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CERN COURIER

VOLUME 48 NUMBER 1 JANUARY/FEBRUARY 2008



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Cover: Engineers check electronics on an LHC dipole magnet. In December 2007, director-general Robert Aymar reported to Council on progress with commissioning the machine (p5).

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LEADING.

CERN

Council appoints Rolf-Dieter Heuer as CERN's next director-general...

On 14 December, at its 145th meeting, CERN Council appointed Rolf-Dieter Heuer to succeed Robert Aymar as CERN's director-general. Heuer will take office on 1 January 2009 and serve a five-year term. His mandate will cover the early years of operation of the LHC and its first scientific results.

Heuer is currently research director for particle and astroparticle physics at the DESY laboratory in Hamburg, but is no stranger to CERN. From 1984 to 1998, he was a staff member at the laboratory, working for the OPAL collaboration at LEP. He was also OPAL's spokesperson from 1994 to 1998.



Rolf-Dieter Heuer. (Courtesy DESY.)

After obtaining a doctorate in 1977 from the University of Heidelberg, Heuer has spent much of his career involved with the construction and operation of large particle detector systems for studying electron-positron collisions. After leaving CERN in 1998 and joining the University of Hamburg he founded a group working on preparations for experiments at a possible future electron-positron collider. With his appointment at DESY in 2004, he became responsible for research at the HERA collider, DESY's participation in the LHC, and R&D for a future electron-positron collider.

...and looks to the LHC start-up and beyond

CERN director-general Robert Aymar, in his end-of-year status account to Council, reported on a year of progress at the LHC, which is due to start operation in the summer.

The machine components are now fully installed in the 27 km tunnel and commissioning is well underway. The successful commissioning of the second of the two transfer lines that will carry beams into the collider took place at the end of October, at the first attempt. Two of the LHC's eight sectors are currently cooling down to their operating temperature of 1.9 K and a further three sectors are being prepared for cool-down. More good news included a successful pressure test of sector 1-2 on 8 December. This was the final sector to undergo this test, which assesses the ability

of the mechanical design to withstand a pressure 25% above its design value.

Aymar told Council that CERN is on course for the LHC to start up in early summer 2008. However, it will not be possible to fix a definite date before the whole machine is cold and magnet electrical tests are positive. This should be in the spring, but any difficulties encountered during the commissioning that require a sector of the machine to be warmed up will lead to a delay of two to three months.

Installation of the LHC detectors is approaching its conclusion, and the collaborations are turning more attention towards physics analysis, including testing of the full data chains from the detectors through the Grid to data storage. All of the collaborations expect to have their initial

detectors ready for April. Some are already routinely taking data with cosmic rays, and baseline Grid services are in daily operation.

Council also approved a budget for CERN in 2008 that will allow consolidation of CERN's aging infrastructure to begin, together with provision for preparations for an intensity upgrade for the LHC. This paves the way for the renovation of the LHC's injector complex, including replacement of the venerable PS, which was first switched on in 1959. This process will allow the LHC's beam intensity to be increased by around 2016, thereby improving the sensitivity of the experiments to rare phenomena. The 2008 budget includes additional funds for this work, with special contributions being made by CERN's host states, France and Switzerland.

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FUNDING

UK and US announce budget bombshells for particle physics

Within one week in December 2007, particle physicists in the UK and the US received unexpectedly bad budget news, which rocked the two communities. The funding decisions have together provided a large blow to work on a future International Linear Collider (ILC).

On 11 December the UK's Science and Technology Facilities Council (STFC) announced its Delivery Plan for 2008/9 to 2011/12. The plan sets out how the council intends to deliver world-class science, in part through providing access to international facilities, within the finances allocated in the 2007 Comprehensive Spending Review. Though this review gave the STFC an increase of some 13.5% over the period in question, the news for UK particle physicists – and their colleagues in astronomy – was far from good. The most serious aspect for particle physicists was summed up in a simple statement: “We will cease investment in the

International Linear Collider.” Astronomers received the news of withdrawal from “future investment in the twin 8-m Gemini telescopes”. The consequences of the overall UK budget announcement are still being assessed, but redundancies are likely.

This news immediately reverberated around the world, as the UK was a major contributor to the ILC, but bad news was also in store for their colleagues in the US. A week later on 18 December, the US budget for fiscal year 2008 was finally announced after several delays. In the rush to get the budget approved, several projects suffered big reductions, including “\$0 for the US contribution to ITER [the international fusion project]”, and no funds for the NOvA project at Fermilab's Tevatron. In addition the budget allowed for only 25% – \$15 million instead of \$60 million – of the amount requested for R&D on the ILC. This is much worse than it

appears, as the US system works in such a way that FY2008 began last October, so this allocation may already have been spent.

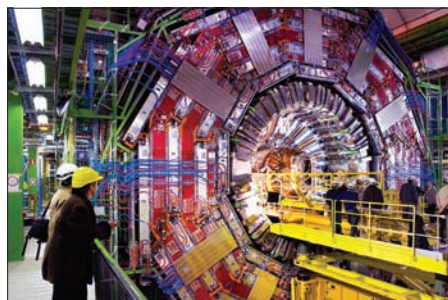
While these two adverse developments represent a major setback for the ILC, there are also immediate ramifications for personnel at Fermilab and SLAC. Pierre Oddone, Fermilab's director, had the unenviable task of announcing that some 200 layoffs from a workforce of about 2000 would probably be necessary, and that employees would now have two days enforced unpaid leave a month. Persis Drell, in her new role as director of SLAC (see p40), had to announce that work on the ILC had to stop on 1 January and that the B-factory would have to shut down prematurely. The laboratory would have to reduce its workforce by about 15%, implying 125 layoffs in addition to the nearly 100 announced previously as SLAC changes focus in its research.

LHC DETECTORS

CERN installs giant CMS tracking detector

The world's largest silicon tracking detector is now in its final location in the CMS detector at CERN. This completes the installation of sub-detectors inside CMS's huge solenoid magnet, which was lowered into the experiment's cavern on the LHC ring on 28 February last year.

With a total surface area of 205 m², the CMS Silicon Strip Tracking Detector is the largest detector of its kind ever constructed. Its sensors provide 10 million individual detection strips, each of which is read out by one of 80 000 custom-designed microelectronics chips. The silicon sensors are precisely assembled on 15 200 modules, which are in turn mounted on an extremely low-mass carbon fibre structure that maintains the position of the sensors to less than 100 µm. They will allow the charged



The Silicon Strip Tracking Detector has now reached its final resting place in the CMS experiment.

particles that are produced in the LHC's collisions at the heart of the detector to be tracked with a precision of better than 20 µm.

The overall assembly of the silicon tracking detector began in December 2006 and was completed in March 2007. All of the systems

were then fully commissioned, with 20% of the full detector operating over several months, during which it recorded 5 million cosmic-ray tracks. This commissioning demonstrated that the detector fully meets the experiment's requirements.

Finally, in the early hours of 13 December the detector began its journey from the main CERN site to the site of the CMS experiment near Cessy, France. Later that day it was lowered 90 m into the cavern. Installation began on 15 December and was concluded the following morning.

More than 500 scientists and engineers from 51 research institutions worldwide have contributed to the success of the project. These institutions are located in Austria, Belgium, CERN, Finland, France, Germany, Italy, Switzerland, the UK and the US.

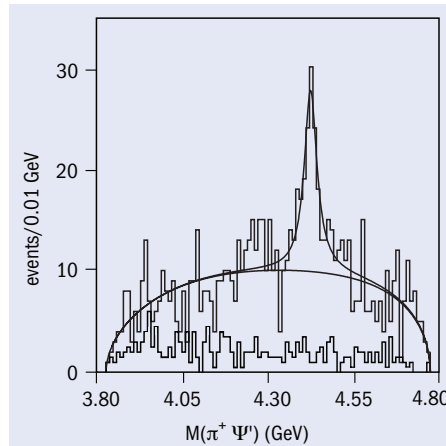
KEK

Belle Collaboration discovers new meson

The Belle collaboration at KEK has recently announced the discovery of an exotic new particle with non-zero electric charge. This particle, which the researchers have named the Z(4430), does not fit into the usual scheme of mesons.

The Z(4430) particle has appeared in the decay products of B mesons (containing a bottom quark), which are produced in large numbers at KEKB, the B-factory at the KEK laboratory in Japan. While investigating various decays of B mesons in a data sample containing nearly 660 million pairs of B and anti-B mesons, the Belle team observed 120 B mesons that decay into a Z(4430) and a K meson. The Z(4430) then instantly decays into a Ψ' and a π meson. The team found that the new particle has negative charge and a mass about 4.7 times that of the proton.

Both Belle and the BaBar experiment at SLAC have found a number of peculiar new particles during the past few years, such as the X(3872), Y(4260), X(3940) and Y(3940). These all have masses in the region of 4–4.5 times the proton's mass, and decay



This diagram shows the distributions of the measured mass for combinations of a detected π meson and a Ψ' meson. The newly discovered Z(4430) is visible as the peak at 4430 MeV.

into J/Ψ or Ψ' particles and π mesons. A simple explanation for these particles would be that they are examples of charmonium, the family of bound states of a charm quark (c) and antiquark (\bar{c}) that includes the

J/Ψ and Ψ' . However, their masses and decay properties do not match theoretical expectations for charmonium, so theorists have proposed other explanations.

One possibility is that some of the new particles are multiquark states containing a c and (\bar{c}) together with another lighter quark and antiquark, for example, an up quark (u) and antiquark (\bar{u}) or down quark (d) and antiquark (\bar{d}). However, because the particles previously discovered are electrically neutral, it has not been possible experimentally to rule out entirely that they are unusual charmonium states.

The newly discovered Z(4430), on the other hand, has non-zero electric charge, a characteristic that clearly distinguishes it from charmonium. This raises the possibility that it could be indeed be a multiquark state, containing a c and \bar{c} together with a quark and different antiquark, for example $cu\bar{c}\bar{d}$.

Further reading

K Abe *et al.* 2007 <http://arxiv.org/pdf/0708.1790>.

LHC NEWS

Lead ions knock at the LHC's door

There was jubilation in the CERN Control Centre late in the afternoon on 12 November. Only a few hours before the annual winter shutdown of the accelerators, monitoring screens showed that a beam of lead ions dispatched from the SPS had reached the threshold of the LHC. For the first time the beam had been extracted close to the LHC along the TT60 transfer line. It marked another milestone towards the final target of circulating lead ions in the LHC to produce collisions.

Since the installation of the Low Energy Ion Ring (LEIR) in 2005, the team working on I-LHC, the project to deliver heavy ions to the LHC, has focused on the injector chain in order to supply ion beams to the LHC in optimal conditions. A year previously, ions that had been accumulated in LEIR and sent to the PS were ejected at the threshold of the SPS for the first time.

In 2007, ions were successfully injected into the SPS from the beginning of September. After many adjustments and studies, the beam had been accelerated with a view to its extraction into one of the two transfer lines linking the SPS and the LHC. But technical problems had arisen,

including a vacuum leak detected in the PS at the beginning of November. By increasing ion losses, this leak had resulted in a reduction in the intensity of the ion beam, placing the success of the operation in jeopardy. However, at approximately 5.00 p.m. on 12 November, thanks to an increase in beam intensity to 20 million ions per bunch, the long-awaited beam finally made its appearance on the screens in the control room.

The next stage will be to refine and optimize the beam to reach the nominal intensity for the LHC of 100 million ions per bunch – this will be five times higher than that recently obtained.

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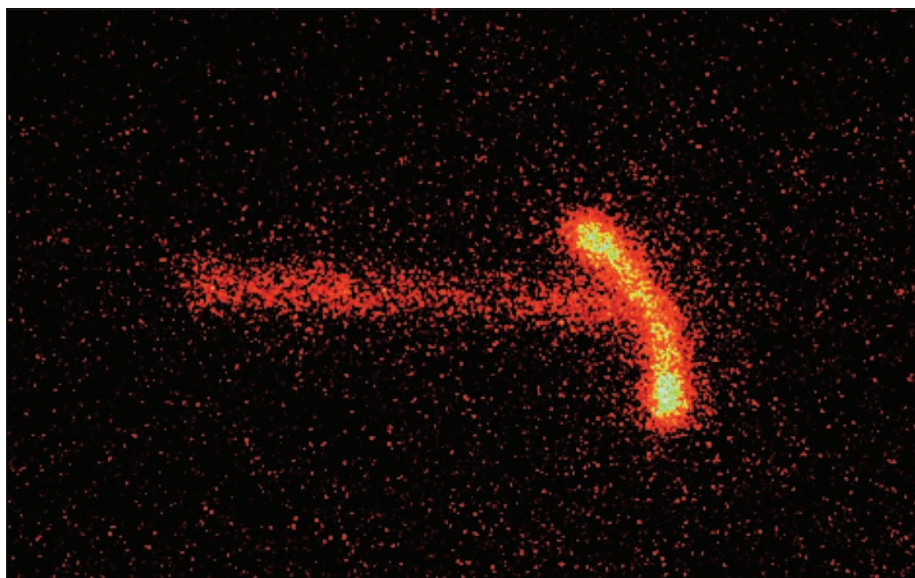
NUCLEAR PHYSICS

Camera captures image of two-proton decay

In work that harks back to the early days of nuclear physics, an international team of researchers at Michigan State University's National Superconducting Cyclotron Laboratory (NSCL) has used a novel detector incorporating a CCD camera to record optically the tracks of charged particles emitted in the two-proton decay of iron-45 (^{45}Fe). The technique has allowed the first measurement of correlations between the two protons, demonstrating that the process is indeed a three-body decay. Besides shedding light on a novel form of radioactive decay, the technique could lead to additional discoveries about short-lived rare isotopes, which may hold the key to understanding processes inside neutron stars and determining the limits of nuclear existence.

Although it is more than 100 years since Henri Becquerel opened the door to nuclear physics with his discovery of radioactivity, there are still open questions that continue to nag experimentalists. One such example is the mechanism underlying the two-proton emission of neutron-deficient nuclei, first observed in the 1980s (*CERN Courier* December 2002 p27).

Now Krzysztof Miernik and colleagues from Poland, Russia and the US have taken several steps towards an answer, by peering closely at the radioactive decay of a rare iron isotope at the edge of the known nuclear map (Miernik *et al.* 2007). The researchers set out to obtain a better understanding of two-proton emission from ^{45}Fe , which has a nucleus of 26 protons and 19 neutrons; in comparison, the stable form of iron most abundant on Earth has 30 neutrons. One possibility was that the neutron-deficient ^{45}Fe might occasionally release a diproton – an energetically correlated pair of protons. It was also possible that the two protons, whether emitted in quick succession or simultaneously, were unlinked.



A two-proton decay recorded by Optical Time Projection Chamber. A ^{45}Fe ion enters the chamber from the left. The two bright, short tracks are protons of approximately 0.6 MeV. (K Miernik *et al.* 2007.)

The experiment's key device was the novel imaging detector built by Marek Pfitzner and colleagues from Warsaw University – the Optical Time Projection Chamber (OPTC). This consists of a front-end gas chamber that accepts and slows down rare isotopes in a beam from the NSCL Coupled Cyclotron Facility. Electrons from the ionized tracks drift in a uniform electric field to a double amplification structure, where UV emission occurs. A luminescent foil converts these photons to optical wavelengths, for detection by a CCD camera. In this way, the camera records the projection of the particle tracks on the luminescent foil. A photomultiplier tube also detects the photons from the foil to provide information on the drift time of the electrons, and hence the third dimension, normal to the plane of the CCD.

Analysis of these images ruled out the proposed diproton emission and indicated that the correlations between emitted protons

are best described by a three-body decay. A theory of this process has been described by Leonid Grigorenko, a physicist at JINR, and a co-author of the paper.

The experiment itself recalls the early days of experimental nuclear physics in which visual information served as the raw data, with tracks recorded in photographic emulsion. Indeed, this was the process that lay behind Becquerel's discovery of radioactivity. The new result may represent the first time in modern nuclear physics that fundamental information about radioactive decays has been captured in a camera image and in a digital format. Usually, nuclear physics experiments provide digitized data and numerical information of various types, but not images.

Further reading

K Miernik *et al.* 2007 *Phys. Rev. Lett.* **99** 192501.

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ASACUSA moves towards new antihydrogen experiments

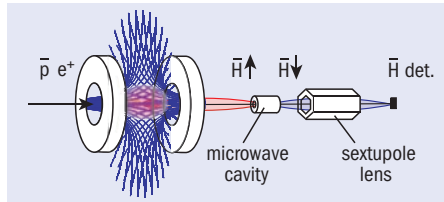
Antihydrogen experiments under way at CERN's Antiproton Decelerator have so far aimed at making high-precision measurements of the frequency of optical transitions, such as that between antihydrogen's 1S ground state and its first excited, 2S state, near 2466THz. Comparing this with the same frequency for ordinary hydrogen constitutes a highly sensitive test of CPT symmetry, which involves simultaneous inversions of charge (C), parity (P) and time (T) (see p23).

Recently, the Japanese-European ASACUSA group made the first steps towards producing a low-velocity antihydrogen beam, which may be used to measure the hyperfine transition frequency between the two spin substates of antihydrogen's ground state. Its value for ordinary hydrogen is near 1420 MHz.

