-energy and nuclear physics in 2005.

## DESY

# Horst Köhler visits FLASH laser

The German federal president Horst Köhler visited DESY on 23 August, one highlight being a tour of the Free-electron LASER in Hamburg (FLASH) facility (p8). The 260 m long facility is currently in operation and so could be presented "live" to the president. On his walk through the FLASH tunnel, Köhler took a close look at the superconducting technology used to accelerate the electrons and the sophisticated magnet sections in which the laser flashes are generated.

FLASH is currently the only free-electron laser (FEL) facility to produce radiation in the soft X-ray range. It therefore has an important pioneering role for future FEL facilities that will generate laser flashes of even shorter wavelengths. Among these will be the 3.4 km European X-ray free-electron laser (XFEL), which is being prepared at DESY with international co-operation, and which should begin operation in 2013. During his visit, Köhler heard of two recent important milestones for the European XFEL: the approval statement for the construction and



From left: Ole von Beust, first mayor of Hamburg; Horst Köhler, federal president; Albrecht Wagner, DESY directorate chair; Rolf-Dieter Heuer, DESY director in charge of high-energy physics and astroparticle physics; Jürgen Mlynek, president of the Helmholtz Association.

operation of the facility, and the *Technical Design Report*, containing all the basic

information on the technical design of the XFEL and its research potential.

AWARDS

# FEL Prize 2006 goes to Rossbach and Saldin

Jörg Rossbach of the University of Hamburg and Evgueni Saldin of DESY have won the FEL Prize 2006. The prize has been awarded since 1988 to recognize outstanding contributions to free-electron laser (FEL) science and technology.

Saldin is one of the two inventors of self-amplified spontaneous emission (SASE), which is used to generate laser-like FEL pulses, such as at the FLASH facility at DESY. He moved to DESY about 10 years ago and in 2001 joined the DESY accelerator group to which Rossbach also belonged. Both Saldin and Rossbach helped DESY to establish the record for the shortest FEL wavelength (100 nm) in February 2000, and to push this record towards shorter wavelengths ever since. In April 2006, FLASH generated radiation at a wavelength of only 13.1 nm (CERN Courier June 2006 p7).



Left to right: Jörg Rossbach and Evgueni Saldin receive the FEL Prize 2006 from the chair of the prize committee, Lex van der Meer of FOM Rijnhuizen. (Courtesy BESSY, Berlin.)

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## OUTREACH

## Hungarian teachers arrive at CERN...



This summer, 38 Hungarian teachers took part in CERN's new-look programme for secondary-school teachers. Held on 20–26 August, this was the first session of the new short programme that was introduced this year, which is held in the participants' mother tongue – in this case, Hungarian.

For a week, the teachers alternated between physics lessons, experiments, visits to the laboratory and local outings, all of which took place in a relaxed and friendly atmosphere. By holding 6–8 sessions of this kind a year, it should be possible to reach more teachers.

## ...and China's top students pay a visit



Twenty of China's best physics PhD students visited CERN this summer during a three-week tour of major laboratories in Germany and Switzerland, including DESY and the Max Planck Institute, as a reward for winning the "E = mc<sup>2</sup> to modern science" Einstein Award, co-sponsored by the German and Swiss Embassies to celebrate the Year of Physics in 2005. For many years, Germany, Switzerland and China have been involved in various areas of scientific research and co-operation.

China's Ministry of Education and the Chinese Academy of Sciences selected the students from various regions of China, including Beijing, Shanghai and central China.

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OBITUARY

# Ed Watson 1940–2006

Ed Watson passed away suddenly on 1 August 2006 in Geneva. He leaves his wife and two children. Ed arrived at CERN in March 1973 to work on digital electronics and CAMAC systems under Bob Dobinson, after many years at Rolls-Royce in Scotland. He joined the European Muon Collaboration (EMC) in 1976, where he played a major role in the design, deployment and running of its data-acquisition system (DAQ) with David Botterill, Bob Dobinson and Vicky White. The CAMAC-ROMULUS system was by far the largest and most advanced of its time and became a defining standard for DAQ systems for years to come.

Ed was deeply involved in the detailed planning of the control rooms and the experiment cabling, as well as sharing responsibility for the CAMAC readout system. He had a talent for troubleshooting and played a vital part in supporting the experiment throughout its lifetime. Colleagues, often baffled by some obscure DAQ problem, would watch as Ed, with the aid of a rapidly written CATY program, would identify and fix the problem and then explain it in a burst of terse, to-the-point northern English. He offered great moral support to the younger members of the collaboration and helped them a great deal with their work. The EMC had a wonderful social life to which Ed was a major contributor and organizer – who



can forget the barbecues?

Many will also remember Vox, Coco and Anis, Ed's large and loveable Old English sheepdogs, who would accompany their master everywhere that he went.

In 1987, Ed joined the CPLEAR experiment. He once again played an important role in getting the experiment running and maintaining it until its completion. He worked in particular on the design of custom high-speed digital electronics for the trigger/DAQ system. He took early retirement in January 2003.

For many generations of students and postdocs, Ed will also be fondly remembered on skis, or on the end of a climbing rope. In the mountains too, he was a great teacher. In expressions of sympathy from all over the world, people have recalled the help and encouragement that he gave them and the excitement of the mountains that he instilled in them. In 1988, Ed began a long involvement with handicapped competition skiing, giving freely of his time to assist and train members of the British team for European, World and Paralympic Championships. In particular, he became coach and trainer for one of his colleagues, Chris Bee, who was in the team. Ed's sporting interests also included sailing, being an enthusiastic and active member of the CERN Yachting Club in the 1980s and 1990s.

Ed Watson was a generous, larger-than-life character who was always ready to help and advise people. He was a great friend, teacher and mentor for many, and will be sorely missed. RIP "Captain".

*His friends and colleagues.*

MEETINGS

The **IEEE/NPSS Real Time Conference 2007** will be at the Fermi National Accelerator Laboratory on 29 April – 4 May 2007. This interdisciplinary conference is on the latest real-time computing applications in plasma physics, nuclear physics, particle physics, astrophysics, space science, accelerators, medicine and biology. See

<http://computing.fnal.gov/cd/rt07/> or contact Cynthia M Sazama (e-mail: [sazama@fnal.gov](mailto:sazama@fnal.gov); fax: +1 630 840 8589).

The **5th Flavour Physics and CP Violation Conference** will take place in Bled, Slovenia on 12–16 May 2007. The conference will cover topics including Cabibbo–Kobayashi–

Maskawa matrix elements, semileptonic B decays, charm and charmonium spectroscopy, and rare B, charm and K decays. The aim is to encourage the exchange of new ideas, present the latest experimental and theoretical results, and discuss future projects in the field. For more details see [www-f9.ijs.si/fpcp07/](http://www-f9.ijs.si/fpcp07/) or e-mail [FPCP2007@ijs.si](mailto:FPCP2007@ijs.si).