Before this can be done antiprotons must be confined and cooled in an evacuated container in which magnetic and/or electric fields produce restoring forces that stop the antiprotons drifting to the container walls, where they would annihilate. To do this, the MUSASHI group of the ASACUSA collaboration has introduced a novel variant of the familiar Helmholtz coils. The MUSASHI coils differ from the usual configuration by having antiparallel rather than parallel excitation currents. This produces a magnetic quadrupole field rather than the normal constant one, and is symmetric about the coil axis. If a suitable electrostatic multipole field is added to this so-called "magnetic cusp" field, all of the restoring forces needed to confine both positive and negative charges are present within the container.

This "cusp trap" can thus also hold positrons, with which the antiprotons recombine to create the antihydrogen, as well as electrons. The latter can be used to cool the antiprotons to the extremely low temperature at which recombination occurs. In the recent tests, some 3 million antiprotons were stored in the trap and cooled with electrons.

A well known obstacle to CPT tests with antihydrogen is that both the hyperfine



Oppositely wound Helmholtz coils produce an axially symmetric quadrupole field to which an electric multipole field is added. These produce trapping potentials for positive and negative particles, as well as for low-field seeking antihydrogen atoms. After de-excitation to the ground state, a beam of spin-polarized antihydrogen atoms emerges.

and the 1S–2S frequency measurements must be performed on ground-state atoms, while it appears that positron-antiproton recombination produces them in very highly excited states. One great advantage of the cusp trap is that if these neutral atoms are cold enough its quadrupole field pulls on their large magnetic moment, causing them to seek the field minimum at the trap centre. They remain confined there until they reach the ground state. However, since their magnetic moment falls as they de-excite, the pull weakens. This means that in the ground state, only antihydrogen atoms in one of the two possible spin states are pulled to the centre, while those in the other state are expelled along the trap axis, emerging as a spin-polarized, ground-state antihydrogen beam.

This is ideal for the classical type of slow atomic beam experiment in which a microwave cavity induces spin flips when tuned to the correct hyperfine frequency (see figure). The resonant frequency can then be detected using a sextupole magnet which focuses flipped atoms onto a detector but defocuses unflipped ones. Comparison with the well measured hydrogen frequency then gives a stringent test of CPT symmetry.

Although much of this remains to be done, the recent successes are so encouraging that further steps along the road to a slow antihydrogen beam are now planned.



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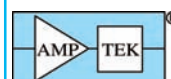
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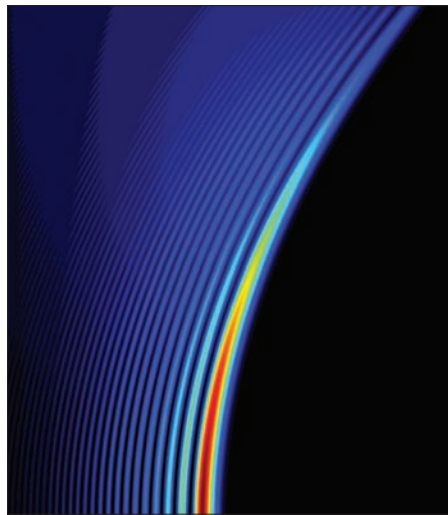
Scientists find light doesn't always travel in straight lines

A remarkable experiment by researchers at the University of Central Florida in Orlando demonstrates for the first time unusual beams of light that propagate without diffraction and bend as they travel. These so-called "Airy beams", which were predicted theoretically nearly 30 years ago, are wave packets constructed through the use of carefully designed phase masks.

While not violating any of the accepted principles of physics, these are nevertheless striking examples of how one can bypass what would seem at first sight to be unavoidable constraints on how the world works.

Further reading

G A Siviloglou *et al.* 2007 *Phys. Rev. Letts.* **99** 213901.



Bending of an "Airy beam" (Siviloglou *et al.* 2007).

Knots become experimental

Knots are usually either a practical matter for sailors and boy scouts, or a relatively abstruse branch of mathematics. Now, however, they have become a proper experimental subject. Dorian Raymer and Douglas Smith of the University of California in San Diego have looked at what happens if you toss a piece of string into a box, spin the box around, and tie the loose ends together.

The experiment often ends up with a knotted loop of string, and the information found on how often different sorts of knots form connects with a theoretical model. This could be the start of a new line of research.



An example of string before (left) and after (right) tumbling experiments. The study could lead to novel applications (Raymer and Smith 2007).

Further reading

Dorian M Raymer and Douglas E Smith 2007 *PNAS* **104** 16432.

Ancient Americans took to chocolate

It looks as though chocolate has been enjoyed for longer than anyone had thought, according to new research by John Henderson of Cornell University and colleagues.

Chemical analyses of pottery vessels from Puerto Escondido in Honduras show that

chocolate was consumed before 1000 BC, which is 500 years earlier than had been previously established. The analysis is based on looking for traces of theobromine in the pottery. Theobromine is a caffeine-like stimulant that is present in chocolate, but is found in practically nothing else.

Further reading

John S Henderson *et al.* 2007 *PNAS* **104** 18937.

Cherenkov effect produces radio signals in ice

The Antarctic Impulsive Transient Antenna (ANITA) experiment plans to use balloon-borne detectors to look for radio-frequency Cherenkov radiation produced by cosmic-ray induced electromagnetic showers in Antarctic ice. Now the basic idea has received laboratory confirmation.

PW Gorham of the University of Hawaii in Manoa and colleagues used the electron linac at SLAC to fire a beam of 28.5 GeV electrons into a 7.5 tonne block of ice. They looked for radio signals and found results consistent with the "Askaryan effect", named after Gurgun Askaryan, who first proposed the radio Cherenkov phenomenon back in 1962. The tests form an important part of the validation for the ANITA concept.

Further reading

PW Gorham *et al.* 2007 *Phys. Rev. Letts.* **99** 171101.

Black holes could help us glimpse the naked singularity

Physicists often assume that nature conspires to shield gravitational singularities behind event horizons – something that Roger Penrose described as cosmic censorship: "thou shalt not behold a naked singularity". However, black holes are in danger of violating this rule if they acquire too much electric charge or too much angular momentum.

Now, George Matsas and André da Silva have shown that quantum effects could allow particles to fall into a black hole increasing its angular momentum so much that the naked singularity would be revealed. This new insight and fundamental tension between classical expectations and quantum calculations could shed light on the nature of quantum gravity.

Further reading

George EA Matsas and André RR da Silva 2007 *Phys. Rev. Letts.* **99** 181301.

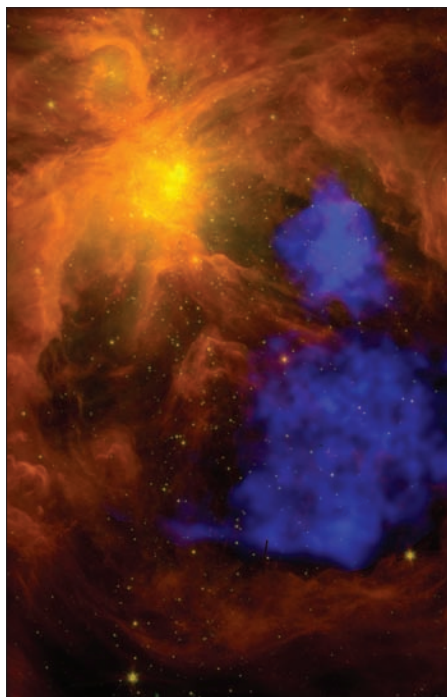
Hot plasma fills the Orion nebula

Observations with the XMM-Newton satellite have revealed soft X-ray emission from an extended region in the Orion nebula. The most massive stars in the heart of the nebula are probably at the origin of this million-degree plasma flowing through it.

The Orion nebula (Messier 42), is more than a thousand light-years away, but is visible to the naked eye. It is the most spectacular star-forming region in the northern sky. The nebula hosts the Trapezium group of four recently formed very massive stars – seen by eye as a single star called Θ Orionis – which illuminate and ionize the surrounding gas.

A team of astronomers led by Manuel Güdel from the Paul Scherrer Institute in Switzerland has discovered that a hot plasma pervades the nebula. The extended plasma emission, which reaches a temperature of about 2 million degrees, was observed with the relatively wide-field camera of the European X-ray Multi-Mirror satellite (XMM-Newton).

In the absence of a supernova bubble in this very young nebula, which is about 3 million years old, the only source of energy available to heat the gas is the fast wind from the Trapezium stars. The brightest star in the group is about 40 times more massive than the Sun and generates a wind of plasma with a speed up to 1650 km/s. The violent collision between this wind and the surrounding dense gas heats the plasma to millions of degrees, but only about a ten-thousandth of the wind's kinetic energy is needed to account for the X-ray luminosity of the hot plasma.



Spitzer image of the Orion nebula in the infrared overlaid with the distribution of hot gas observed by XMM-Newton in blue. The Trapezium stars are located in the brightest region in the upper-left part of the image. (Courtesy AAAS/Science/ESA XMM-Newton and NASA Spitzer data.)

Further calculations by Güdel and colleagues show that the hot X-ray plasma is approximately in pressure equilibrium with the ambient ionized gas, because although it is cooler the latter compensates the pressure

by being much denser. This equilibrium could explain the presence of the hot gas in a cavity in the nebula: the hot gas would be channelled by the cooler, denser structures and slowly flow into the cavity.

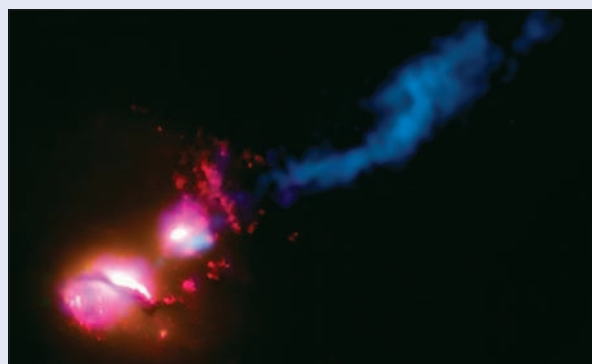
This is not yet the end of the journey, however. Güdel and colleagues further speculate that the hot gas could continue its flow out of the cavity into the nearby Eridanus superbubble, like a river flowing out of a lake into the sea. This giant bubble is 400 light-years wide and extends over 20 degrees of the sky. The wind-shocked gas from the Trapezium stars would thus slowly replenish the Eridanus superbubble, which was formed by supernova explosions from previous generations of massive stars. The team plans further observations to test this scenario, which could also explain how the observed radioactive aluminium-26 could have migrated from the Orion nebula into this superbubble (*CERN Courier* January/February 2006 p10).

If the proposed scenario is correct, it means that the gas in our galaxy is not only enriched by heavy elements – such as carbon, oxygen, nitrogen or iron – from sudden supernova explosions. It could also be gently enriched over millions of years by the continuous stellar wind of massive stars that leaks out of star-forming regions into the interstellar medium.

Further reading

M Güdel *et al.* 2007 *Science Express*
DOI: 10.1126/science.1149926.

Picture of the month



This composite image shows for the first time a jet from a supermassive black hole striking the edge of a companion galaxy in the system known as 3C 321. Supermassive black holes at the centre of galaxies can produce a pair of powerful plasma jets that are ejected in opposite directions (*CERN Courier* July/August 2006 p10).

The peculiarity of 3C 321 is that the jet (blue) from the main galaxy at the lower left of the image hits a companion galaxy only 20 000 light-years away and gets deflected by this interaction. The image combines X-ray data from Chandra (purple), ultraviolet and optical data from Hubble (red and orange), and radio emission from the Very Large Array (VLA) and MERLIN (blue). (Courtesy X-ray: NASA/CXC/CfA/D Evans *et al.*; optical/UV: NASA/STScI; radio: NSF/VLA/CfA/D Evans *et al.*, STFC/JBO/MERLIN.)

CERN

Neutrino results: 1963–1964

A large-scale experiment on neutrinos began at CERN in June 1963. Its aims were essentially threefold: to verify with more precision the conclusion of the 1962 Brookhaven experiment, that there are two different kinds of neutrino; to gain new information on weak-interaction processes; and, in particular, to search for the intermediate boson, known as the W particle, postulated as the “carrier” of the weak force by analogy with the mesons that “carry” the strong force.

Preliminary results were announced at the Sienna conference in October 1963. Before committing themselves to final statements on the existence of the W, however, the physicists waited for the results of more accurate calibration experiments and further experimental runs. Sufficient progress had been made by August 1964 for the results to be presented at a special neutrino session of the Dubna conference, summarized in a rapporteur’s talk by Prof. G Bernardini. The conclusions can perhaps be best understood as the answers to seven questions, in the way that Prof. Bernardini presented them in a talk at CERN in November.

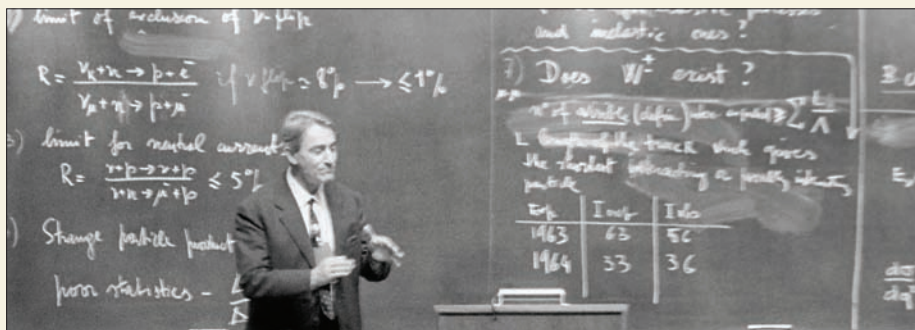
If the theory of the Universal Fermi Interaction is true, are the electron neutrino and the muon neutrino two different particles; if so to what extent might it still be possible for them to be interchangeable?

Definitely two different particles, any mixing being less than 1%. The results also indicate that the Universal Fermi Interaction holds up to momentum transfers of at least 1 GeV/c.

Is there a “neutrino flip”, in the sense that a kaon decaying directly to a muon may produce simultaneously an electron neutrino rather than a muon neutrino?

No. In any event not more than 10% of the kaons decaying in this way could produce an electron neutrino.

Do “neutral currents” exist in weak interactions? For example, if the weak interaction is due to the mediation of a particle could this particle have



Prof. G Bernardini, with a board full of questions, during the seminar at CERN in November 1964.

no electric charge, making possible a scattering such as $\nu + p \rightarrow \nu + p$ in addition to the normal reaction $\nu + n \rightarrow \mu^- + p$?

No, any possible neutral current being less than 3% of the charged currents.

Are strange particles produced in neutrino interactions, and if so can they appear singly, or always in pairs by “associated production”? This forms a test for the $\Delta S = \Delta Q$ rule (that the strangeness can only change by the same number of units as the charge of the heavy particle in a weak interaction).

They are produced at the higher neutrino energies, perhaps at a greater rate than previously expected and probably only in pairs, though the total number of events seen is still low. The $\Delta S = \Delta Q$ rule seems to be at least 80% true.

Is the “muon” lepton number conserved in these reactions, in the same way as the electron number; for example, is it certain that a neutrino (particle) can only interact “elastically” with a neutron to produce a proton and a negative muon (particle) and never with a proton to give a neutron and a positive muon (antiparticle)?

Yes, at least to within 2%.

What is the value of the “axial-vector form factor”? This is one of the terms that appear in the equation describing the weak interaction theoretically.

The same as that of another term, the vector

form factor, plus or minus 25%, again for all values of the momentum transfer up to 1 GeV/c. This is the first time that this factor has been measured.

Is there an intermediate boson?

We don’t know. All [results] led to the final conclusion that there was not yet any proof for its existence. It can be inferred that if the boson exists it has a mass greater than about 1.8 GeV/c², depending to some extent on the theoretical assumptions made. It now seems unlikely that the W particle, even if it exists, can be produced with present-day accelerators.

● Compiled from the article on pp8–9.

COMPILER’S NOTE

With bosons on everyone’s mind as the LHC start-up approaches, it is interesting to revisit these questions and answers from 1963/64. Less than a decade after Bernardini’s talk, CERN discovered neutral currents in the Gargamelle bubble chamber, in 1973. The W[±] and Z⁰ carriers of the weak force were produced in proton–antiproton collisions at the SPS in 1983, with masses of 91 and 80 GeV/c², respectively, some 45–50 times the limit quoted here. Then in 1989 LEP clinched the question of how many distinct types of neutrino exist: three and only three, related to the electron, muon and τ.

● Sincere apologies to our German readers for scrambling the poem last month; please see p43 of this issue.

Electronics for LHC-era experiments and beyond

Mike Letheren and **François Vasey** report on TWEPP '07, a workshop that reviewed experience gained from developing electronics for LHC experiments and which looked at the challenges for future projects.

The Topical Workshop on Electronics for Particle Physics (TWEPP '07) recently brought together more than 160 participants from the international high-energy physics community, specialized technical institutes and industry. Held in Prague on 3–7 September 2007, the workshop was organized by Charles University, the Czech Technical University, the Institute of Physics and the Nuclear Physics Institute of the Czech Academy of Sciences. It represented both a continuation and a significant broadening of the scope of the series of annual Workshops on Electronics for LHC Experiments initiated in 1994.

This series of workshops began within the framework of the R&D programme supervised initially by CERN's Detector Research and Development Committee and later by the LHC Committee. The goal was to promote collaboration and dissemination of relevant expertise within the LHC community, harness specialized knowledge from industry and technical institutes and encourage common approaches and the adoption of standards. The proceedings of the previous 12 workshops show that the programme met these aims. Overall progress has often been spectacular, from the initial R&D phase to the installation and commissioning of the large-scale and complex high-technology electronics systems for LHC experiments. Despite the successful resolution of the many initial R&D challenges, several practical electrical engineering aspects have recently proved to cause some of the biggest headaches in assembling the full LHC detector systems.

With the LHC experiments now well into their commissioning phase, the meeting in Prague was a timely occasion to review lessons learned from more than a decade of design, production and installation of detector electronics. It was also a time to look forward to the challenges of developments in electronics for potential experimental facilities beyond the LHC, such as the Super-LHC (SLHC), the International Linear Collider (ILC) and the Compact Linear Collider study, as well as neutrino and fixed-target experiments. The workshop featured 89 submitted presentations, nine invited talks, topical sessions on supply and distribution of power in detectors, working groups on microelectronics and optoelectronics, and an optional tutorial on robust ASIC designs for hostile environments. While the majority of contributions (58%) described electronics for



The cryostat flange of the ATLAS barrel showing the material added by services (cables, pipes and protections). (Courtesy H Pernegger/CERN.)

LHC experiments, 9% of the papers addressed an SLHC upgrade issue and 33% concerned the ILC or other experiments. Some 16% of participants were from non-European institutes.

Some lessons learnt

Approximately 40% of the workshop contributions were on electronics systems, installation and commissioning. This is no surprise given the advanced state of the LHC experiments. Speakers reported on significant progress in integrating the sub-detectors in the LHC experiments and in commissioning tests with cosmic rays. In general, the performance of the front-end and back-end electronics and the associated software and firmware for controls, monitoring and readout, agrees well with expectations. This major achievement is largely a result of the tremendous effort that the community has made to deliver complex and functional electronics systems to the experiments. However, installation and verification of the complicated services for the front-end electronics (power, cooling, cables etc) often turned out to be much more difficult than anticipated. One particular point of concern relates to the supply and distribution of power to the experiments. In the current LHC detectors, typically only around 30–40% of the power produced is really dissipated in the front-end circuits, the remainder being lost in long power cables and through conversion inefficiencies in power supplies.

A more efficient power distribution system would have reduced the amount of material required in the form of power cabling and cooling infrastructure to remove the heat; this in turn would have allowed improved tracking detectors. The development of such power supply ▷

and distribution systems will be critical for the successful construction of future detectors. In a possible SLHC luminosity upgrade, for example, a 10-fold increase in luminosity will require detectors with higher granularity and hence an increased number of electronic channels. The use of advanced front-end ASIC technology holds the promise of reduced power dissipation per channel, and therefore should help to contain any increase in the global power dissipation of the whole front-end electronics systems. Nevertheless, these advanced IC technologies operate at lower voltages than those employed in the LHC detectors today, so the fraction of power dissipated in power cabling at the SLHC detectors is at risk of increasing.

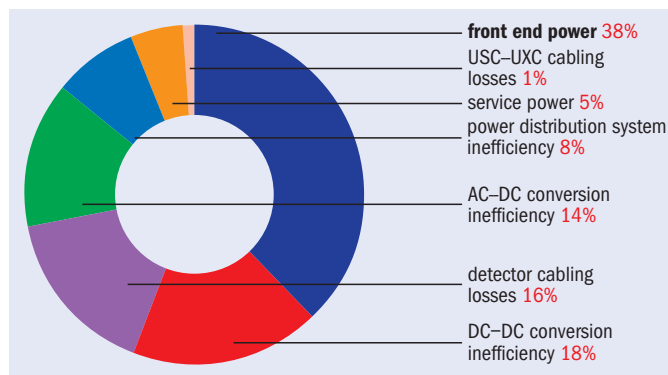
To review the present situation and discuss future orientations, the workshop devoted a day to topical sessions on power management and distribution in large detector systems, with presentations and discussions about several new approaches. At the ILC for instance, the time structure with bunch trains of around 1 ms interspersed with 200 ms of idle time offers the possibility of placing the electronics in quiescent mode during the idle periods, which could lead to a 99% reduction in the average power consumed by the front-end electronics. This power cycling technique cannot be used at the SLHC, but local DC–DC conversion and serial powering are strong alternative options. The first of these alternative approaches delivers power to the front-end modules at high voltage (say, 24 V) and then uses a local DC–DC converter to step down to the required ASIC supply voltage (1.5 V for 130 nm CMOS). In the serial-powering approach the floating modules are powered in series and fed with a constant current. Each module is equipped with a voltage regulator and a current shunt in order to maintain the required drop in supply voltage, regardless of load variations or possible module failure.

The topical sessions concluded with general agreement on the need to adopt a coordinated approach to the supply, management and distribution of power for large experiments in order to avoid *a posteriori* systems engineering. A working group will be established to assess power-related issues, including lessons learnt from LHC detectors; power management developments required for future upgrades and experiments; and methodologies for the quality control and qualification of power systems.

Front-end to back-end

The second largest session of the workshop focused on ASIC developments. In view of the considerable challenge presented by electronics for the future SLHC or ILC detectors, clear signs of vigorous development activity are excellent news. The ASIC session covered a rich set of applications, including front-end circuits for pixel and micro-strip detectors for tracking, front-end electronics for calorimetry at the LHC, SLHC and ILC, and generic functions, such as single-event upset-tolerant programmable logic and optical transfer of data, clock and trigger signals at multi-gigabit rates. ASIC projects presented at the workshop employed a range of standard CMOS technologies (with minimum feature sizes of 350 nm, 250 nm, 180 nm and 130 nm), as well as other technologies chosen to meet the specific requirements of different detectors. The latter included silicon-germanium processes to handle signals with a wide dynamic range, high-voltage processes for DC–DC converter developments, and silicon-on-insulator technology for the development of monolithic integrated pixel detectors.

A large fraction of the contributions on ASICs were related to the ILC detectors, where a low material budget within the detector and



The global efficiency of the CMS power supply chain is 38%. (Data courtesy S Lusin/Fermilab.)

low-power front-end electronics are particularly important. Developments addressing these requirements include monolithic pixel systems, ASICs to read out CCD arrays and ASICs to read out silicon microstrips in advanced 130 nm CMOS technology with built-in support for power cycling.

The ASICs being developed for particle detector readout are now becoming real “systems on chips”, and their increasing complexity requires ever more expertise from larger and larger development teams, as well as an approach that takes system aspects into account from an early stage of the development. The appropriate choice of technology will depend strongly on the specific development timescale of the different projects, as well as the global cost of accessing such technologies, including qualification and the design support environment. The use of a common technology base would allow sharing of building blocks and reduction of the global effort needed for radiation hardness qualification.

A Microelectronics Users’ Group meeting directly followed the ASIC session to spread information about progress in making deep sub-micrometre technologies available to the particle-physics community. CERN has negotiated access to 130 nm and 90 nm CMOS technologies following a similar model to that used for the 250 nm technology employed in many of the developments for LHC experiments. A design kit and a commercial library facilitating digital and mixed-signal ASIC developments in 130 nm CMOS are already available for the SLHC, ILC and other future projects.

The transmission of signals between the front-end ASICs and the readout, trigger, timing and control crates in the counting rooms of the LHC experiments has in nearly all cases been implemented with radiation-resistant high-bandwidth optical links. The production, assembly, integration and commissioning of these optical links involved large-scale quality-assurance programmes. Contributors to the workshop presented various quality-control tools for integration of optical link systems, commissioning and in-field fault diagnosis. Despite initial fears about their fragility, the quality of the systems installed so far has proved to be very high, with the fraction of unrecoverable faulty connections in the per mille range. Recently, efforts have begun to investigate the possibility of using similar optical systems at the SLHC. Although the rapid evolution of technology is making available optical links with sufficient bandwidth, effort on the selection and radiation hardness qualification of optical fibres, lasers, and pin photodiodes is just starting. Results were presented at the workshop on radiation tests of optical fibres and vertical cavity surface-emitting

lasers (VCSELs) operating at 850 nm wavelength. A working group met to coordinate work on future optical systems with the aim of promoting common development, testing and qualification paths.

In parallel to the highly customized front-end electronics, impressive progress is also being made in commissioning the trigger and data-acquisition interface electronics for LHC experiments. The back-end electronics in the counting rooms typically employ large, high-density boards housing optical transceivers and several field-programmable gate arrays (FPGAs). Manufacturing problems with the high-density circuit boards have been largely overcome through close co-operation with the manufacturers and ongoing attention to detail. The use of FPGAs provides complex data-processing functionality in a reduced board area, and their reconfigurability is ideal for the flexible implementation and evolution of trigger algorithms. A downside of this flexibility is the potential proliferation of firmware versions and variants across a large number of board designs and different types of FPGA. The maintenance of the firmware and the software will present a considerable support challenge over the lifetime of the experiments.

The TWEPP '07 workshop confirmed that most electronics systems for LHC experiments are ready and functioning according to specifications. In addition, it took a further step towards extending the original goals of the earlier Workshops on Electronics for LHC Experiments to the wider community of particle physicists engaged in developing future experimental facilities. It provided an excellent forum to exchange novel ideas, technical know-how and practical experience between different sectors of the international particle-physics community. In a context where electronics is an essential enabler for future experiments, such a forum will certainly contribute to improving the quality and reliability of the systems built. It will also lead to the formation of new collaborations and the preparation of common projects.

Further reading

For more information about TWEPP '07, visit <http://indico.cern.ch/event/11994>. For past workshops on electronics for LHC experiments, visit <http://lhc-electronics-workshop.web.cern.ch/>. TWEPP '08 will take place in Naxos on 15–19 September, see <http://indico.cern.ch/event/21985>.

Résumé

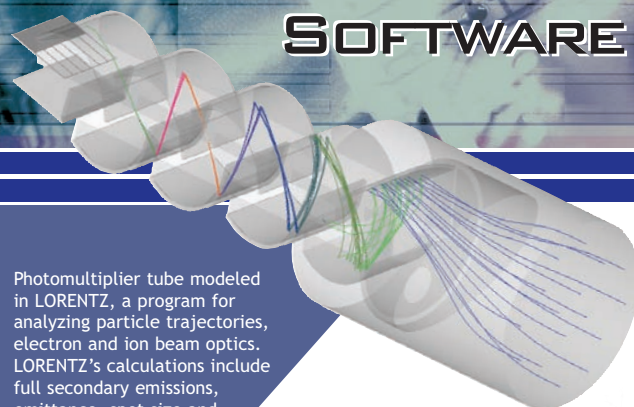
TWEPP '07: l'électronique pour les expériences du LHC et au-delà

L'atelier TWEPP '07, consacré à l'électronique pour la physique des particules, a rassemblé plus de 160 participants venant de laboratoires de physique des hautes énergies, d'instituts techniques spécialisés et de l'industrie. À l'heure où les expériences du LHC se trouvent bien engagées dans leur phase de mise en service, la réunion était l'occasion idéale de tirer les enseignements de plus d'une décennie de conception, de production et d'installation de systèmes électroniques pour les détecteurs, et d'envisager les nouveaux systèmes qui équiperont les futures installations. Les sujets abordés allaient de la gestion et la distribution du courant électrique jusqu'aux nouveautés en matière de liaisons optiques à grande largeur de bande.

Mike Letheren and **François Vasey**, CERN, on behalf of the TWEPP scientific committee.

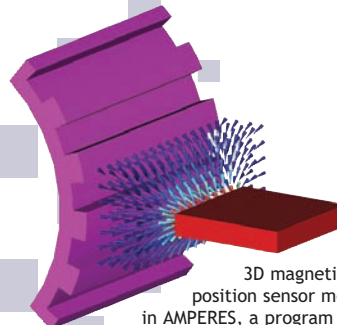
integrated

ELECTROMAGNETIC SIMULATION SOFTWARE



Photomultiplier tube modeled in LORENTZ, a program for analyzing particle trajectories, electron and ion beam optics. LORENTZ's calculations include full secondary emissions, emittance, spot size and radius. Image courtesy of ADIT.

ES' easy-to-use field solver software gives you fast and accurate answers.



3D magnetic position sensor modeled in AMPERES, a program for analyzing magnetic components incorporating linear, non-linear and permanent magnet materials. AMPERES' calculations include force, torque, flux linkage and inductance.

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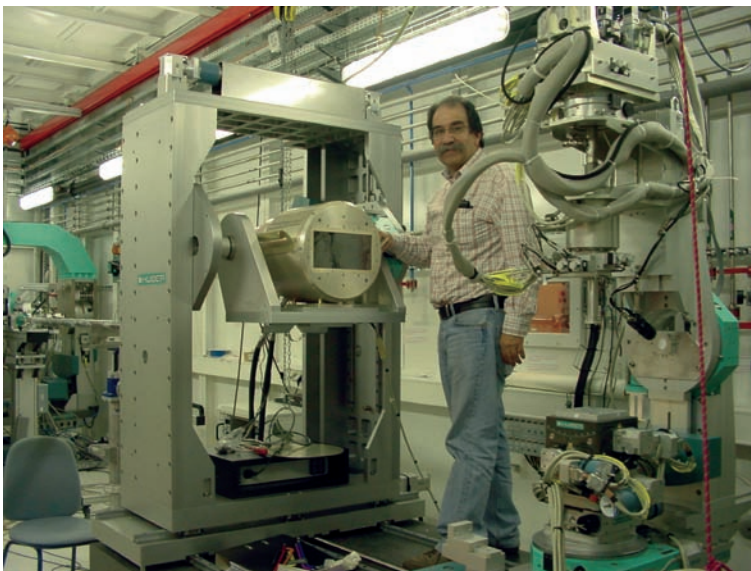
Photonic Science brings a new generation of CCD detectors for synchrotrons that deliver small and bright beams, with the aim of screening micro samples in a more flexible way.

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This requires simultaneous exposure and read out, with 100% duty cycle capability, and allows working at constant goniometer speed with excellent reproducibility when performing fine angular slicing.

Dynamic range and statistics can be then monitored via multiscans at constant speed and/or with dual scans at two different but constant speeds. This can only be achieved thanks to an excellent anti-blooming efficiency that can suppress saturation artifacts when merging dual scans together.

Keeping a small pixel size will maintain a tight PSF response and will also result in smaller working distances making the most of small convergent microbeams.



German Castro at the ESRF BM25 with the new VHR camera system

Diane BRAU

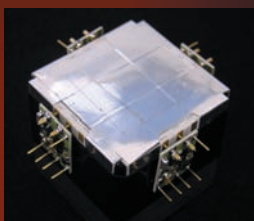
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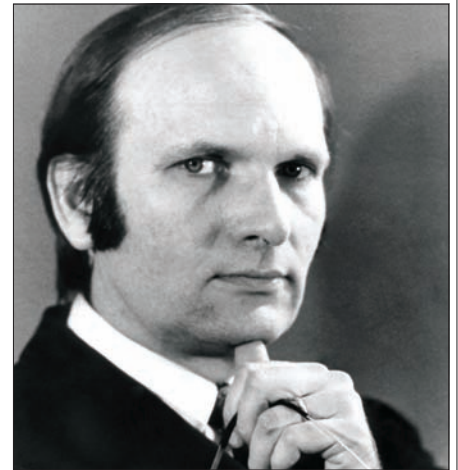
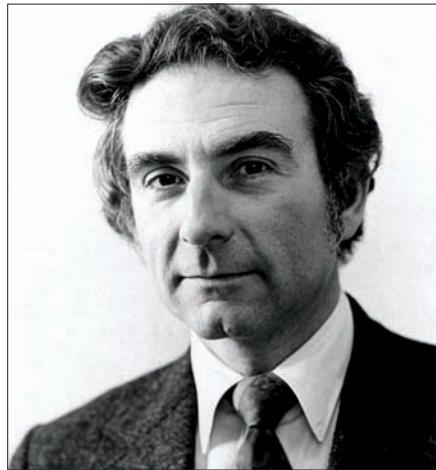
The model 411C, typical of the group, has a sensitivity of 0.1 V/A, a 3dB bandwidth from 25 Hz to 20 MHz, and a 5,000 amp peak current rating. Pulse rise times down to 20 nanoseconds can be viewed. Accuracy of 1%, or better, is obtainable across the mid-band.

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John Bardeen (left) Leon Cooper (centre) and Robert Schrieffer (right), proposed their theory of superconductivity in 1957. They received the Nobel Prize in Physics 15 years later in 1972. (Courtesy AIP Emilio Segrè Visual Archives, WF Meggers Gallery of Nobel Laureates.)

From BCS to the LHC

Steven Weinberg reflects on spontaneous symmetry breaking, and the connection between condensed-matter physics and particle physics, in a talk at the University of Illinois in Urbana, celebrating the 50th anniversary of the BCS theory of superconductivity.

It was a little odd for me, a physicist whose work has been mainly on the theory of elementary particles, to be invited to speak at a meeting of condensed-matter physicists celebrating a great achievement in their field. It is not only that there is a difference in the subjects that we explore. There are deep differences in our aims, in the kinds of satisfaction that we hope to get from our work.

Condensed-matter physicists are often motivated to deal with phenomena because the phenomena themselves are intrinsically so interesting. Who would not be fascinated by weird things, such as superconductivity, superfluidity, or the quantum Hall effect? On the other hand, I don't think that elementary-particle physicists are generally very excited by the phenomena they study. The particles themselves are practically featureless, every electron looking tediously just like every other electron.