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### RESEARCH POSITIONS - LIGO LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY (CALTECH) MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT)

The Laser Interferometer Gravitational-Wave Observatory (LIGO) has as its goal the development of gravitational wave astronomy. The LIGO Laboratory is managed by Caltech and MIT, and is sponsored by the National Science Foundation. It has built and now operates facilities equipped with laser interferometric detectors at Hanford, Washington and Livingston, Louisiana. The detectors have reached design sensitivity and a broad observational program is underway, with extensive participation by the LIGO Scientific Collaboration (LSC). Running will be interleaved with incremental improvement of the instruments over the coming years. In addition, a vigorous R&D program supports the development of future detectors.

The LIGO Laboratory expects to have positions at Caltech, MIT and at the two observatory sites. Scientists will be involved in the operation of LIGO itself, analysis of data, both for diagnostic purposes and astrophysics searches, as well as the R&D program for future detector improvements. Expertise related to astrophysics, modeling, data analysis, electronics, laser optics, vibration isolation and control systems is useful. Most importantly, candidates should be broadly trained physicists, willing to learn new experimental and analytical techniques, and ready to share in the excitement of pioneering the new field of gravitational wave astrophysics. In general, appointments will be at the post-doctoral level with one-year initial

appointments with the possibility of renewal for up to two subsequent years. In some cases, appointments with an initial term of three years or of an indefinite term may be considered. Appointment is contingent upon completion of all requirements for a Ph.D.

Applications for positions at any LIGO Laboratory site (Caltech, MIT, Hanford, or Livingston) should be sent to either:

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Dr. David Shoemaker  
MIT  
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Applications should include curriculum vitae, list of publications and the names, addresses, email addresses and telephone numbers of three or more references. Applicants should request that three or more letters of recommendations be sent directly to Dr. Marx or Dr. Shoemaker. Consideration of applications will begin December 1, 2006 and will continue until all positions have been filled. Electronic Portable Document Format (PDF) submittals are preferred. Email to: [HR@ligo.caltech.edu](mailto:HR@ligo.caltech.edu)

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Applicants have to satisfy the legal requirements for appointments of professors in accordance with §100 Berliner Hochschulgesetz - BerHfG.

The Humboldt-University aims at increasing the fraction of female staff and encourages women to apply. Equally qualified but disabled candidates will be appointed preferentially.

Applications including the usual professional documentation and referring to code number **PR/011/06** should be sent **within 6 weeks to Humboldt-Universität zu Berlin, Dekan der Mathematisch-Naturwissenschaftlichen Fakultät I, Prof. Dr. C. Limberg, Newtonstrasse 15, D-12489 Berlin, Germany**. For speeding up the procedure, it is strongly recommended that applicants provide their application material also in electronic form (<https://www.physik.hu-berlin.de/ssl/CallEEP2>).



### Director, Particle Astrophysics Center, Fermi National Accelerator Laboratory And Professor of Astronomy and Astrophysics, University of Chicago

Fermi National Accelerator Laboratory and The University of Chicago invite applications for a joint appointment as Director of the Particle Astrophysics Center at Fermilab and Professor of Astronomy and Astrophysics at The University of Chicago.

Applicants are expected to have an outstanding record of leadership and scientific accomplishment. The Director of the Particle Astrophysics Center will provide the leadership and vision to shape the Fermilab particle-astrophysics program, which now includes groups involved in theoretical astrophysics, the Sloan Digital Sky Survey, the Cryogenic Dark Matter Search, the Pierre Auger Experiment, and the Supernova Acceleration Probe. The appointment of Professor of Astronomy and Astrophysics will involve both research and teaching.

Applications received before November 15, 2006 will receive full consideration.

Applications, including a curriculum vita, a list of publications, and suggestions for outside references should be sent to:

Joint Search Committee  
Particle Astrophysics Center  
MS 209  
Fermi National Accelerator Laboratory  
P.O. Box 500  
Batavia, IL 60510-0500



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### Junior Faculty Appointment in Theoretical Physics Harvard University Faculty of Arts and Sciences

Applications are invited for faculty appointments in theoretical high energy physics, broadly defined, at Harvard University. The initial appointment as an assistant professor for the academic year 2006-2007 would normally be for a term of five years, with promotion (to untenured associate professor and subsequently to tenured professor) possible for outstanding candidates. Applications should be sent by November 1, 2006 to:

**Theoretical Search Committee, c/o Ms. B. Currier, Department of Physics  
Harvard University, Jefferson Physical Laboratory, Room 370, 17 Oxford St.  
Cambridge, MA 02138**

Applications should include a curriculum vitae, a publication list, and a brief research statement. Candidates should ask three referees to send professional evaluations.

*Harvard University is an Equal Opportunity/Affirmative Action employer.  
Applications from women and minority candidates are especially encouraged.*

## National Synchrotron Light Source-II

National Synchrotron Light Source-II (NSLS-II) will be a new, ultra-low emittance synchrotron that will deliver ultra-high brightness and flux and exceptional beam stability. With its advanced insertion devices, optics, detectors and scientific instruments, NSLS-II will facilitate forefront research in the material, chemical, environmental, biological, medical, and physical sciences. Brookhaven National Laboratory invites applications from physicists and engineers with expertise in the areas of accelerators, beamlines, and instrumentation for NSLS-II.

Successful candidates will have an advanced degree in Physics or Engineering and substantial experience in their field. Experience in the research and development, design and construction, or operation of accelerators, beamlines, or instrumentation is required. Areas of special interest include, but are not limited to: determining and designing the optimum configuration of the lattice to maximize the machine performance for high brightness; determining methods to meet the dynamic aperture challenge by maximizing the stable phase space area of the electron beam; developing schemes to produce short x-ray pulses; developing ways to improve injection efficiency, beam stability, and lifetime; designing and commissioning state-of-the-art beamlines and optics to provide high-energy and high-spatial resolution; generating and developing user populations and scientific research programs for the beamlines.

Qualified and interested applicants may submit their resumes to [jhall@bnl.gov](mailto:jhall@bnl.gov). For further information about BNL, NSLS-II or other job openings, please visit [www.bnl.gov](http://www.bnl.gov) or [www.bnl.gov/nsls2/](http://www.bnl.gov/nsls2/).

BNL, a multiprogram research facility managed by Brookhaven Science Associates for the U.S. Department of Energy, is an equal opportunity employer committed to building and maintaining a diverse work force.