Another aim of condensed-matter physics is to make discoveries that are useful. In contrast, although elementary-particle physicists like to point to the technological spin-offs from elementary-particle experimentation, and these are real, this is not the reason that we want these experiments to be done, and the knowledge gained by these experiments has no foreseeable practical applications.

Most of us do elementary-particle physics neither because of the intrinsic interestingness of the phenomena that we study, nor because of the practical importance of what we learn, but because we are pursuing a reductionist vision. All of the properties of ordinary matter are what they are because of the principles of atomic and nuclear physics, which are what they are because of the rules

of the Standard Model of elementary particles, which are what they are because...well, we don't know, this is the reductionist frontier, which we are currently exploring.

I think that the single most important thing accomplished by the theory of John Bardeen, Leon Cooper, and Robert Schrieffer (BCS) was to show that superconductivity is not part of the reductionist frontier (Bardeen *et al.* 1957). Before BCS this was not so clear. For instance, in 1933 Walter Meissner raised the question of whether electric currents in superconductors are carried by the known charged particles, electrons and ions. The great thing that Bardeen, Cooper, and Schrieffer showed was that no new particles or forces had to be introduced to understand superconductivity. According to a book on superconductivity that Cooper showed me, many physicists were even disappointed that "superconductivity should, on the atomistic scale, be revealed as nothing more than a footling small interaction between electrons and lattice vibrations". (Mendelssohn 1966).

The claim of elementary-particle physicists to be leading the exploration of the reductionist frontier has at times produced resentment among condensed-matter physicists. (This was not helped by a distinguished particle theorist, who was fond of referring to condensed-matter physics as "squalid state physics".) This resentment surfaced during the debate over the funding of the Superconducting Super Collider (SSC). I remember that Phil Anderson and I testified in the same Senate committee hearing on the issue, he against the SSC and I for it. His testimony was so scrupulously honest that I think >

SYMMETRY BREAKING

it helped the SSC more than it hurt it. What really did hurt was a statement opposing the SSC by a condensed-matter physicist who happened at the time to be the president of the American Physical Society. As everyone knows, the SSC project was cancelled, and now we are waiting for the LHC at CERN to get us moving ahead again in elementary-particle physics.

During the SSC debate, Anderson and other condensed-matter physicists repeatedly made the point that the knowledge gained in elementary-particle physics would be unlikely to help them to understand emergent phenomena like superconductivity. This is certainly true, but I think beside the point, because that is not why we are studying elementary particles; our aim is to push back the reductive frontier, to get closer to whatever simple and general theory accounts for everything in nature. It could be said equally that the knowledge gained by condensed-matter physics is unlikely to give us any direct help in constructing more fundamental theories of nature.

So what business does a particle physicist like me have at a celebration of the BCS theory? (I have written just one paper about superconductivity, a paper of monumental unimportance, which was treated by the condensed-matter community with the indifference it deserved.) Condensed-matter physics and particle physics are relevant to each other, despite everything I have said. This is because, although the knowledge gained in elementary-particle physics is not likely to be useful to condensed-matter physicists, or vice versa, experience shows that the ideas developed in one field can prove very useful in the other. Sometimes these ideas become transformed in translation, so that they even pick up a renewed value to the field in which they were first conceived.

The example that concerns me is an idea that elementary-particle physicists learned from condensed-matter theory – specifically from the BCS theory. It is the idea of spontaneous symmetry breaking.

Spontaneous symmetry breaking

In particle physics we are particularly interested in the symmetries of the laws of nature. One of these symmetries is invariance of the laws of nature under the symmetry group of three-dimensional rotations, or in other words, invariance of the laws that we discover under changes in the orientation of our measuring apparatus.

When a physical system does not exhibit all the symmetries of the laws by which it is governed, we say that these symmetries are spontaneously broken. A very familiar example is spontaneous magnetization. The laws governing the atoms in a magnet are perfectly invariant under three-dimensional rotations, but at temperatures below a critical value, the spins of these atoms spontaneously line up in some direction, producing a magnetic field. In this case, and as often happens, a subgroup is left invariant: the two-dimensional group of rotations around the direction of magnetization.

Now to the point. A superconductor of any kind is nothing more or less than a material in which a particular symmetry of the laws of nature, electromagnetic gauge invariance, is spontaneously broken. This is true of high-temperature superconductors, as well as the more familiar superconductors studied by BCS. The symmetry group here is the group of two-dimensional rotations. These rotations act on a two-dimensional vector, whose two components are the real and imaginary parts of the electron field, the quantum mechanical operator that in quantum field theories of matter destroys electrons. The rotation angle of the broken symmetry group can vary with location

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Theory of Superconductivity*

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(Received July 8, 1957)

A theory of superconductivity is presented, based on the fact that the interaction between electrons resulting from virtual exchange of phonons is attractive when the energy difference between the electron states involved is less than the phonon energy, $\hbar\omega$. It is favorable to form a superconducting phase when this attractive interaction dominates the repulsive screened Coulomb interaction. The normal phase is described by the Bloch individual-particle model. The ground state of a superconductor, formed from a linear combination of normal state configurations in which electrons are virtually excited in pairs of opposite spin and momentum, is lower in energy than the normal state by amount proportional to an average $(\hbar\omega)^2$, consistent with the isotope effect. A mutually orthogonal set of excited states in

one-to-one correspondence with those of the normal phase is obtained by specifying occupation of certain Bloch states and by using the rest to form a linear combination of virtual pair configurations. The theory yields a second-order phase transition and a Meissner effect in the form suggested by Pippard. Calculated values of specific heats and penetration depths and their temperature variation are in good agreement with experiment. There is an energy gap for individual-particle excitations which decreases from about $3.5kT_c$ at $T=0^\circ\text{K}$ to zero at T_c . Tables of matrix elements of single-particle operators between the excited-state superconducting wave functions, useful for perturbation expansions and calculations of transition probabilities, are given.

I. INTRODUCTION

THE main facts which a theory of superconductivity must explain are (1) a second-order phase transition at the critical temperature, T_c , (2) an electronic specific heat varying as $\exp(-T_c/T)$ near $T=0^\circ\text{K}$ and other evidence for an energy gap for individual particle-like excitations, (3) the Meissner-Ochsenfeld effect ($B=0$), (4) effects associated with infinite conductivity ($E=0$), and (5) the dependence of T_c on isotopic mass, $T_c \propto M^{-1/2}$. We present here a theory which accounts for all of these, and in addition gives good quantitative agreement for specific heats and penetration depths and their variation with temperature when evaluated from experimentally determined parameters of the theory.

When superconductivity was discovered by Onnes¹ (1911), and for many years afterwards, it was thought to consist simply of a vanishing of all electrical resistance below the transition temperature. A major advance was the discovery of the Meissner effect² (1933), which showed that a superconductor is a perfect diamagnet; magnetic flux is excluded from all but a

basic. F. London⁴ suggested a quantum-theoretic approach to a theory in which it was assumed that there is somehow a coherence or rigidity in the superconducting state such that the wave functions are not modified very much when a magnetic field is applied. The concept of coherence has been emphasized by Pippard,⁵ who, on the basis of experiments on penetration phenomena, proposed a nonlocal modification of the London equations in which a coherence distance, ξ_0 , is introduced. One of the authors^{6,7} pointed out that an energy-gap model would most likely lead to the Pippard version, and we have found this to be true of the present theory. Our theory of the diamagnetic aspects thus follows along the general lines suggested by London and by Pippard.⁷

The Sommerfeld-Bloch individual-particle model (1928) gives a fairly good description of normal metals, but fails to account for superconductivity. In this theory, it is assumed that in first approximation one may neglect correlations between the positions of the electrons and assume that each electron moves independently in some sort of self-consistent field determined by the other conduction electrons and the ions.

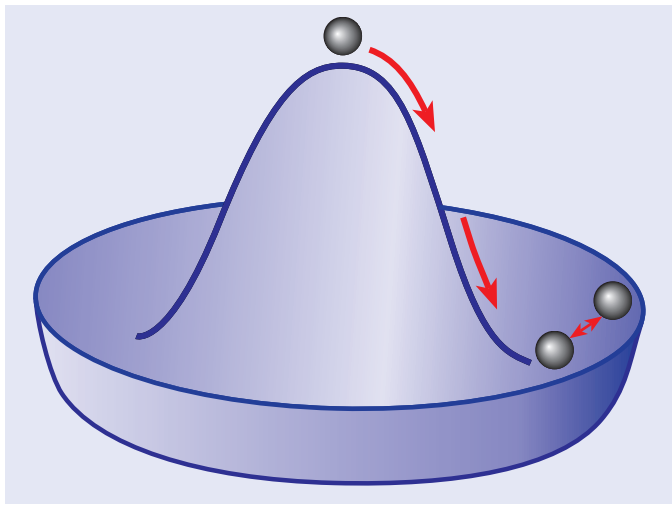
The BCS paper, published in Physical Review on 1 December 1957.

in the superconductor, and then the symmetry transformations also affect the electromagnetic potentials, a point to which I will return.

The symmetry breaking in a superconductor leaves unbroken a rotation by 180° , which simply changes the sign of the electron field. In consequence of this spontaneous symmetry breaking, products of any even number of electron fields have non-vanishing expectation values in a superconductor, though a single electron field does not. All of the dramatic exact properties of superconductors – zero electrical resistance, the expelling of magnetic fields from superconductors known as the Meissner effect, the quantization of magnetic flux through a thick superconducting ring, and the Josephson formula for the frequency of the AC current at a junction between two superconductors with different voltages – follow from the assumption that electromagnetic gauge invariance is broken in this way, with no need to inquire into the mechanism by which the symmetry is broken.

Condensed-matter physicists often trace these phenomena to the appearance of an “order parameter”, the non-vanishing mean value of the product of two electron fields, but I think this is misleading. There is nothing special about two electron fields; one might just as well take the order parameter as the product of three electron fields and the complex conjugate of another electron field. The important thing is the broken symmetry, and the unbroken subgroup.

It may then come as a surprise that spontaneous symmetry breaking is mentioned nowhere in the seminal paper of Bardeen, Cooper and Schrieffer. Their paper describes a mechanism by which electromagnetic gauge invariance is in fact broken, but they derived the properties of superconductors from their dynamical model, not from the mere fact of broken symmetry. I am not saying that Bardeen, Cooper, and Schrieffer did not know of this spontaneous symmetry breaking. Indeed, there was already a large literature on the apparent violation of gauge invariance in phenomenological theories of superconductivity, the fact that the electric current produced by an electromagnetic field in a superconductor



A Mexican hat illustrates the Goldstone theorem. Though the hat is invariant under rotations about a vertical axis, a small ball will come to rest off the axis of symmetry, somewhere on the brim of the hat, but it can move freely with no restoring force around the brim. Broken approximate symmetry is illustrated by slightly tilting the hat; this produces a small restoring force, analogous to the small mass of the pion.

depends on a quantity known as the vector potential, which is not gauge invariant. But their attention was focused on the details of the dynamics rather than the symmetry breaking.

This is not just a matter of style. As BCS themselves made clear, their dynamical model was based on an approximation, that a pair of electrons interact only when the magnitude of their momenta is very close to a certain value, known as the Fermi surface. This leaves a question: How can you understand the exact properties of superconductors, like exactly zero resistance and exact flux quantization, on the basis of an approximate dynamical theory? It is only the argument from exact symmetry principles that can fully explain the remarkable exact properties of superconductors.

Though spontaneous symmetry breaking was not emphasized in the BCS paper, the recognition of this phenomenon produced a revolution in elementary-particle physics. The reason is that (with certain qualification, to which I will return), whenever a symmetry is spontaneously broken, there must exist excitations of the system with a frequency that vanishes in the limit of large wavelength. In elementary-particle physics, this means a particle of zero mass.

The first clue to this general result was a remark in a 1960 paper by Yoichiro Nambu, that just such collective excitations in superconductors play a crucial role in reconciling the apparent failure of gauge invariance in a superconductor with the exact gauge invariance of the underlying theory governing matter and electromagnetism. Nambu speculated that these collective excitations are a necessary consequence of this exact gauge invariance.

A little later, Nambu put this idea to good use in particle physics. In nuclear beta decay an electron and neutrino (or their antiparticles) are created by currents of two different kinds flowing in the nucleus, known as vector and axial vector currents. It was known that the vector current was conserved, in the same sense as the ordinary electric current. Could the axial current also be conserved?

The conservation of a current is usually a symptom of some symmetry of the underlying theory, and holds whether or not the

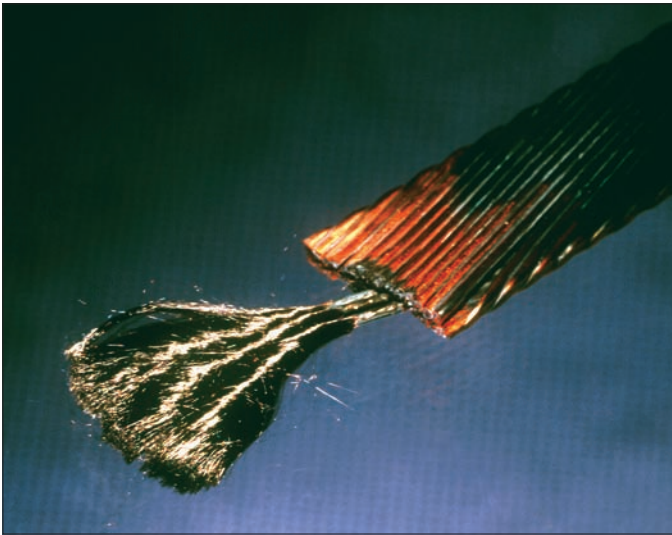
symmetry is spontaneously broken. For the ordinary electric current, this symmetry is electromagnetic gauge invariance. Likewise, the vector current in beta decay is conserved because of the isotopic spin symmetry of nuclear physics. One could easily imagine several different symmetries, of a sort known as chiral symmetries, that would entail a conserved axial vector current. However, it seemed that any such chiral symmetries would imply either that the nucleon mass is zero, which is certainly not true, or that there must exist a triplet of massless strongly interacting particles of zero spin and negative parity, which isn't true either. These two possibilities simply correspond to the two possibilities that the symmetry, whatever it is, either is not, or is, spontaneously broken, not just in some material like a superconductor, but even in empty space.

Nambu proposed that there is indeed such a symmetry, and it is spontaneously broken in empty space, but the symmetry in addition to being spontaneously broken is not exact to begin with, so the particle of zero spin and negative parity required by the symmetry breaking is not massless, only much lighter than other strongly interacting particles. This light particle, he recognized, is nothing but the pion, the lightest and first discovered of all the mesons. In a subsequent paper with Giovanni Jona-Lasinio, Nambu presented an illustrative theory in which, with some drastic approximations, a suitable chiral symmetry was found to be spontaneously broken, and in consequence the light pion appeared as a bound state of a nucleon and an antinucleon.

So far, there was no proof that broken exact symmetries always entail exactly massless particles, just a number of examples of approximate calculations in specific theories. In 1961 Jeffrey Goldstone gave some more examples of this sort, and a hand-waving proof that this was a general result. Such massless particles are today known as Goldstone bosons, or Nambu–Goldstone bosons. Soon after, Goldstone, Abdus Salam and I made this into a rigorous and apparently quite general theorem.

Cosmological fluctuations

This theorem has applications in many branches of physics. One is cosmology. You may know that today the observation of fluctuations in the cosmic microwave background are being used to set constraints on the nature of the exponential expansion, known as inflation, that is widely believed to have preceded the radiation-dominated Big Bang. But there is a problem here. In between the end of inflation and the time that the microwave background that we observe was emitted, there intervened a number of events that are not at all understood: the heating of the universe after inflation, the production of baryons, the decoupling of cold dark matter, and so on. So how is it possible to learn anything about inflation by studying radiation that was emitted long after inflation, when we don't understand what happened in between? The reason that we can get away with this is that the cosmological fluctuations now being studied are of a type, known as adiabatic, that can be regarded as the Goldstone excitations required by a symmetry, related to general co-ordinate invariance, that is spontaneously broken by the space–time geometry. The physical wavelengths of these cosmological fluctuations were stretched out by inflation so much that they were very large during the epochs when things were happening that we don't understand, so they then had zero frequency, which means that the amplitude of these fluctuations was not changing, so that the value of the amplitude relatively close to the present tells us what it was during inflation. ▷



Superconducting cable (left) the heart of the magnets for the LHC at CERN (right), where experiments will search for the Higgs boson.

But in particle physics, this theorem was at first seen as a disappointing result. There was a crazy idea going around, which I have to admit that at first I shared, that somehow the phenomenon of spontaneous symmetry breaking would explain why the symmetries being discovered in strong-interaction physics were not exact. Werner Heisenberg continued to believe this into the 1970s, when everyone else had learned better.

The prediction of new massless particles, which were ruled out experimentally, seemed in the early 1960s to close off this hope. But it was a false hope anyway. Except under special circumstances, a spontaneously broken symmetry does not look at all like an approximate unbroken symmetry; it manifests itself in the masslessness of spin-zero bosons, and in details of their interactions. Today we understand approximate symmetries such as isospin and chiral invariance as consequences of the fact that some quark masses, for some unknown reason, happen to be relatively small.