[www.bnl.gov](http://www.bnl.gov)



## TWO FACULTY POSITIONS IN EXPERIMENTAL NUCLEAR PHYSICS

The Department of Physics and Astronomy at the University of Kentucky invites applications from well qualified candidates for two tenure-track Assistant Professorships in our experimental nuclear physics group. The candidates must have a Ph.D. in physics and postdoctoral research experience. The nuclear physics program at UK focuses on the detailed understanding of the structure, interactions, and symmetries of hadrons in terms of their fundamental constituents. Our group has leadership roles in the polarized 3He program in Hall A at Jefferson Lab and in the LANL neutron EDM experiment which is expected to run at the newly established SNS (ORNL). Interested candidates should have experience in electromagnetic nuclear physics or in fundamental symmetry tests at low energies. The successful candidates are expected to strengthen our efforts in existing programs and to establish their own research careers, as well as contribute to the Department's undergraduate and graduate teaching missions.

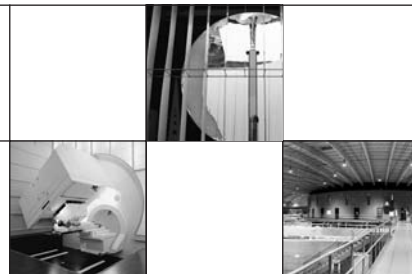
Details about our department can be found at <http://www.pa.uky.edu>. Applicants should submit a curriculum vitae, a brief statement of present and future research plans, a publications list, and arrange for three letters of recommendation to be sent to

**Prof. W. Korsch, Department of Physics and Astronomy, University of Kentucky, 177 Chem.-Phys. Bldg., Lexington, KY 40506-0055.**

Initial consideration of applications will begin December 1, 2006 with an anticipated starting date of August, 2007.

*The University of Kentucky is an equal opportunity employer and strongly encourages applications from women and minorities.*

PAUL SCHERRER INSTITUT



The Paul Scherrer Institut is a centre for multi-disciplinary research and one of the world's leading user laboratories. With about 1200 employees it belongs as an autonomous institution to the Swiss ETH domain and concentrates its activities on solid-state research and materials sciences, elementary particle physics, energy and environmental research as well as biology and medicine.

PSI is developing and operating proton and electron accelerators for fundamental and applied research. A proton accelerator with the highest average power worldwide is the driver for the spallation neutron source SINQ and the generation of pions and muons for structural analysis. An upgrade program is under way for an increase of the proton current from 2 to 3 mA and correspondingly the beam power from 1.2 to 1.8 MW.

The electron storage ring of the Swiss Light Source (SLS) is used to generate highly brilliant and coherent light from the UV to the X-ray range. It is considered as the technically most advanced light source with exceptional intensity and position stability generated by top-up injection. An upgrade is currently in completion for the generation of femtosecond X-ray pulses.

A Free Electron Laser is in development to extend the capabilities of the SLS. Its fully coherent, short pulse (femtosecond) radiation with orders of magnitude higher power and brightness will make this facility an extremely valuable light source for scientific research. It is based on a novel concept of an electron gun using field emission from nano-structured tip arrays.

The Paul Scherrer Institut is sponsoring a

## PSI Postdoctoral Fellowship for Excellence in Accelerator Science and Technology

This special postdoctoral fellowship is open to an outstanding doctoral physicist or engineer who is at the starting point of a promising career. The fellowship will be awarded in the areas of accelerator physics and technology, beam diagnostics and advanced computational beam simulations. The successful candidate will be a recent graduate with a PhD or equivalent education. The fellowship consists of a two year contract with a competitive post-doctoral salary and additional benefits.

For further information please contact Prof. Dr. Leonid Rivkin, Head of the Department Large Research Facilities, ph. +41 56 310 3214, e-mail [leonid.rivkin@psi.ch](mailto:leonid.rivkin@psi.ch),

Candidates should submit their application with a description of their accomplishments and two letters of recommendation before October 31, 2006, to: Paul Scherrer Institut, Human Resources, Mr. Thomas Erb, ref. code 8000, 5232 Villigen PSI, Switzerland.

Also for the new project of a Free Electron Laser (FEL) at PSI we are looking for a

## Physicist (Postdoc or Junior scientist)

to strengthen the team which is developing an advanced concept for the FEL and, in particular, to contribute to the evaluation and optimization of the FEL performance.

The work will involve the design of a low-emittance accelerator concept, Start-to-End simulations and performance analysis of the low-emittance linac concept and the expected FEL performance, verification that the machine design is technically realistic both in terms of construction and operation, design of correction and feedback concepts and design of diagnostic stations.

The profile of a successful candidate will include a good background in electromagnetism, preferably experience in both theoretical AND experimental accelerator physics and knowledge of Unix and scripting languages as well as programming experience in FORTRAN and/or C++.

For further information please contact Dr. Rene Bakker, ph.+41 56 310 5101, e-mail: [rene.bakker@psi.ch](mailto:rene.bakker@psi.ch).

Please send your application to: Paul Scherrer Institut, Human Resources, Mr. Thomas Erb, ref. code 0600, 5232 Villigen PSI, Switzerland.

## Assistant Professor(s), Experimental and Theoretical Particle Physics

The Department of Physics, University of Alberta ([www.phys.ualberta.ca](http://www.phys.ualberta.ca)) invites applications for two tenure-track faculty positions. One position will be in experimental particle physics, as part of our plan to expand into the areas of direct detection of dark matter, searches for neutrinoless double beta decay, and measurements of neutrino oscillations and properties, by exploiting the new Sudbury Neutrino Observatory Laboratory (SNOLAB). The second position will be in theoretical particle physics. We primarily seek candidates at the Assistant Professor level, but exceptional candidates at a more senior level will be considered. The start date for these positions is July 1, 2007.

Applicants must possess a Ph.D., have outstanding promise in research and be committed to teaching. The successful candidates will be expected to build a strong research program, supervise graduate students and teach at the undergraduate and graduate levels.

The Department of Physics has approximately 35 faculty and 115 graduate students. Our particle physics group includes members with research interests in collider physics, particle and nuclear

astrophysics, and the standard model and we plan to expand in both experimental and theoretical particle physics. The Department has excellent electronics, machine shop and computational facilities and staff, as well as access to high performance computational infrastructure (see [www.westgrid.ca](http://www.westgrid.ca)).

Initiatives by the Governments of Alberta and Canada provide exceptional opportunities for additional funding to establish new research programs at the University of Alberta. See, for example, [www.albertaingenuity.ca](http://www.albertaingenuity.ca), [www.gov.ab.ca/sra](http://www.gov.ab.ca/sra), [www.icore.ca](http://www.icore.ca), and [www.innovation.ca](http://www.innovation.ca) for further information.

The application should include a curriculum vitae, a research plan, and a description of teaching experience and interests. The applicant must also arrange to have at least three confidential letters of reference sent to the relevant selection committee. For details about the positions and application procedures please see: [www.careers.ualberta.ca/opportunities](http://www.careers.ualberta.ca/opportunities) or [www.phys.ualberta.ca/jobs/](http://www.phys.ualberta.ca/jobs/) or contact the Department of Physics by e-mail at [dept@phys.ualberta.ca](mailto:dept@phys.ualberta.ca).

All qualified candidates are encouraged to apply; however, Canadians and permanent residents will be given priority. If suitable Canadian citizens and permanent residents cannot be found, other individuals will be considered. The University of Alberta hires on the basis of merit. We are committed to the principle of equity in employment. We welcome diversity and encourage applications from all qualified women and men, including persons with disabilities, members of visible minorities, and Aboriginal persons.

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E-mail: [kathryn.zerboni@iop.org](mailto:kathryn.zerboni@iop.org)

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## WILSON FELLOWSHIP IN EXPERIMENTAL PHYSICS

The Wilson Fellowship program at Fermilab seeks applications from Ph.D. physicists of exceptional talent with at least two years of post-doctoral work. The fellowships are awarded on a competitive basis and support physicists early in their careers by providing unique opportunities for self-directed research in experimental physics. Fellows will work on the Fermilab particle physics experiment of their choice. The Fermilab experimental program includes collider physics at both the Tevatron and LHC, studies of neutrino and astroparticle physics, as well as R&D for future colliders and high intensity beams.

The Wilson Fellowships are tenure track positions with an annual salary fully competitive with university assistant professorships. The appointment is for an initial term of three years and can be renewed for an additional two years upon the completion of a successful review after the first two years.

Each candidate should submit a research statement describing a proposed research program, a curriculum vitae, and should arrange to have four letters of reference sent to the address below. Application materials and letters of reference should be received by November 3, 2006.

Materials, letters and requests for information should be sent to:

**Wilson Fellows Committee**  
Fermi National Accelerator Laboratory  
MS122, Attention: Cathryn Laue  
P.O. Box 500, Batavia, IL 60510-0500  
Email: [wilson\\_fellowship@fnal.gov](mailto:wilson_fellowship@fnal.gov)

Additional information is available at:  
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UPPSALA  
UNIVERSITET

### Assistant Professor/Research Associate in Experimental Elementary Particle Physics with ATLAS at LHC

The High Energy Physics Collider Group of the Department of Nuclear and Particle Physics at Uppsala University in Sweden is involved in the ATLAS project at CERN's Large Hadron Collider (LHC). The Group has provided 300 of the 2000 SemiConductor Tracker (SCT) modules of the ATLAS central tracking system and is responsible for the build-up and operation of the SCT Detector Control System. The Group is currently pursuing an extensive program of physics simulation studies of the potential to discover the charged Higgs boson with ATLAS. For further information about the Group see <http://www4.tsl.uu.se/~Atlas/index.html> and about the Department <http://www.isv.uu.se>.

The Research Associate position can be held for a maximum of 4 years. The task of the appointee is to perform physics analysis of ATLAS data, which includes supervision of students at postgraduate level, and to participate in the operation of the ATLAS detector. The opportunity to teach at undergraduate and postgraduate level will be given. The candidate must have a PhD. Priority will be given to applicants who have completed their PhD within 5 years of the application deadline. The candidate should have the necessary skills and qualifications to teach physics undergraduate courses in Swedish or English. In the selection among the qualified applicants particular importance will be attached to scientific excellence in Elementary Particle Physics. Applicants with a successful record in simulation studies and data analysis of collider-based particle physics experiments will be given first priority.

The salary level is 27 000 SEK/month and upwards depending on qualifications.

A complete version of this advertisement is available at  
<http://www.personalavd.uu.se/ledigaplats/engindex.html>

The application must be written in English and be addressed to the Vice-Chancellor of Uppsala University and have reached the University Registrar, UFV-PA 2006/2060, Box 256, SE-75105 Uppsala, Sweden, fax +46 18 471 2000 by latest 2006-10-31. A fax should be followed by a signed original of the application sent within a week of the deadline. The applicant is required to submit two copies of documents and one copy of publications according to instructions found on the web site <http://www.teknat.uu.se/english/instructions.php>

For further information about the position, please contact Prof. Tord Ekelof, phone +46 18 471 3847, e-mail [Tord.Ekelof@tsl.uu.se](mailto:Tord.Ekelof@tsl.uu.se)



## THE UNIVERSITY OF CHICAGO ENRICO FERMI INSTITUTE ENRICO FERMI POSTDOCTORAL RESEARCH FELLOWSHIP AND THE ROBERT R. MCCORMICK POSTDOCTORAL RESEARCH FELLOWSHIP

### HEAD OF ELECTRONICS DEVELOPMENT GROUP

The Enrico Fermi Institute of the University of Chicago is searching for a Head of our Electronics Development Group (EDG). This group, which in addition to the Head includes two electronics engineers and support personnel, has a long history of designing innovative electronics for elementary particle physics and astrophysics experiments. Some recent projects include the front-end electronics for the ATLAS hadron calorimeter, the CDF silicon vertex trigger, and electronics for the QUIET cosmic microwave background experiment. Each of these projects employed high-speed digital and analog electronics.

The successful candidate should have extensive experience in project-level electronics design for high energy physics and/or particle astrophysics. The Head of the EDG plays a central role in developing creative strategies for systems, in addition to developing electronics designs that will meet the needs of experiments. Most projects are designed and built by a close collaboration of engineers and physicists, so the electronics group leader must be able to manage the group's professional staff as well as work effectively with physicists and graduate students. The use of EDA tools is an important part of our design process.

A bachelors' degree in electronics engineering is the minimum requirement but a Masters or Ph.D. is preferred.

Candidates should apply on-line at: <https://jobopportunities.uchicago.edu> where you will be asked to set up an academic profile. The requisition number for this posting is: 073799. They will be asked to supply the following documents:

- Your Curriculum Vitae
- Your bibliography of publications

Material provided on-line need not be sent to the Fermi Institute.

In addition, candidates should ensure that three letters of recommendation are sent to:

**EDG Search Committee**  
The University of Chicago  
Enrico Fermi Institute  
5640 South Ellis Ave, RI-183  
Chicago, IL 60637

Applicants who submit their materials by October 30, 2006 will be given priority consideration. Review of applications will begin at that time. The position will remain open until filled.