Though based on a false hope, this disappointment had an important consequence. Peter Higgs, Robert Brout and François Englert, and Gerald Guralnik, Dick Hagen and Tom Kibble were all led to look for, and then found, an exception to the theorem of Goldstone, Salam and me. The exception applies to theories in which the underlying physics is invariant under local symmetries, symmetries whose transformations, like electromagnetic gauge transformations, can vary from place to place in space and time. (This is in contrast with the chiral symmetry associated with the axial vector current of beta decay, which applies only when the symmetry transformations are the same throughout space–time.) For each local symmetry there must exist a vector field, like the electromagnetic field, whose quanta would be massless if the symmetry was not spontaneously broken. The quanta of each such field are particles with helicity (the component of angular momentum in the direction of motion) equal in natural units to +1 or –1. But if the symmetry is spontaneously broken, these two helicity states join up with the helicity-zero state of the Goldstone boson to form the three helicity states of a massive particle of spin one. Thus, as shown by Higgs, Brout and Englert, and Guralnik, Hagen and Kibble, when a local symmetry is spontaneously broken, neither the vector particles with which the symmetry is associated nor the Nambu–Goldstone particles produced by the symmetry breaking have zero mass.

This was actually argued earlier by Anderson, on the basis of the example provided by the BCS theory. But the BCS theory is non-relativistic, and the Lorentz invariance that is characteristic of special relativity had played a crucial role in the theorem of Goldstone, Salam and me, so Anderson’s argument was generally ignored by particle theorists. In fact, Anderson was right: the reason for the exception noted by Higgs *et al.* is that it is not possible to quantize a theory with a local symmetry in a way that preserves both manifest Lorentz invariance and the usual rules of quantum mechanics, including the requirement that probabilities be positive. In fact, there are two ways to quantize theories with local symmetries: one way that preserves positive probabilities but loses manifest Lorentz invariance, and another that preserves manifest Lorentz invariance but seems to lose positive probabilities, so in fact these theories actually do respect both Lorentz invariance and positive probabilities; they just don’t respect our theorem.

Effective field theories

The appearance of mass for the quanta of the vector bosons in a theory with local symmetry re-opened an old proposal of Chen Ning Yang and Robert Mills, that the strong interactions might be produced by the vector bosons associated with some sort of local symmetry, more complicated than the familiar electromagnetic gauge invariance. This possibility was specially emphasized by Brout and Englert. It took a few years for this idea to mature into a specific theory, which then turned out not to be a theory of strong interactions.

Perhaps the delay was because the earlier idea of Nambu, that the pion was the nearly massless boson associated with an approximate chiral symmetry that is not a local symmetry, was looking better and better. I was very much involved in this work, and would love to go into the details, but that would take me too far from BCS. I’ll just say that, from the effort to understand processes involving any number of low-energy pions beyond the lowest order of perturbation theory, we became comfortable with the use of effective field theories in particle physics. The mathematical techniques developed in this work in particle physics were then used by Joseph Polchinski and others to justify the approximations made by BCS in their work on superconductivity.

The story of the physical application of spontaneously broken local symmetries has often been told, by me and others, and I don't want to take much time on it here, but I can't leave it out altogether because I want to make a point about it that will take me back to the BCS theory. Briefly, in 1967 I went back to the idea of a theory of strong interactions based on a spontaneously broken local symmetry group, and right away, I ran into a problem: the subgroup consisting of ordinary isospin transformations is not spontaneously broken, so there would be a massless vector particle associated with these transformations with the spin and charges of the ρ meson. This, of course, was in gross disagreement with observation; the ρ meson is neither massless nor particularly light.

Then it occurred to me that I was working on the wrong problem. What I should have been working on were the weak nuclear interactions, like beta decay. There was just one natural choice for an appropriate local symmetry, and when I looked back at the literature I found that the symmetry group I had decided on was one that had already been proposed in 1961 by Sheldon Glashow, though not in the context of an exact spontaneously broken local symmetry. (I found later that the same group had also been considered by Salam and Robert Ward.) Even though it was now exact, the symmetry when spontaneously broken would yield massive vector particles, the charged W particles that had been the subject of theoretical speculation for decades, and a neutral particle, which I called the Z particle, to mediate a "neutral current" weak interaction, which had not yet been observed. The same symmetry breaking also gives mass to the electron and other leptons, and in a simple extension of the theory, to the quarks. This symmetry group contained electromagnetic gauge invariance, and since this subgroup is clearly not spontaneously broken (except in superconductors), the theory requires a massless vector particle, but it is not the ρ meson, it is the photon, the quantum of light. This theory, which became known as the electroweak theory, was also proposed independently in 1968 by Salam.

The mathematical consistency of the theory, which Salam and I had suggested but not proved, was shown in 1971 by Gerard 't Hooft; neutral current weak interactions were found in 1973; and the W and Z particles were discovered at CERN a decade later. Their detailed properties are just those expected according to the electroweak theory.

There was (and still is) one outstanding issue: just how is the local electroweak symmetry broken? In the BCS theory, the spontaneous breakdown of electromagnetic gauge invariance arises because of attractive forces between electrons near the Fermi surface. These forces don't have to be strong; the symmetry is broken however weak these forces may be. But this feature occurs only because of the existence of a Fermi surface, so in this respect the BCS theory is a misleading guide for particle physics. In the absence of a Fermi surface, dynamical spontaneous symmetry breakdown requires the action of strong forces. There are no forces acting on the known quarks and leptons that are anywhere strong enough to produce the observed breakdown of the local electroweak symmetry dynamically, so Salam and I did not assume a dynamical symmetry breakdown; instead we introduced elementary scalar fields into the theory, whose vacuum expectation values in the classical approximation would break the symmetry.

This has an important consequence. The only elementary scalar

quanta in the theory that are eliminated by spontaneous symmetry breaking are those that become the helicity-zero states of the W and Z vector particles. The other elementary scalars appear as physical particles, now generically known as Higgs bosons. It is the Higgs boson predicted by the electroweak theory of Salam and me that will be the primary target of the new LHC accelerator, to be completed at CERN sometime in 2008.

But there is another possibility, suggested independently in the late 1970s by Leonard Susskind and me. The electroweak symmetry might be broken dynamically after all, as in the BCS theory. For this to be possible, it is necessary to introduce new extra-strong forces, known as technicolour forces, that act on new particles, other than the known quarks and leptons. With these assumptions, it is easy to get the right masses for the W and Z particles and large masses for all the new particles, but there are serious difficulties in giving masses to the ordinary quarks and leptons. Still, it is possible that experiments at the LHC will not find Higgs bosons, but instead will find a great variety of heavy new particles associated with technicolour. Either way, the LHC is likely to settle the question of how the electroweak symmetry is broken.

It would have been nice if we could have settled this question by calculation alone, without the need for the LHC, in the way that Bardeen, Cooper and Schrieffer were able to find how electromagnetic gauge invariance is broken in a superconductor by applying the known principles of electromagnetism. But that is just the price we in particle physics have to pay for working in a field whose underlying principles are not yet known.

Further reading

J Bardeen, LN Cooper and JR Schrieffer 1957 *Phys. Rev.* **108** 1175.

K Mendelssohn 1966 *The Quest for Absolute Zero* (McGraw-Hill, New York).

- This article is based on the talk given by Steven Weinberg at BCS@50, held on 10–13 October 2007 at the University of Illinois at Urbana–Champaign to celebrate the 50th anniversary of the BCS paper. For more about the conference see www.conferences.uiuc.edu/bcs50/.

Résumé

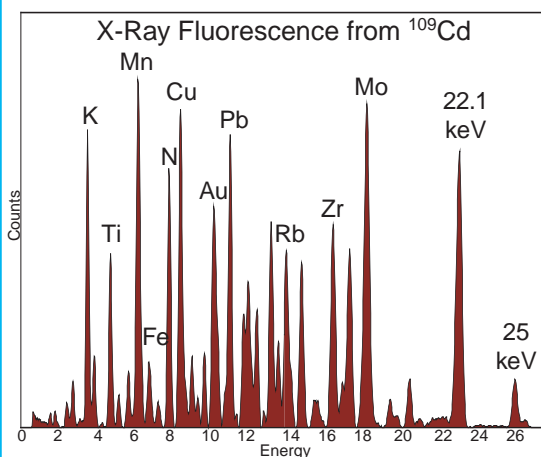
De la théorie BCS à la machine LHC

Lors d'un colloque organisé à l'occasion du cinquantenaire de la théorie BCS de la supraconductivité, Steven Weinberg fait part de ses réflexions sur la rupture spontanée de la symétrie et les liens entre la physique de la matière condensée et la physique des particules. En particulier, les physiciens des particules ont repris de la théorie BCS l'idée de la rupture spontanée de la symétrie, et Weinberg et Abdus Salam l'ont utilisée pour mettre au point la théorie électrofaible, pour laquelle, conjointement avec Sheldon Glashow, ils ont reçu le prix Nobel en 1979. À présent, le LHC s'appête à régler la question du processus exact de la rupture de la symétrie électrofaible: s'agit-il du mécanisme de Higgs ou y a-t-il une autre explication?

Steven Weinberg, University of Texas at Austin.

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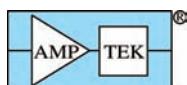


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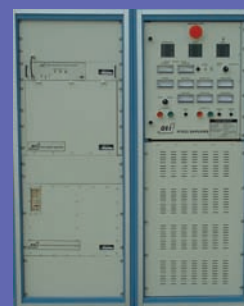
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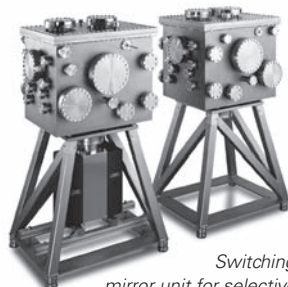
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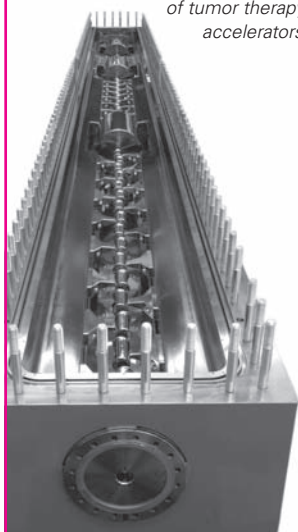


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CPT '07 goes in quest of Lorentz violation

Indiana University's 2007 meeting on CPT and Lorentz symmetry highlighted the intense activity of the physics community in testing Lorentz symmetry and other fundamental properties of nature.

Lorentz symmetry and the closely related CPT symmetry, which combines charge conjugation (C), parity reversal (P) and time reversal (T), are well tested properties of nature. Nevertheless, efforts to find experimental evidence of Lorentz and CPT violation have increased in number, motivated in part by the quest for a theory to unite quantum mechanics and gravity. Further impetus has come from the introduction of a framework for Lorentz and CPT violation known as the Standard Model Extension (SME) which encompasses the panorama of physical theories. Since its development by Alan Kostelecký and co-workers at Indiana University in the 1990s, the SME has been used widely to guide experimental efforts and allow comparisons of results from different experiments.

This field is the topic of a series of meetings that have run triennially since 1998 at the Indiana University physics department, bringing together researchers to share results and ideas. In 2007, the fourth meeting on Lorentz and CPT Symmetry (CPT '07) was held on 8–11 August, with contributed and invited talks, and a poster session during the conference reception.

The meeting opened with a welcome from Bennett Bertenthal, dean of the university's College of Arts and Sciences. Ron Walsworth of Harvard University and the Harvard Smithsonian Center for Astrophysics gave the first scientific talk, in which he reflected on the progress in experimental studies of Lorentz violation since 1997, when the SME coefficients first appeared in their current form. He also discussed his group's current work to upgrade its noble-gas maser, with the aim of improving the sensitivity to a variety of SME coefficients.

Accelerator-based tests

The SME has opened a rich variety of possibilities for Lorentz violation in the context of neutrino oscillations. Recent work has shown that some, or perhaps even all, of the oscillation effects seen in existing data may be attributable to Lorentz violation. Talks included a presentation by Rex Tayloe of the MiniBooNe collaboration at Fermilab, who provided an overview of the recent data and considered their relation to earlier results from the



Alan Kostelecký of Indiana University (left), originator of the Standard Model Extension, and neutrino experimentalist Kerry Whisnant of Iowa State University. (Courtesy N Russell.)

Liquid Scintillator Neutrino Detector experiment at Los Alamos. He also discussed the three-parameter “tandem” model based on SME coefficients.

The physics of neutral-meson oscillations provides an abundance of theoretical possibilities for Lorentz and CPT violation that can be tested in current and planned experiments. Antonio Di Domenico of the KLOE collaboration showed the first results of a search for CPT-violating effects using K mesons at the DAΦNE collider in Frascati. New results also came from David Stoker of University of California, Irvine, who presented the first constraints on all four coefficients for CPT violation in the B_d system, based on results from the BaBar experiment at SLAC.

Possible signals of Lorentz violation in the muon system hinge on variations in the anomaly frequency, which could be detected by performing instantaneous frequency comparisons and sidereal-variation searches. The results described by Lee Roberts from Boston University and the Muon ($g-2$) Collaboration at Brookhaven represent the highest-sensitivity test of Lorentz and CPT violation for leptons, and improve previous results with muonium, electrons and positrons by about an order of magnitude.

Lorentz and CPT violation may be detectable using antihydrogen spectroscopy. Such tests would involve looking for sidereal changes in the spectra, or looking for direct differences between the spectra of antihydrogen and conventional hydrogen. Theoretical considerations have shown that the hyperfine transitions are of particular interest in these tests. Ryugo Hayano, spokesperson for the ASACUSA collaboration at CERN, provided details of his group's progress towards tests of this type (see p9). Niels Madsen of Swansea gave an overview of the status of the ALPHA ▷



The official logo of the CPT '07 meeting shows two clocks with features and relationships symbolizing concepts that are related to Lorentz violation. For an animated version of the logo see the web at www.indiana.edu/~cpt07/program.html. (Courtesy M Mewes.)

experiment at CERN, which has the potential to test Lorentz and CPT symmetry in a variety of ways using trapped antihydrogen (*CERN Courier* July/August 2007 p13).

Gravitational and astrophysical effects

There have been extensive studies of signals of Lorentz violation in the gravitational sector during the past few years, and the results include the identification of 20 coefficients for Lorentz violation in the pure-gravity sector of the minimal SME. The meeting featured presentations of the first ever measurements of SME coefficients in the gravitational sector by two experimental groups. Holger Müller of Stanford University announced measurements of seven such coefficients for Lorentz violation, based on work with Mach–Zehnder atom interferometry. Other first results were unveiled by James Battat of Harvard University, placing limits on six gravitational-sector SME coefficients from the analysis of more than three decades of archival lunar-laser-ranging data from the McDonald Observatory in Texas and the Observatoire de la Côte d'Azur in France. The Apache Point Observatory in New Mexico should achieve further improvements in lunar-laser ranging, down to a sensitivity level of 1 mm, as Tom Murphy of the University of California at San Diego explained.

The fundamental nature of Lorentz symmetry means that there are subtle conceptual issues to be addressed. Roman Jackiw of MIT considered one example, and showed that symmetry breaking may be a mask for co-ordinate choice in a diffeomorphism invariant theory. Robert Bluhm of Colby College in Maine provided a comprehensive discussion of the Nambu–Goldstone and massive fluctuation modes about the vacuum in gravitational theories. Other theoretical topics included approaches to deriving the Dirac equation in theories that violate Lorentz symmetry, presented by Claus Lämmerzahl of Bremen University, and Chern–Simons electromagnetism, which Ralf Lehnert of MIT described.

Satellites offer unique opportunities to probe Lorentz symmetry in a low-gravity environment. Tim Sumner of Imperial College gave an overview of approaches to space-based experiments with high-sensitivity instruments, and looked at ESA's upcoming plans. James Overduin of Stanford University likewise reviewed the ongoing analysis of data from the Gravity Probe B satellite.

Cosmological and astrophysical sources also provide a number of intriguing possibilities for testing the fundamental laws and symmetries of nature. Matt Mewes of Marquette University presented recent work using the cosmic microwave background to place limits on Lorentz-violation coefficients in the renormalizable and non-renormalizable sectors of the SME. The Pioneer anomaly – apparent deviations in the paths of spacecraft in the outer solar system, such as the Pioneer 10 and 11 – provides a possibility for new physics, as Michael Nieto of Los Alamos described, giving

perspectives on the underlying physics that may be responsible for the observations. Synchrotron radiation and inverse Compton scattering from high-energy astrophysical sources may also show sensitivity to a variety of SME coefficients, as Brett Altschul of the University of South Carolina explained.

Atomic-physics tests

There have been tests of the electromagnetic sector of the SME for several years using low-energy experiments that include optical and microwave cavity oscillators, torsion pendulums, atomic clocks, and interferometric techniques. Experimental innovations have led to steadily improving resolutions and the ability to access better the geometrical components of the SME coefficient space.

Achim Peters of the Humboldt University in Berlin announced improvements by a factor of 30 on certain photon-sector SME coefficients using a cryogenic precision optical resonator on a rotating turntable. Another test in the photon sector has been performed by Michael Tobar of the University of Western Australia, who has used a Mach–Zehnder interferometer to improve the sensitivity to one particular coefficient by six orders of magnitude. The team at Princeton University has recently developed innovations for a second-generation comagnetometer. Sylvia Smullin and group leader Mike Romalis described this work, and also presented the results from the experiment's first-generation predecessor.

The Eöt-Wash torsion pendulum group at the University of Washington in Seattle has made major contributions to the search for Lorentz violation, including several of the tightest constraints on SME coefficients in the electron sector, which they recently generated using a spin-polarized torsion pendulum with a macroscopic intrinsic spin. Group member Blayne Heckel described preliminary results achieving yet greater sensitivity to a number of electron coefficients using a further refined version of the apparatus.

In all, the 2007 meeting on CPT and Lorentz symmetry highlighted the intense efforts of the physics community in testing Lorentz symmetry and other fundamental properties of nature. Should the minuscule traces of Lorentz violations be found, it would be a paradigm-changing event, leading to profound alterations to our current theories describing the forces of nature.

Résumé

CPT '07: à la recherche de la violation de la symétrie de Lorentz

La réunion 2007 sur la symétrie de Lorentz et la CPT a mis en évidence l'intense activité de la recherche en physique visant à mettre à l'épreuve la symétrie de Lorentz ainsi que d'autres propriétés fondamentales de la nature. Les efforts entrepris pour trouver une trace expérimentale de la violation de Lorentz et de la violation de CPT sont motivés en partie par la recherche d'une théorie permettant de concilier mécanique quantique et gravitation. D'autres apports sont venus de développements théoriques connus sous le nom d'extension du modèle standard. Lors de la réunion, il a été question de divers travaux d'expérimentation, allant d'expériences effectuées auprès d'accélérateurs de particules jusqu'à l'étude d'effets gravitationnels au moyen de la télémétrie laser lunaire.

Neil Russell, Northern Michigan University.

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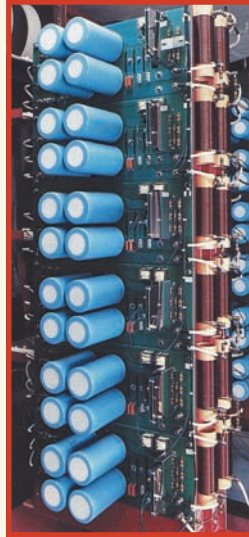


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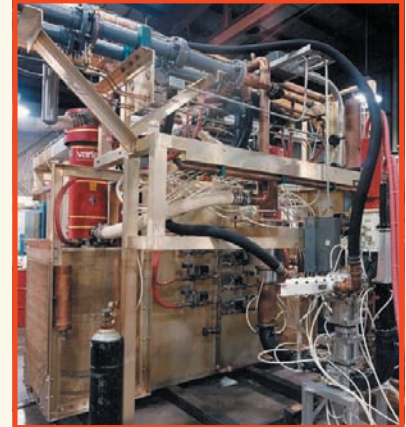
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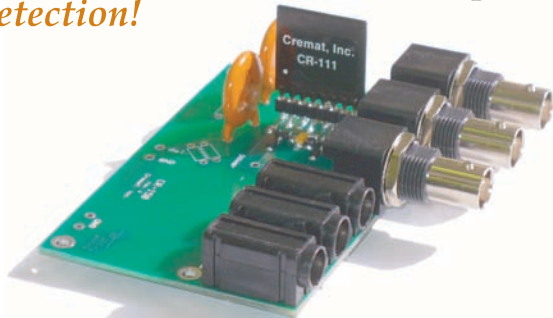
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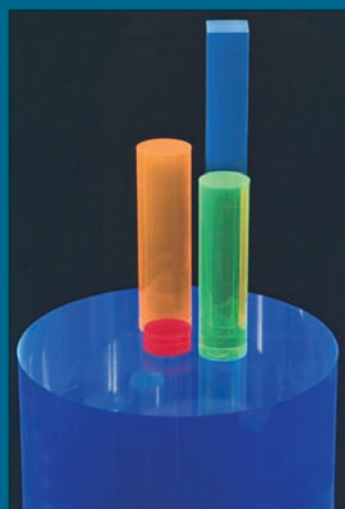
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Autumn leaves in New York's Lake Placid region provided a colourful backdrop to Vertex 2007. (Courtesy Stephan Hänsel, HEPHY Vienna.)

Vertex 2007 prepares for the radiation challenge

Scientists gathered at New York's stunning Lake Placid to review progress and future challenges in the use of vertex detectors, both in high-energy physics and other fields.

The use of precision position information at the level of a few micrometres has become an increasingly important part of high-energy physics experiments. The purpose of the annual International Workshop on Vertex Detectors is to review progress on silicon-based vertex detectors, investigate the possibilities of new materials and design structures, and discuss applications to medical and other fields. More than 70 physicists participated in the 16th meeting in the series, which was held at the Crowne Plaza Hotel in Lake Placid, New York, on 23–28 September and hosted by the high-energy physics group of Syracuse University. Lake Placid provided a splendid venue (at the height of the autumn tree colours) and created an inspiring atmosphere for excellent talks and discussions. The workshop also included a new poster session to showcase the work of bright young researchers.

The programme included extensive reviews of the almost completed systems for the major LHC experiments – ALICE, ATLAS, CMS and LHCb. The talks and informal discussions showed the

great progress there has been in commissioning these impressive systems with test beams and cosmic rays. As the experiments gear up for data-taking, the teams are validating and refining the tracking, alignment and vertex-reconstruction software tools. There are, however, concerns about exposing these detectors at frighteningly close distances to the beams in an accelerator that has not yet run. There were presentations of plans for experiment protection at the LHC, but the information provided did not quell the debate.

While everyone is eagerly awaiting data-taking at the LHC, there are already plans for upgrades and new facilities. The world community is poised to meet the challenges of vertex detectors for the proposed International Linear Collider, high-luminosity upgrades of the LHC – the Super LHC (SLHC) – and flavour physics experiments (a Super B-factory and an upgrade of the LHCb experiment). Many upgrade paths require vertex detectors with improved radiation hardness and higher segmentation to cope with the higher multiplicities and higher event rates. In addition, several ▷

DETECTORS

considerations, not the least of which is the amount of material, motivate the effort towards detector thinning.

Upgraded experiments will also require upgraded analysis tools. Many important new particles, such as Higgs bosons, are likely to decay into B particles. These leave displaced vertices, so algorithms that provide this information, especially in the earlier stages of the trigger processor, will be necessary. This is a paramount consideration in the LHCb upgrade and provides a strong motivation to pursue a pixel-based vertex detector.

Novel devices

A strong focus of this workshop centred on the evaluation of new devices developed to address a variety of the challenges posed by future projects. Radiation hardness, for example, is a critical consideration for SLHC upgrades. This is the motivation behind RD50, a large R&D effort based at CERN that involves scientists from all over the world. After years of R&D on a variety of technologies and structures, this group is now reaching important conclusions. In particular, devices using “n+” electrodes (pixels or strips) implanted on p-type substrates appear to be one of the most effective options to cope with increased radiation fluence. Speakers presented recent results and showed that microstrip detectors can still be operated after being irradiated at fluencies up to 10^{16} neutrons/cm², as required in the innermost layers at SLHC luminosities (figure 1). One plane of a strip-detector implemented on p-type substrates has been installed in LHCb, “the first full-scale SLHC silicon plane”. Although the traditional emphasis of this conference is on silicon-based technology, discussions also covered the naturally radiation-hard diamond detectors, in particular the promising single-crystal diamond devices.

The reduced collection distance achievable at high levels of irradiation has helped to inspire renewed interest in thinned silicon. The workshop learned that this performs just as well as “thick” 300- μ m detectors after sufficient radiation, as the charge cannot be collected out of the thicker sensors. In addition, examples were shown of detectors thinned down to 10 μ m that are functional and mechanically stable. Other novel detector concepts included 3-dimensional detectors; monolithic devices, where the readout chip is made on the same silicon substrate as used for the sensor; and DEPFET, where each pixel is a p-channel FET on a completely depleted bulk. Another interesting development is the so-called “3D integration”, featuring integration of the sensor and several layers of readout electronics, which is facilitated by the strong push towards miniaturization in the computer industry.

Silicon micropattern detectors are central to precision imaging in several areas of research, from medicine to biology, to astrophysics and astroparticle physics. The field is in rapid evolution and several interesting talks highlighted a broad spectrum of applications. Examples of imaging geared towards medical or biological applications included the MEDIPIX chip, 3H imaging, NANO-CT

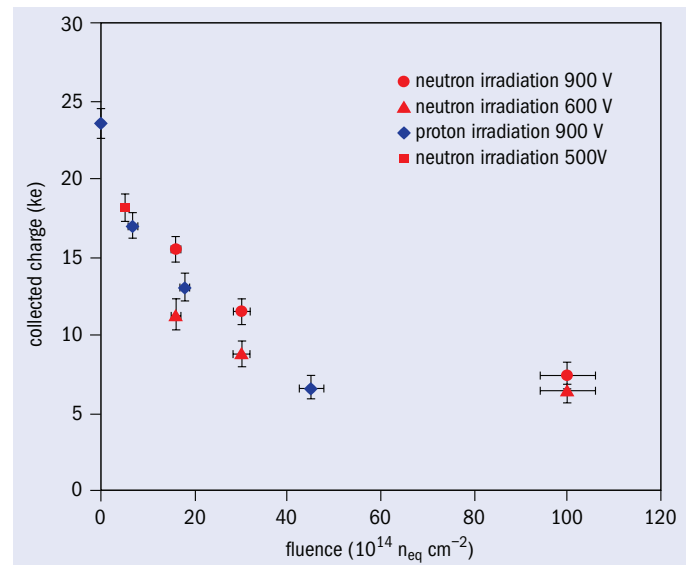


Fig. 1. Charge collection efficiency for microstrip detectors for fluences up to 10^{16} neutrons/cm² (Gianuigi Casse, RD50/Liverpool University).

scanning, and the PILATUS system – a pixelated hybrid silicon X-ray detector developed for protein crystallography at the Swiss Light Source (CERN Courier March 2007 p29). Astrophysics applications included PAMELA, now taking data in space, and the more futuristic EXIST, a proposed large-area telescope for X-ray astronomy.

• The next meeting in the series will be run by Richard Brenner and held near Stockholm in the summer.

Further reading

For more information visit <http://vertex2007.syr.edu>.

Résumé

Vertex 2007: des détecteurs résistant aux rayonnements

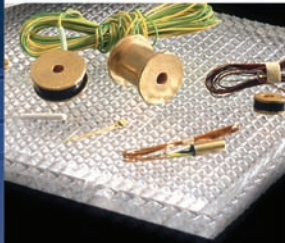
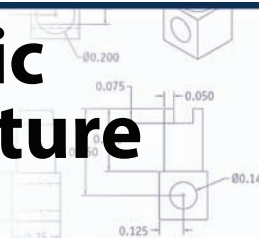
L'utilisation d'informations de position de précision au niveau de quelques microns est de plus en plus importante pour les expériences de physique des hautes énergies. Le but de l'atelier annuel international sur les détecteurs de vertex est d'examiner les progrès réalisés sur les détecteurs de vertex au silicium, de rechercher les possibilités de nouveaux matériaux et de nouvelles structures de conception, et d'envisager les applications au domaine médical et à d'autres domaines. La 16ème édition, tenue en septembre à Lake Placid, s'est penchée tout particulièrement sur les détecteurs de vertex destinés au LHC et aux machines futures, et sur de nouveaux systèmes permettant de satisfaire à des contraintes exigeantes, notamment en matière de rayonnements.

Marina Artuso and Sheldon Stone, Syracuse University.

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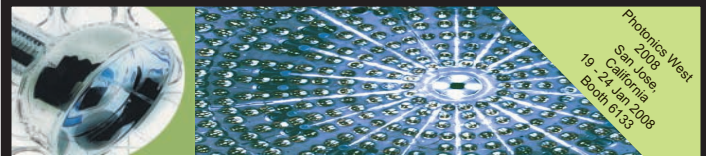
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Constructing HERA: r

At 11.28 p.m. on 30 June 2007, DESY's HERA collider was shut down after almost 16 years of operation. **Dieter Trines** looks back at the challenge of building the first and only electron–proton collider, based on a superconducting-magnet ring.

Ideas for an electron–proton collider based on storage rings first arose after the famous experimental results on deep inelastic electron–proton scattering from SLAC in 1969, which indicated a granular structure for the proton. Using two storage rings to collide electrons and protons head-on, rather than directing an electron beam at a proton target, would allow for higher centre-of-mass energies. This would in turn result in a better resolution for measurements of the internal structure of the proton. So, in the early 1970s, several laboratories – Brookhaven, CERN, DESY, Fermilab, IHEP (Moscow), Rutherford Laboratory, SLAC and TRIUMF – began to think about building an electron–proton collider.

At DESY, Bjørn Wiik in particular was a major advocate for the construction of an electron–proton collider. In 1972, Horst Gerke, Helmut Wiedemann, Günter Wolf and Wiik wrote a first report in which they proposed using the existing double-storage ring DORIS for electron–proton collisions. Then, in 1981, after several workshops organized by the European Committee for Future Accelerators (ECFA), DESY submitted a proposal to the government of the Federal Republic of Germany (FRG) for the construction of a completely new machine called HERA. It was to be an electron–proton collider with a circumference of 6.3 km and it had the strong support of the European high-energy physics community and ECFA.

Early discussions on electron–proton colliders had already considered the use of superconducting magnets for the proton ring. Then, in the 1980s, this demanding technology became feasible for large systems, thanks to the courageous and pioneering work at Fermilab on superconducting magnets for the construction of the Tevatron. When it came into operation in 1983, the Tevatron was the world's first superconducting synchrotron at high energies.

DESY had no major experience in this technology, so in 1979 Hartwig Kaiser and Siegfried Wolff were sent to work with colleagues at Fermilab and profit from their know-how. The successful dipole and quadrupole magnets developed at Fermilab naturally influenced the design of the superconducting accelerator magnets for HERA, and the first dipoles built at DESY were basically copies of the Fermilab magnets. However, with increasing experience, the physicists and engineers at DESY started to add major improvements of



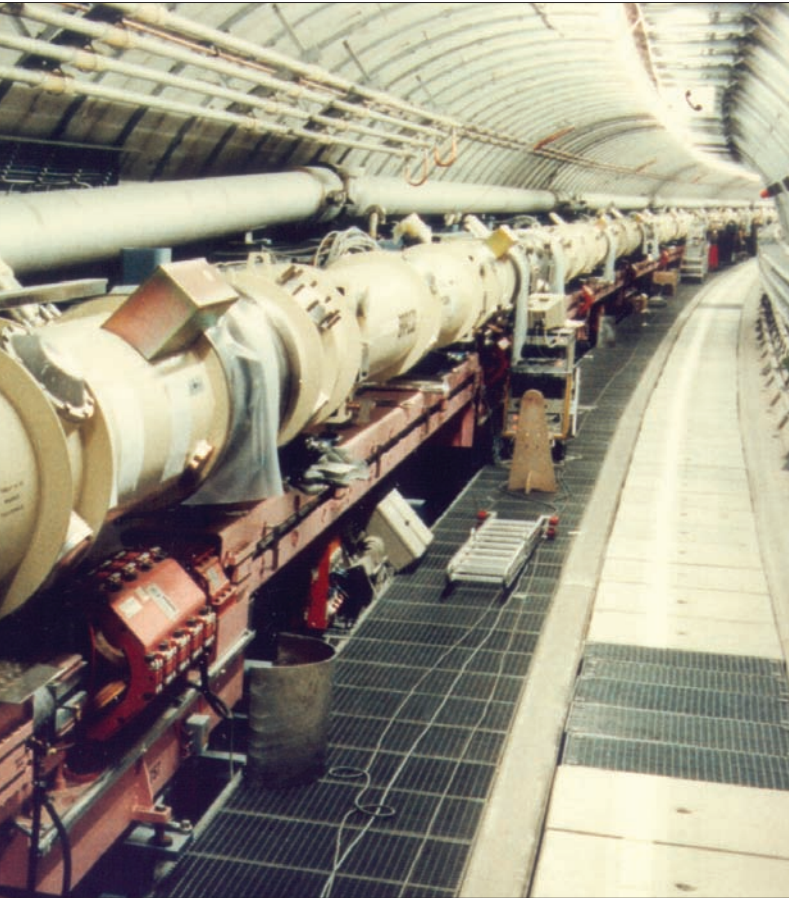
Inside the HERA tunnel: the proton accelerator with its superconducting magnets (be

their own, leading to the characteristic design of the HERA magnets, which proved extremely successful over the lifetime of the accelerator. As the superconducting magnet ring was the most challenging part of HERA, this article will focus on its design in particular.

The superconducting coil is the most critical component of a superconducting magnet. Coils several metres long are fabricated with cross-sections accurate to a few hundredths of a millimetre. This demanding task was solved at Fermilab by using laminated tooling for the production and curing of the coils. These are surrounded by collars punched from stainless-steel sheets, which provide the precise coil geometry and sustain the huge magnetic forces. Only special types of steel, which do not become brittle or magnetic at cryogenic temperatures, are suitable. For the coils of the HERA dipoles, the collars are made from an aluminium alloy with high yield-strength, thus eliminating magnetic effects.

In the HERA dipoles, this collaring is reinforced by the iron yoke, which, unlike its Fermilab counterpart, is located inside the cryostat. This “cold iron” concept has several advantages. First, it leads

rising to the challenge



... lies above the normally conducting magnets of the electron ring. (Courtesy DESY.)