*The University of Chicago is an Affirmative Action/Equal Opportunity Employer.*



## Harvard University ATLAS Postdoctoral Position

The Laboratory for Particle Physics and Cosmology (LPPC) at Harvard University has two openings for Postdoctoral Research Fellows with our DoE funded ATLAS group. Candidates interested in working on the CDF experiment during the early stage of their appointment will also be considered. The successful candidates will be expected to work on physics analysis topics, software development and detector commissioning. The Harvard ATLAS group has participated in the design, construction and commissioning of the precision muon chambers, and we plan to continue this work through commissioning of the detector. At CDF, we are interested in top physics and searches for the Higgs boson, and are also involved in the operations of the silicon detector and central drift chamber. For any questions regarding these openings please contact either Prof. Joao Guimaraes <[guimaraes@physics.harvard.edu](mailto:guimaraes@physics.harvard.edu)> or Prof. Masahiro Morii <[morii@physics.harvard.edu](mailto:morii@physics.harvard.edu)>.

For these positions experience with state-of-the-art detector systems and with particle physics analysis software are required. Interested applicants should send their CV, a statement of interest, and three (3) letters of reference sent to:

**Dr. George W. Brandenburg** <[brandenburg@physics.harvard.edu](mailto:brandenburg@physics.harvard.edu)>, Director, Harvard University LPPC, 18 Hammond Street, Cambridge, MA 02138 (PDF files preferred).

*Harvard is an equal opportunity, affirmative action employer.*

invite applications for the joint position of a

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GSI Darmstadt and the University of Mainz provide a broad spectrum of research opportunities in the field of the heaviest elements. We are seeking an outstanding individual who will focus on the synthesis, nuclear structure, and atomic physics of the heaviest elements.

He/she will lead a research team at GSI and is expected to participate in the scientific program of GSI in close collaborations with the University of Mainz and other German and foreign research institutions. He/she will represent his/her area in teaching at the University of Mainz.

After the appointment to Professor at the University of Mainz, the successful candidate will be granted a leave of absence to GSI.

The advancement of women in the scientific field is an integral part of the university's and GSI's policy. Women, therefore, are especially encouraged to apply. Persons with disabilities will be given preference over other applicants with comparable qualifications.

Applications including the curriculum vitae, the list of publications, and research experience and teaching records should be sent until **November 15, 2006**, to:

**Johannes Gutenberg-Universität Mainz, Dekanat des Fachbereichs 09,  
55099 Mainz, GERMANY**

and a copy to

**Prof. Dr. Karlheinz Langanke  
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These postdoctoral research fellowships are intended to attract outstanding young scientists to the University of Chicago at an early stage in their career. We expect to award two fellowships each year from a pool of international candidates. To date, there have been 93 such fellows, many of whom have gone on to careers as influential scientists.

The initial appointment is for one year, renewable annually, for up to three years. The appointment carries a salary of \$54,000 per annum with an additional allocation of up to \$6,000 for independent research support. Appointees are given the freedom of either working independently or associating with EFI faculty in a research area of common interest. Appointment would be at the University internal rank of Research Associate (Instructor). There are no teaching responsibilities with this position.

The Enrico Fermi Institute is an interdisciplinary research unit within the Division of Physical Sciences of the University of Chicago. The Institute's activities include the following: string theory and theoretical high energy physics, experimental high energy physics, theoretical astrophysics and cosmology, experimental astrophysics and space physics, infrared and optical astronomy, cosmic microwave background observations, general relativity, cosmochemistry, scanning electron & ion microscopy, secondary ion mass spectrometry.

One application is sufficient to be considered for both research fellowships.

Applying for the Enrico Fermi and/or the Robert R. McCormick Postdoctoral Research Fellowship at the rank of Research Associate (Instructor):

Candidates should apply on line at <https://jobopportunities.uchicago.edu>, using requisition number: 074051

They will be asked to supply the following documents:

- Curriculum Vitae
- Bibliography of publications and preprints
- Description of research interests to be pursued at the University

*Material provided on-line need not be sent to the Fermi Institute*

In addition, candidates should ensure that three letters of recommendation are sent to: **Enrico Fermi Institute, Office of the Director, 5640 S. Ellis Avenue, RI-183, Chicago, Illinois 60637** or by fax to (773) 702-8038. Letters should be from faculty members or senior research scientists who are active in the field of study in question. Applicants who submit their materials by November 10th will be given priority consideration. Review of applications will begin at that time and candidates will be notified of the results by late December.

Contact Nanci Carrothers at: [n-carrothers@uchicago.edu](mailto:n-carrothers@uchicago.edu) in case of questions.

*The University of Chicago is an Affirmative Action/Equal Opportunity Employer. It also participates in the Exchange Visitor Program and will facilitate the granting of visas to foreign applicants.*

## Associate Laboratory Director for Nuclear and Particle Physics

Brookhaven National Laboratory (BNL) is seeking candidates for the position of Associate Laboratory Director of its Nuclear and Particle Physics Directorate (NPP). This Directorate is one of five science Directorates at the Laboratory and contains both major research programs and accelerator and facility operations. The annual budget of the Directorate is about \$180 M with a staff of over 600.

The Associate Laboratory Director (ALD) is responsible for the scientific and managerial leadership of the Directorate. He/she reports to the Laboratory Director. The successful candidate must have a Ph.D. degree and a distinguished research career in the physics accompanied by proven experience in the management of a mid-sized research effort. BNL is interested in candidates who will develop internationally leading programs that are aligned with the mission of the Department of Energy, and who will maintain and enhance a world-class scientific and technical staff. The ALD is the primary contact with BNL's programs and facility sponsors, principally the U.S. Department of Energy.

The ALD participates at the Director's level in the Laboratory-wide planning for new programs and user facilities and has line responsibility for safe and environmentally sound operation of his/her program. Recent areas of scientific focus include relativistic heavy ion physics, spin physics, high energy physics at the LHC (ATLAS), neutrino physics together with operation of the RHIC complex, the Superconducting Magnet Division and the Instrumentation Division. New directions in expanding the range of QCD studies are envisioned.

BNL is a multi-disciplinary laboratory engaged in a broad scope of world-class basic and applied research in a highly stimulating and competitive science environment. It is managed by Brookhaven Science Associates under contract with the U.S. Department of Energy. Applications should be sent electronically to [hempfling@bnl.gov](mailto:hempfling@bnl.gov), or by regular mail to **Bill Hempfling, Human Resources Division, Brookhaven National Laboratory, Bldg. 185, PO Box 5000, Upton, LI, NY 11973-5000**.

BNL welcomes diversity and encourages applications from all qualified individuals.