Bjørn Wiik in the HERA tunnel. The “father” of the HERA electron–proton collider went on to become director of DESY. (Courtesy DESY.)

to an additional gain of 12% in the central magnetic field, as the iron is closer to the coil. Second, the cryogenic load at 4 K is reduced as a result of the longer support rods. Finally, a passive protection scheme with parallel diodes can protect the coil against damage from the stored energy should it become normally conducting (quench). The resulting larger cold mass leads to longer cool-down and warm-up times of about five days. However, this turned out to be no drawback as there were only a few occasions during the whole lifetime of HERA, outside regular shutdowns, when the magnets had to be warmed up. Hartwig Kaiser, Karl Hubert Mess and Peter Schmüser were the main people responsible for this development.

In a superconducting magnet ring, the protection of the coils against quenches is of utmost importance and is a challenging technology in itself. It involves both the detection of a quench (by monitoring the voltage over the coils) and the installation of quench heaters to force the quenching coil to become normally conducting, thus distributing the energy deposited by the magnet current over its whole length. As many magnet coils are powered serially

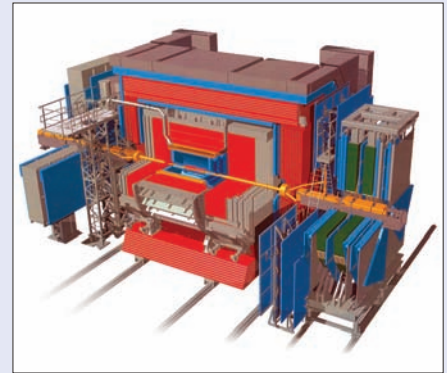
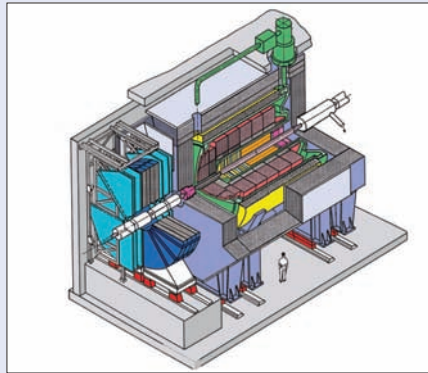
in long strings, the current coming from the power supply has to be bypassed around the quenching magnet and its stored energy safely dissipated in a resistive load. A switch is required to bypass the magnet. At Fermilab, this was in the form of a thyristor mounted outside the vacuum vessel, which had to be triggered in case of a quench. The current leads to the thyristor were connected to the coil at 4 K, thus adding to the cryogenic load.

For the HERA magnets, Mess applied a different idea, first considered at Brookhaven, in which a “cold” diode inside the cryostat at 4 K automatically switches the current of about 5000 A in case of a quench. This was one of the most innovative and courageous technological steps of the HERA project. First, a suitable diode had to be found. Of course, no commercially available diodes were made for such an application. Mess did eventually find one that promised to be up to the task, but only after extensive searching and testing. Then, the mechanical mounting and electrical connections of the diodes had to be devised in such a way as to guarantee their reliable operation inside the helium, where they were exposed to ▷

The challenge of the HERA detectors

H1 and ZEUS, the two colliding-beam detectors at HERA, were operated successfully for 16 years at steadily increasing beam intensities and luminosities. The main design emphasis was on hermetic electron calorimetry using lead and liquid argon in H1, and on hadron calorimetry using compensating uranium scintillator technology in ZEUS. Both experiments measured charged particles in high-resolution tracking detectors immersed in solenoidal magnetic fields generated by strong superconducting coils. Silicon vertex detectors added close to the beam pipe could detect particles with charm and beauty quarks by their decay lengths of a few tenths of a millimetre. Iron structures for magnetic-flux return surrounded the detectors and were instrumented for muon detection. The experiments extended up to 220 m into the HERA tunnel with detectors for elastically scattered protons and neutrons, and calorimeters for bremsstrahlung photons to measure the collider's luminosity. HERA's high bunch-crossing frequency of 10.4 MHz posed a major challenge. The experiments required fast trigger decisions and readout with minimal deadtime, which they achieved using state-of-the-art and custom electronics. Each experiment logged about 10^9 events during its lifetime. The detectors worked well, fulfilling the design specifications, and provided data for a rich harvest of physics.

The combination of a polarized atomic-hydrogen/deuterium target with the polarized HERA lepton beam made the



Schematic of the H1 detector (left) and the ZEUS detector (right) at HERA. (Courtesy DESY.)

HERMES experiment unique. The polarized target was in effect a compact atomic physics laboratory operating inside the interlocks of a major high-energy physics accelerator. As the target was composed of gaseous atoms, the exact quantum states could be selected, monitored and rapidly changed, making it an ideal target. Many years of development work were required to maximize the target density and polarization before a target that was usable for high-energy spin physics could be built. The polarization of HERA's lepton beam was also a major breakthrough. When HERMES was proposed, there was sufficient concern about the achievable beam polarization that a demonstration of high polarization was demanded before approval was given. It is a tribute to the dedication and commitment of the machine group that polarizations of more than 50% were routine. The most challenging detectors in HERMES were the transition radiation detector, which could

distinguish between leptons and hadrons with a 99% certainty, and the ring-imaging Cherenkov detector, able to distinguish between protons, pions and kaons.

The fourth HERA experiment, HERA-B, was designed to look for CP violation in the B meson system using HERA's proton beam and a wire target. Developing the detector was a major technological challenge because, compared to the electron-positron detectors at the B-factories at SLAC and KEK, not a single prototype existed for HERA-B. In particular, it was necessary to develop detector components with unprecedented radiation hardness, as well as a data-acquisition system that could handle HERA-B's huge particle flux. In the end, the B-factories beat HERA-B to the goal. The developments achieved for HERA-B were, however, pioneering for future experiments with similarly harsh conditions – playing a major role, for instance, in the development of the LHC detectors.

rapid and extreme thermal cycles. Comprehensive tests of all of the diodes were carried out to qualify them and validate the design of the mounting – an example of innovative engineering at its best.

To save costs and keep the cryogenic load at 4 K as low as possible, the various corrector magnets were connected via superconducting cables inside the 4 K helium pipe over an octant of the ring. The cables were held in a special fixture between the magnets and had to be soldered together before the 4 K helium tubes were joined by a welding sleeve. To make sure that all of the 20 or so cables were correctly connected, clever clamping devices – which supplied electrical contact to all of the wires simultaneously – were installed at two intersections. By applying voltages to the various contacts, a computerized central measuring station determined whether the cables were connected correctly in a time-effective way. There are many other cases that required ingenious ideas, such as solving the

problem with persistent currents in the superconducting coils as Schmäser and his students did, but unfortunately it is impossible to cover these in a short article.

There were many systems for the superconducting magnet ring where little or no experience existed at DESY. One example is the huge cryogenic system with the cryogenic plant and the magnet cryostats, various cryogenic boxes, and transfer lines and pipes for cold and room-temperature helium, respectively. One pipe, the quench gas-collection pipe, was connected to the 4 K helium volume of the dipole magnets but separated by a special valve, named the Kautzky valve after its inventor at Fermilab. This valve opens automatically when the pressure inside the cryostat exceeds a preset value. It is sealed by a conical plastic piece inside a conical body. However, some of these valves would start to rattle during a quench, indicating that they were closing and opening in rapid succession. This effect quite often

cracked the plastic cone, so the valves would no longer seal for normal operation and had to be exchanged. Despite intensive studies and tests of various materials – the high radiation level in the HERA tunnel meant that the Teflon of the original design could not be used – the problem was never solved. It did not become an operational problem thanks to the small number of quenches. This was an example where the work on HERA did not evolve from the heritage of Fermilab.

One clear evolutionary step, however, was the strong involvement of industry in the production of the superconducting magnets for HERA. For European industry in particular, HERA presented a unique opportunity: it was the first time that companies had an opportunity to gain experience in superconducting technologies and cryogenics on such a large scale. This step was beneficial for both DESY and the industrial companies, and also for later projects using superconducting-magnet technology.

Another step forward, this time in terms of financing and organizing large research projects, was the construction of HERA in collaboration with research laboratories from other countries: the so-called “HERA model”. It is to the credit of both Wiik and Volker Soergel that they brought the collaboration together with contributions from Canada, France, Israel, Italy, the Netherlands and the US, with additional manpower provided by institutes in China, Czechoslovakia, Poland, Switzerland, the UK, and USSR as well as institutes from both the FRG and the German Democratic Republic. The particularly large contribution by Italy of half of the superconducting dipoles cannot be overemphasized, and was to the great merit of Antonino Zichichi, who made this happen.

At DESY, we clearly stood on the shoulders of Fermilab’s pioneering work when realizing HERA, and the experiences and technological advancements made at HERA were valuable for later projects, such as RHIC at Brookhaven and the LHC at CERN. When DESY began the adventure of constructing the superconducting magnet ring for HERA, several people were worried that there would be problems with such a novel system and that its operation would become very difficult. Fortunately, none of the worries were substantiated and the operation of the “cold” ring essentially went without problems. I am sure that people at CERN now have similar worries concerning the LHC. I would like to express my best wishes to them, with the hope that they might be as fortunate and successful with the LHC as we were with HERA.

Résumé

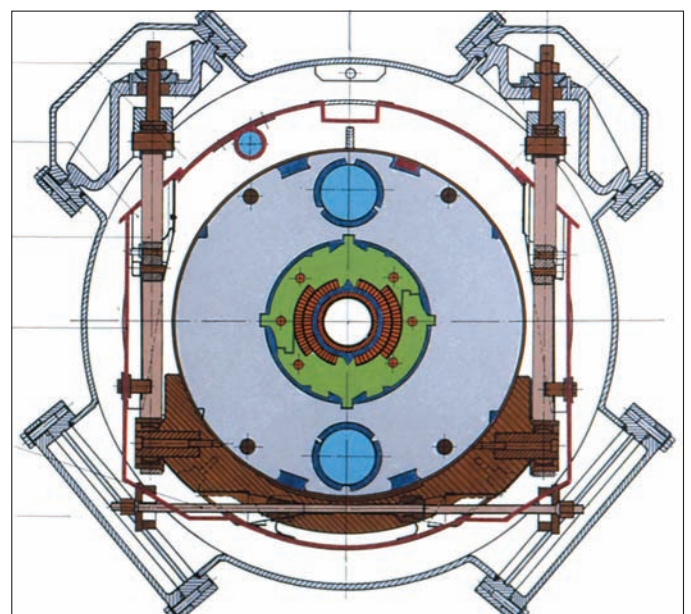
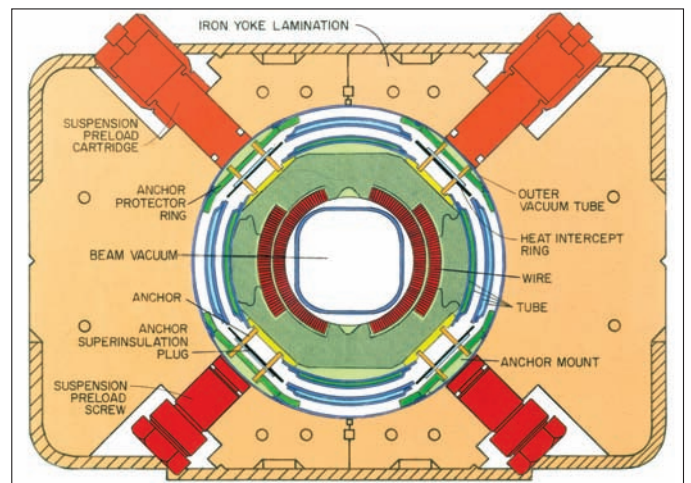
Le défi HERA

L’installation HERA de DESY, qui a cessé de fonctionner fin juin après 16 années d’exploitation, était exceptionnelle. C’était le seul accélérateur au monde dans lequel un faisceau d’électrons (ou de positons) entrait en collision frontale avec un faisceau de protons. Dieter Trines évoque ici certains aspects de la construction de l’élément le plus exigeant du collisionneur – l’anneau d’aimants supraconducteurs, d’une circonférence de 6,3 km, permettant de guider les protons de haute énergie. Au début du projet, DESY n’avait aucune expérience de cette technologie. Les équipes ont tiré parti des travaux d’avant-garde du Laboratoire Fermi, en apportant les innovations nécessaires. Les détecteurs de HERA ont également représenté de nouveaux défis.

Dieter Trines, DESY.



In the accelerator control room Bjørn Wiik (centre) and Gustav-Adolf Voss (centre right) raise their glasses to celebrate the first electron–proton collisions in HERA on 19 October 1991. (Courtesy DESY.)



These schematics show how the Tevatron dipole (top) served as a model for the development of the dipoles in the proton ring at HERA (bottom).

HERA leaves a rich legacy of knowledge

Rolf-Dieter Heuer and **Albrecht Wagner** take stock of the rich harvest of physics that came out of HERA, and the exciting prospects opened up by the ongoing data analysis.

The HERA facility at DESY was unique: it was the only accelerator in the world to collide electrons (or positrons) with protons, at centre-of-mass energies of 240–320 GeV. In collisions such as these, the point-like electron “probes” the interior of the proton via the electroweak force, while acting as a neutral observer with regard to the strong force. This made HERA a precision machine for QCD – a “super electron microscope” designed to measure precisely the structure of the proton and the forces within it, particularly the strong interaction. HERA’s point-like probes also gave it an advantage over proton colliders such as the LHC: while protons can have a much higher energy, they are composite particles dominated by the strong force, which makes it much more difficult to use them to resolve the proton’s structure. The results from HERA, many of which are already part of textbook knowledge, promise to remain valid and unchallenged for quite some time.

Into the depths of the proton

The proton’s structure can be described by using various structure functions, each of which covers different aspects of the electron–proton interaction. HERA was the world’s only accelerator where physicists could study the three structure functions of the proton in detail. During the first phase of operation (HERA I), the colliding-beam experiments H1 and ZEUS already provided surprising new insights into F_2 , which describes the distribution of the quarks and antiquarks as a function of the momentum transfer (Q^2) and the momentum fraction (x) of the proton’s total momentum. When HERA started up in 1992, physicists already knew that the quarks in the proton emit gluons, which give rise to other gluons and to quark–antiquark pairs in the virtual “sea”. However, the general assumption was that, apart from the three valence quarks, there were only very few quark–antiquark pairs and gluons in the proton.

Thanks to HERA’s high centre-of-mass energy, H1 and ZEUS pushed forward to increasingly shorter distances and smaller momentum fractions, and measured F_2 over a range that spans four orders of magnitude of x and Q^2 – two to three orders of magnitude more than were accessible with earlier experiments (figure 1). What the two experiments discovered came as a great surprise: the smaller the momentum fraction, the greater the number of quark–antiquark

pairs and gluons that appear in the proton (figure 2). The interior of the proton therefore looks much like a thick, bubbling soup in which gluons and quark–antiquark pairs are continuously emitted and annihilated. This high density of gluons and sea quarks, which increases at small x , represented a completely new state of the strong interaction – which had never been investigated until then.

The proton sea, however, comprises not only up, down and strange quarks. Thanks to the high luminosity achieved during HERA’s second operating phase (HERA II), the experiments for the first time revealed charm and bottom quarks in the proton, with charm quarks accounting for 20–30% of F_2 in some areas, and bottom quarks accounting for 0.3–1.5%. It appears that all quark flavours are produced democratically at extremely high momentum-transfers, where even the mass of the heavy quarks becomes irrelevant. The analysis of the remaining data will further enhance the precision and lead to a better understanding of the generation of heavy quarks, which is particularly important for physics at the LHC.

During HERA II, H1 and ZEUS also used longitudinally polarized electrons and positrons. This boosted the experiments’ sensitivity for the structure function xF_3 , which describes the interference effects between the electromagnetic and weak interactions within the proton. These effects are normally difficult to measure, but their intensity increases with the polarization of the particles, making them clearly visible.

Shortly before HERA’s time came to an end, the accelerator ran at a reduced proton energy for several months (460 and 575 GeV, instead of 920 GeV). Measurements at different energies, but under otherwise identical kinematic conditions, filter out the third structure function F_L , which provides information on the behaviour of the gluons at small x . These measurements are without parallel and are particularly important for the understanding of QCD.

HERA provided another surprise soon after it went into operation. In events at the highest Q^2 , a quark is violently knocked out of the proton. In 10–15% of such cases, instead of breaking up into many new particles, the proton remains completely intact. This is about as surprising as if 15% of all head-on car crashes left no scratch on the cars. Such phenomena were familiar at low energies, and were generally described using the concepts of diffractive physics, which

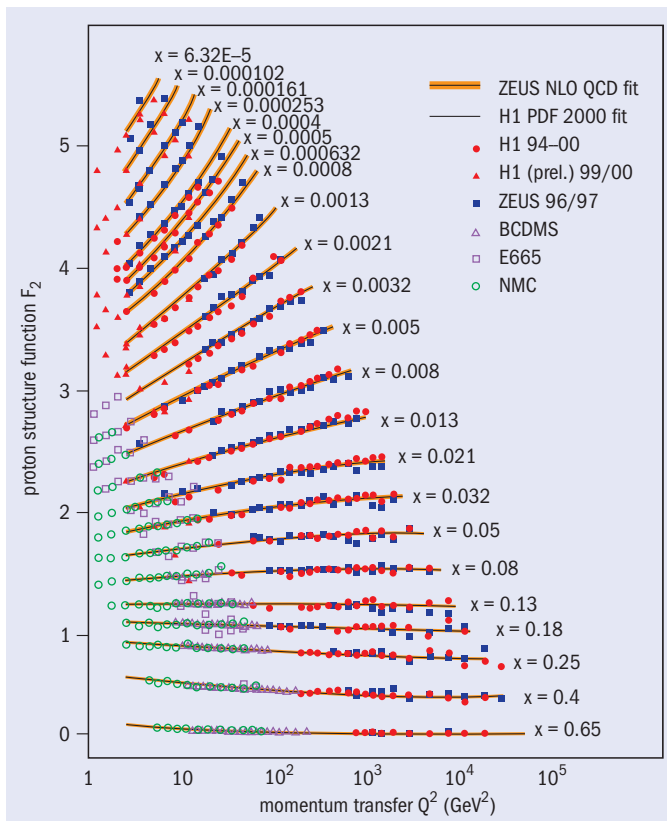


Fig. 1. The proton structure function $F_2(x, Q^2)$ as measured by H1 and ZEUS. The rapid increase of F_2 with Q^2 at decreasing values of x is evident.

involve the pomeron, a hypothetical neutral particle with the quantum numbers of the vacuum. However, early HERA measurements showed that this concept did not hold up, failing completely in the hard diffraction range.