[www.bnl.gov](http://www.bnl.gov)

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Institute of Physics PUBLISHING



Jefferson Science Associates, LLC

Thomas Jefferson National Accelerator Facility

## SRF Accelerator Physicist (Structures & Simulations) And SRF Post Doc (2 positions)

Thomas Jefferson National Accelerator Facility (Jefferson Lab), located in Newport News, VA, USA, is a world-class scientific laboratory centered around a high-intensity, continuous wave electron beam, which provides a unique capability for nuclear physics research. The lab also has a pioneering FEL program and is active in ILC and other projects. The lab is managed for the Department of Energy by Jefferson Sciences Associates.

Jefferson Lab is currently seeking exceptional candidates for an **SRF accelerator physicist position (Salary Range: \$62,100 - \$123,000)** to provide simulations and measurement support to all ongoing SRF institute activities, which may include operational support of CEBAF and the FEL, cavity and cryomodule R&D, ILC support and production or new projects. The incumbent will provide a broad range of numerical simulation support for the development of new/improved SRF accelerating structures and components and perform general analysis and problem solving in support of various projects and programs. Minimum qualifications: PhD in Physics, preferably with specialization in RF simulation and measurements plus 5 years post PhD experience applying training in a laboratory environment. Direct experience designing, simulating, and testing cavities and components for accelerator applications and experience with characterization of RF structures via both bench measurements and state-of-the-art simulation software required. Candidate should be expert in the use and interpretation of 3D frequency domain and time domain RF simulation codes such as MAFIA, Microwave Studio, HFSS, etc. Experience with Finite Element Analysis or multi-physics tools, particularly ANSYS, is highly desirable.

In addition, the Lab seeks exceptional candidates for two **Post Doc positions (Salary Range: \$44,200 - \$66,400)** in the SRF Institute in the areas of Structures & Simulations or materials and processes to provide support to ongoing SRF institute activities including operational support of CEBAF and the JLab FEL, cavity and cryomodule R&D and production, ILC or new projects. Minimum qualifications: PhD in Physics or Engineering, preferably with an element of RF simulation or measurements, SRF materials or processing. Some experience in or familiarity with the simulation and RF measurement of accelerating structures and components for accelerators using codes such as MAFIA, Microwave Studio, HFSS, etc. and measuring instruments such as network analyzers desired.

For prompt consideration, reference position AR0826, AT0827 and AT829, respectively, and apply on-line at: [www.jlab.org/jobline](http://www.jlab.org/jobline)

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Die Bereitschaft zur Zusammenarbeit mit den theoretischen und experimentellen Arbeitsgruppen (IceCube, Magic, ATLAS, LHCb, BaBar) vor Ort im Bereich der Teilchenphysik und Astroteilchenphysik wird erwartet. Eine Mitarbeit am interdisziplinären Forschungsband „Modellbildung und Simulation“ ist wünschenswert.

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Bewerbungen mit Lebenslauf, wissenschaftlichem Werdegang, Schriftenverzeichnis und Angaben über die bisherige Lehrtätigkeit sind bis zum 10.11.2006 zu richten an den **Dekan des Fachbereichs Physik der Universität Dortmund, D-44221 Dortmund (Deutschland).**

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# BOOKSHELF

## Books received

### **Philosophy of Science: A New Perspective**

by Afsar Abbas, Indian Institute of Advanced Study. Hardback ISBN 8179860604, Rs150.

This “new perspective” discusses the philosophical issues inherent within the research pursued by scientists at the forefront today. Examples from modern science, in particular the current hot topics in physics, have been provided to clarify the issues under discussion. The book is written so as to be accessible even to non-experts, but experts will find much that is new in the philosophy of science presented here. Detailed treatment of mathematics and space, along with time and matter, have also been provided.

### **Representing Electrons: A Biographical Approach to Theoretical Entities**

by Theodore Arabatzis, The University of Chicago Press. Hardback ISBN 0226024202, £44.50 (\$70). Paperback ISBN 0226024210, £18 (\$28).

Both a history and a metahistory, this book focuses on the development of various theoretical representations of electrons from the late 1890s until 1925, and the methodological problems associated with writing about unobservable scientific entities. Here, the electron – or rather its representation – is used as a historical actor in a novel biographical approach. Arabatzis illustrates the emergence and gradual consolidation of its representation in physics, its career throughout old quantum theory, and its appropriation and reinterpretation by chemists. Furthermore, he argues that the considerable variance in the representation of the electron does not undermine its stable identity or existence. The book should appeal to historians, philosophers of science and scientists alike.

### **Particle Physics and Cosmology: The Quest for Physics Beyond the Standard Model(s) (TASI 2002)**

edited by Howard E Haber and Ann E Nelson, World Scientific. Hardback ISBN 9812388923, £105 (\$172).

This book features three lecture-series courses given at the School of the Theoretical Advanced Study Institute (TASI) on Elementary Particle Physics in 2002. The phenomenology lectures cover a broad spectrum of the research techniques used to interpret present day and future collider data.

The TeV-scale physics lectures focus on modern speculations about physics beyond the Standard Model, with an emphasis on supersymmetry and extra-dimensional theories. The series on astroparticle physics looks at recent developments in theories of dark matter and dark energy, the cosmic microwave background, and prospects for the upcoming era of gravitational wave astronomy. Researchers and graduate students in high-energy physics, mathematical physics and astrophysics will find topics of interest.

### **Classical and Dissipative Quantum**

**Systems** by Mohsen Razavy, Imperial College Press. Hardback ISBN 1860945252, £51 (\$84). Paperback ISBN 1860945309, £29 (\$48).

The aim of this book is to elucidate the origin and nature of dissipative forces and to present a detailed account of attempts to study dissipative phenomena in both classical mechanics and quantum theory. It begins with an introductory review of phenomenological damping forces, and the construction of the Lagrangian and Hamiltonian for the damped motion, and moves on to investigate the use of the classical formulation in the quantization of dynamical systems, and finally the problem of dissipation in interacting quantum mechanical systems. A number of important applications, such as the theory of heavy-ion scattering and the motion of a radiating electron, are also discussed.

### **Statistical Mechanics: Entropy, Order Parameters, and Complexity**

by James P Sethna, Oxford University Press. Hardback ISBN 019856676X, £49.95 (\$99.50). Paperback ISBN 0198566778, £24.95 (\$44.50).

In each generation, scientists must redefine their fields: abstracting, simplifying and distilling the previous standard topics to make room for new advances and methods. This book takes this step for statistical mechanics – a field rooted in physics and chemistry whose ideas and methods are now central to information theory, complexity and modern biology. Aimed at advanced undergraduates and early graduate students in all of these fields, Sethna limits his main presentation to the topics that future mathematicians and biologists, as well as physicists and chemists, will find fascinating

and central to their work. The large supply of carefully crafted exercises, each an introduction to a whole field of study, covers everything from chaos through information theory to life at the end of the universe.

### **Quantum Mechanics in Phase Space: An Overview with Selected Papers**

edited by Cosmas K Zachos, David B Fairlie and Thomas L Curtright, World Scientific. Hardback ISBN 9812383840, £64 (\$86).

Wigner’s quasi-probability distribution function in phase space is a special (Weyl) representation of the density matrix. It has been useful in describing quantum transport in quantum optics; nuclear physics; decoherence, quantum computing and quantum chaos. It is also important in signal processing and the mathematics of algebraic deformation. A remarkable aspect of its internal logic, pioneered by Groenewold and Moyal, has emerged in the last quarter-century, furnishing a third, alternative, formulation of quantum mechanics, independent of the conventional Hilbert space or path integral formulations. This book is a collection of the seminal papers on this formulation, with an introductory overview, an extensive bibliography, and simple illustrations, suitable for application to a broad range of physics problems.

### **Lepton and Photon Interactions at High Energies: Proceedings of the XXII International Symposium**

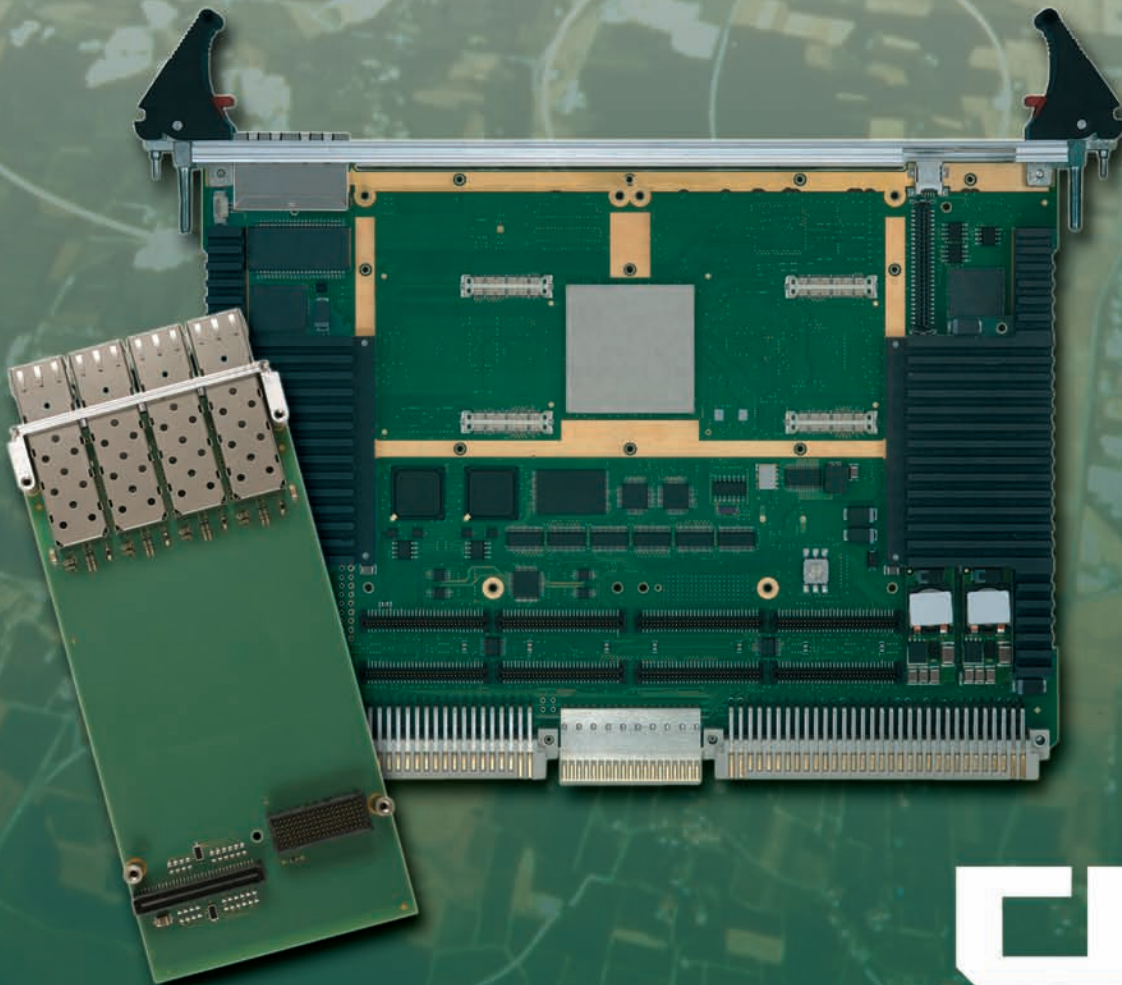
edited by Richard Brenner, Carlos P de los Heros and Johan Rathsman, World Scientific. Hardback ISBN 9812566627, £56 (\$98).

The Lepton–Photon symposia are among the most popular conferences in high-energy physics, since they give in-depth snapshots of the status of the field as provided by leading experts. Inside this volume, readers will find the latest results on flavour factories, quantum chromodynamics, electroweak physics, dark-matter searches, neutrino physics and cosmology, from a phenomenological point of view. It also offers a glimpse of the immediate future through summaries on the status of the next generation of high-energy accelerators and planned facilities for astroparticle physics. The review nature of the articles makes the volume useful to students, as well as to established researchers in high-energy and astroparticle physics.

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## Particle physics and the press

The media have a central role in telling the story of research in particle physics. We need to put aside our differences and keep our eyes on the big picture if we are to make the most of this vast resource, say members of the InterAction collaboration.

These are exciting times for particle physics, and the world's press are taking notice. As the Large Hadron Collider prepares to begin operations, as the International Linear Collider becomes an ever more clearly defined project, as programmes for neutrino physics and astrophysics flourish, and most of all as long-awaited discoveries reveal the secrets of the universe, our friends in the media will share the adventure. Their stories and articles, TV programmes, blogs and podcasts will inform and inspire others with the spirit of excitement that particle physicists are feeling at the start of the 21st century.

The journalists who tell our story will have wildly varying backgrounds, skills and points of view. Their pieces will cover the spectrum of science journalism. They will define and describe; compare and contrast; make judgements and express opinions; and praise and criticize. Writing in language that is accessible to their readers, they will at times seem wanting in their grasp of scientific subtleties. Sometimes they will appear to lack appreciation for something that we care deeply about; occasionally they may even give more credit than we deserve.

It is accepted wisdom that the press almost always get it wrong. Actually, in our experience, ultimately they get it just about right. In the months and years ahead, the majority of journalists who tell the story of 21st-century particle physics will do an excellent job. From time to time, inevitably, they will get it wrong – at least as we see it. A true test of our character as a field is how we react to this level of media coverage.

At a time of extraordinary scientific opportunity in particle physics, we must keep our eyes on the science and enjoy the privilege of taking part in discovering how the universe works. We should equally enjoy the opportunity afforded by the media's interest.

In the past, there have been occasions when our field has devolved into warring



*The InterAction Collaboration of particle-physics communicators met at CERN in March 2006.*

camp, reading each new press article with suspicion, quick to take offence at every real or imagined slight or bias. It's time to change this model. Do we want to be seen as a fractious, contentious community beset by invidiousness, or as a unified community of committed scientists confronting a golden age of discovery? We have the choice. We can set a tone of respect and admiration for all projects and experiments that lead to discovery – or one that begrudges every word of praise for others' work. Without fail, the media will pick up on our tone. So will our colleagues, our students, scientists in other disciplines and we ourselves. It will be part of what defines the kind of field that we are.

Competition will always exist, and this is a good thing. People care passionately about their work. Of course they want to see it recognized, and defend it if it is unfairly criticized. But we have everything to gain by maintaining perspective. There will be hundreds of stories during the years ahead. Today's lukewarm review will be tomorrow's encomium – and vice versa. We should take them all in

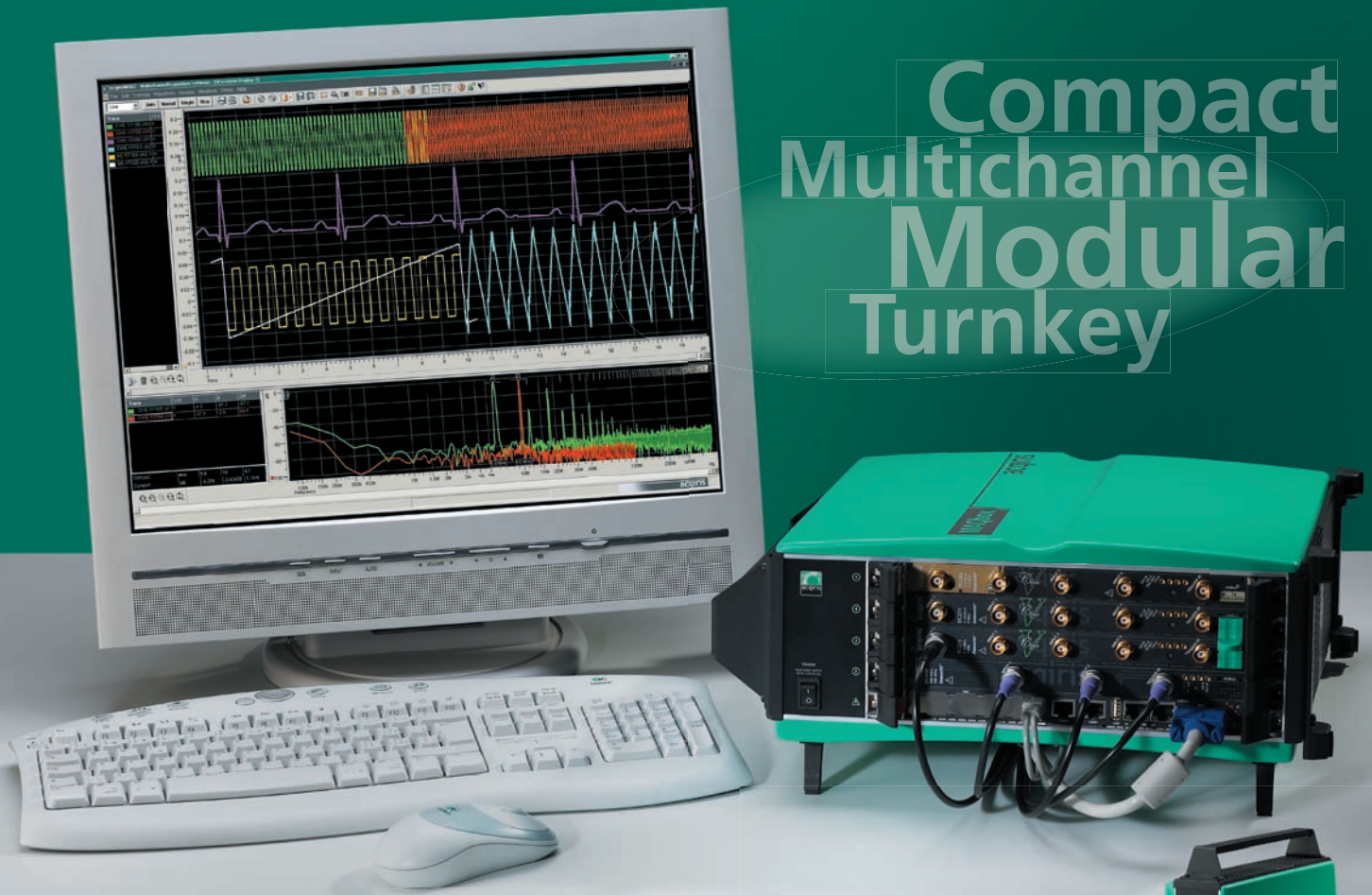
our stride, because we are in this together for the long haul. We all want to discover how the universe works. It's a big universe with room, and credit, enough for everyone.

● This article is being published simultaneously in the October issues of *CERN Courier* and *symmetry* (see [www.symmetrymag.org](http://www.symmetrymag.org)).  
 Members of InterAction, a collaboration of particle-physics communicators from laboratories around the world ([www.interactions.org](http://www.interactions.org)): Roberta Antolini, INFN Gran Sasso; Peter Barratt, PPARC; Natalie Bealing, CCLRC/RAL; Stefano Bianco, INFN Frascati; Karsten Buesser, DESY; Neil Calder, SLAC; Elizabeth Clements, ILC; Reid Edwards, Lawrence Berkeley National Laboratory; Suraiya Farukhi, Argonne National Laboratory; James Gillies, CERN; Judith Jackson, Fermilab; Marge Lynch, Brookhaven National Laboratory; Youhei Morita, KEK, ILC; Christian Mrotzek, DESY; Perrine Royole-Degjeux, IN2P3, ILC; Yves Sacquin, DAPNIA CEA; Ahren Sadoff, Cornell University LEPP; Maury Tigner, Cornell University LEPP; and Barbara Warmbein, ILC.

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