To conform with QCD, at least two gluons must be involved in a diffractive interaction to make it colour-neutral. Could hard diffraction therefore be related to the high gluon density at small x ? The H1 and ZEUS results were clear: the colour-neutral exchange is indeed dominated by gluons. These observations at HERA led to the development of an entire industry devoted to describing hard diffraction, and the analyses and attempts at interpretation continue unabated. There have been some successes, but the results are not yet completely understood. It is therefore important to analyse the HERA data from all conceivable points of view to assess all theoretical interpretations appropriately.

The fundamental forces of nature

A special characteristic of the strong interaction is its unusual behaviour with respect to distance. While the electromagnetic interaction becomes weaker with increasing distance, the opposite is true for the strong force. It is only when the quarks are close together that the force between them is weak (asymptotic freedom); the force becomes stronger at greater distances, thus more or less confining the quarks within the proton. While other experiments have also determined the strong coupling constant α_s as a function of energy, H1 and ZEUS for the first time demonstrated the characteristic running of α_s over a broad range of energies in a single experiment (figure 3). Thus, the HERA results impressively confirmed the special

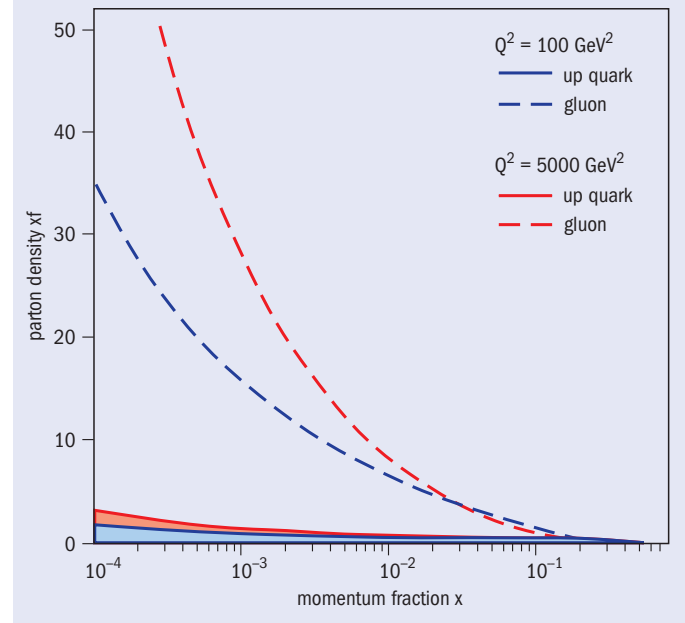


Fig. 2. Parton density distributions of the up quarks and gluons as a function of x at two different values of Q^2 . These show that the gluon density increases dramatically with improved resolution, i.e. at higher Q^2 . (Note that the down quarks behave similarly to the up quarks.)

behaviour of the strong force that David Gross, David Politzer and Frank Wilczek predicted 20 years ago – a prediction for which they won the Nobel Prize in Physics in 2004.

Although the collaborations used HERA mostly for QCD studies, the aim of studying the electroweak interaction was part of the proposal for the machine. For instance, H1 and ZEUS measured the cross-sections of neutral and charged-current reactions as a function of Q^2 . At low-momentum transfers, i.e. large distances, the electromagnetic processes occur significantly more often than the weak ones because the electromagnetic force acts much more strongly than the weak force. At higher Q^2 , and thus smaller distances, both reactions occur at about the same rate, i.e. both forces are equally strong. H1 and ZEUS thus directly observed the effects of electroweak unification, which is the first step towards the grand unification of the forces of nature.

The longitudinal polarization of the electrons in HERA II also opened up new possibilities for studying the electroweak force. For example, theory predicts that because only left-handed neutrinos exist in nature, the transformation of a right-handed electron into a right-handed neutrino via the weak interaction should be impossible. H1 and ZEUS measured the charged currents as a function of the various polarization states, and proved that there are indeed no right-handed currents in nature, even at the high energies of HERA (figure 4).

Particle collisions at the highest Q^2 are comparatively rare. Yet it is here, at the known limits of the Standard Model, that any new effects should appear. Thanks to the higher luminosity of HERA II, the collaborations can study this realm with enhanced precision. They have to date not observed any significant deviations from the Standard Model. The results from HERA substantially broaden the Standard Model's range of validity and restrict the possible phase space for new phenomena, so refining the insights of the Standard Model all the way up to the highest momentum transfers. \triangleright

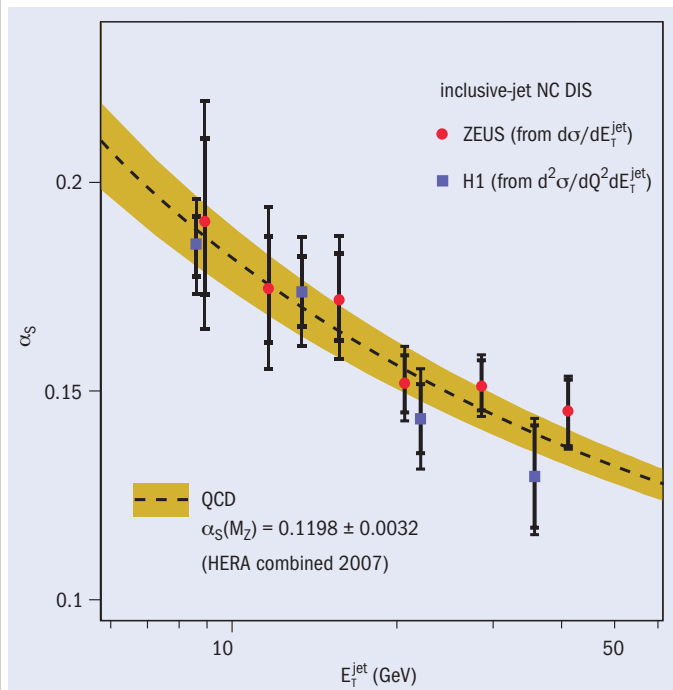


Fig. 3. The running of the strong coupling constant α_s as measured by H1 and ZEUS. (The plot shows only the new, most precise measurements.)

The nucleon-spin puzzle

Another important contribution to our understanding of the proton is provided by another HERA experiment, HERMES, which was designed to study the origin of nucleon spin. In the mid-1980s, experiments at CERN and SLAC discovered that the three valence quarks account for only around a third of the total nucleon spin. Starting in 1995, the HERMES collaboration aimed to find out where the other two-thirds come from, by sending the longitudinally polarized electrons or positrons from HERA through a target cell filled with polarized gases.

During HERA I, HERMES completed its first task, which was to determine the individual quark contributions to the nucleon spin. Using measurements on longitudinally polarized gases, the HERMES collaboration provided the world's first model-independent determination of the separate contributions made to the nucleon spin by the up, down and strange quarks (figure 5). The results revealed that the largest contribution to the nucleon spin comes from the valence quarks, with the up quarks making a positive contribution, the down quarks a negative one. The polarizations of the sea quarks are all consistent with zero. The HERMES measurements therefore proved that the spin of the quarks generates less than half of the spin of the nucleon, and that the quark spins that do contribute come almost exclusively from the valence quarks – a decisive step toward the solution of the spin puzzle.

The HERMES team then turned its attention to gluon spin, making one of the first measurements to give a direct indication that the gluons make a small but positive contribution to the overall spin. The analysis of the latest data will yield more detailed information. Until recently, it was impossible to investigate the orbital angular momentum of the quarks experimentally. Now, using deeply virtual Compton scattering (DVCS) on a transversely polarized target, the HERMES team has made the first model-dependent extraction of the total orbital angular momentum of the up quarks (*CERN Courier*

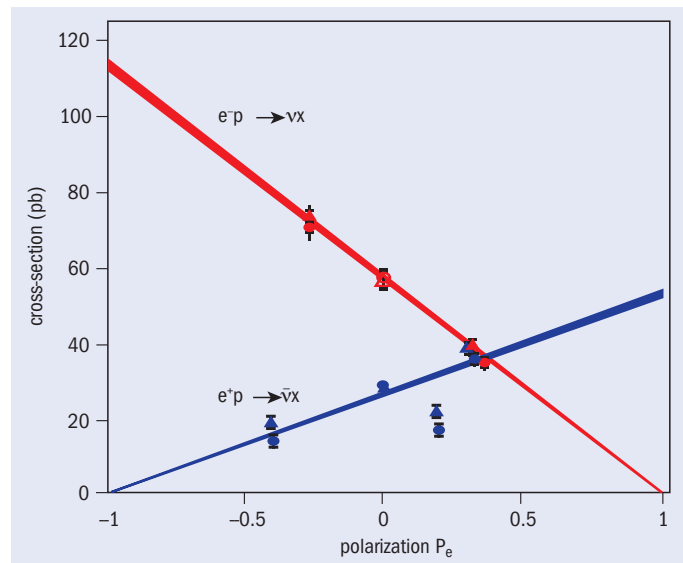


Fig. 4. The cross-sections for charged current scattering as a function of the polarization of the electrons and positrons. In the case of electrons (red), the cross-section for negative, left-handed polarization is higher than for positive, right-handed polarization. The event rates disappear when extrapolating to completely right-handed electrons, $P_e = +1$. The opposite is observed for scattering with positrons (blue).

April 2006 p26). Analysis of the data taken with a new recoil detector in 2006–2007 will perfect the knowledge of DVCS and enable HERMES to make a key contribution to improving the models of generalized parton distributions, in the hope of soon identifying the total orbital angular momentum of the up quarks.

Parton distribution functions characterize the nucleon by describing how often the partons – quarks and gluons – will be found in a certain state. There are three fundamental quark distributions: the quark number density, which the H1 and ZEUS experiments have measured with high precision; the helicity distribution, which was the main result of measurements by HERMES with longitudinally polarized gases; and the transversity distribution, which describes the difference in the probabilities of finding quarks in a transversely polarized nucleon with their spin aligned to the nucleon spin, and quarks with their spin anti-aligned. Using data on transversely polarized hydrogen, the HERMES collaboration can now determine this transversity distribution for the first time. The measurements also provide access to the Sivers function, which describes the distribution of unpolarized quarks in a transversely polarized nucleon. As the Sivers function should vanish in the absence of quark orbital angular momentum, its measurement marks an additional important step in the study of orbital angular momentum in the nucleon. Analysis of the initial data shows that the Sivers function seems to be significantly positive, which indicates that the quarks in the nucleon do in fact possess a non-vanishing orbital angular momentum.

Although HERMES focuses on nucleon spin, the physics programme for the experiment extends much further, including, for example, studies of quark propagation in nuclear matter and quark fragmentation, tests of factorization and searches for pentaquark exotic baryon states. Analysis of the data collected up until the shutdown in June 2007 will provide unique insights here as well.

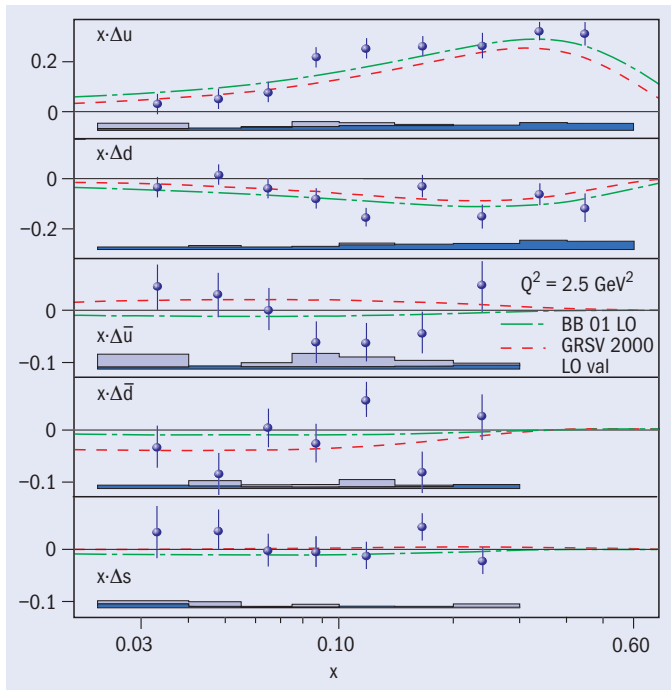


Fig. 5. This diagram shows helicity distributions from HERMES for up, down and strange quarks as a function of x at a common value of Q^2 .

The LHC and beyond

In 2008, the LHC will start colliding protons at centre-of-mass energies about 50 times higher than those at HERA. The results provided by HERA are essential for the interpretation of the LHC data: the proton–proton collisions at the LHC are difficult to describe, involving composite particles rather than point-like ones. It is therefore crucial to have the most exact understanding possible of the collisions' initial state. This comes from HERA, for example, in the form of precise parton distribution functions of the up, down and strange quarks, and also the charm and bottom quarks (figure 6). An accurate knowledge of these distributions is vitally important, particularly for predictions of Higgs particle production at the LHC.

Many of these LHC-relevant measurements could only be carried out at HERA. To support the transfer of knowledge and create a long-term connection that takes account of the overlapping physics interest at HERA and the LHC, DESY and CERN have intensified their co-operation in this area. Many researchers from HERA, along with many students and PhD candidates, are already participating in the LHC experiments.

Over the past 15 years, HERA has enabled us to uncover a wealth of different – and partly unexpected – aspects of the proton and the fundamental forces. The analysis of the data recorded up until HERA's closure in June 2007 is expected to last well into the next decade. The HERA collaborations will be melding these aspects into a vast and cohesive whole – a comprehensive description of strongly interacting matter at small distance scales and short time scales. Given HERA's unique nature, this picture will endure for a long time and define for years, and possibly decades, our understanding of the dynamics of the strong interaction.

With their results, the HERA teams are now handing the baton over to the LHC collaborations, and also to the theorists. From the

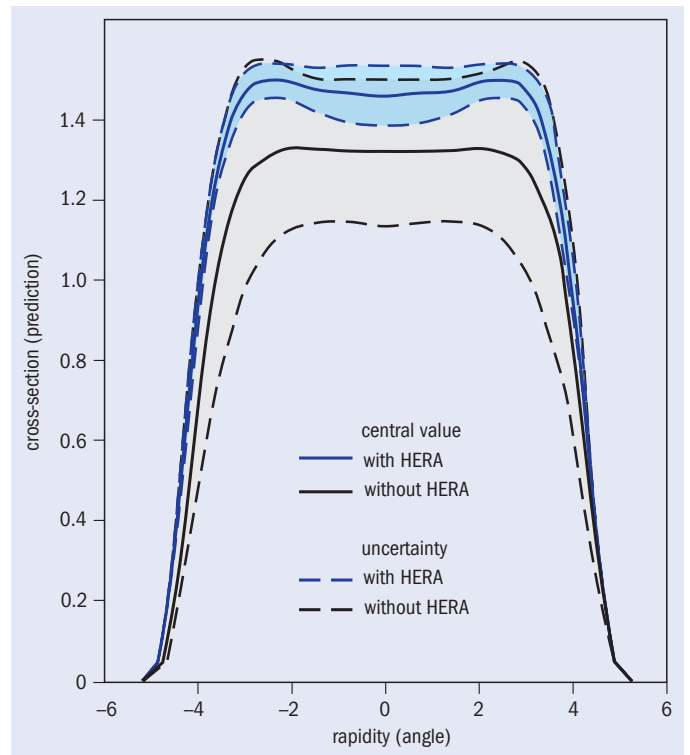


Fig. 6. The cross-section for W^* production at the LHC – with and without input from the HERA results. Without taking into account the parton distributions measured by HERA, the margin of error of the prediction is 17% (indicated by the black dashed lines). Thanks to the HERA data, this error-rate shrinks to about 3% (blue dashed lines).

outset, the results from HERA have stimulated a large amount of theoretical work, particularly in the field of QCD, where an intensive and fruitful collaboration between theory and experiments has arisen. Thus, the knowledge of the proton and the fundamental forces gained from HERA forms the basis, not only for future experiments, but also for many current developments in theoretical particle physics – a rich legacy indeed.

Résumé

L'héritage HERA

Les collisions électron-proton réalisées à HERA ont constitué un «laboratoire» exceptionnel, dans lequel l'électron, de dimension ponctuelle, sondait l'intérieur du proton via la l'interaction électrofaible tout en jouant le rôle d'observateur neutre du point de vue de l'interaction forte. C'est cette configuration qui a fait de HERA une machine de précision pour la chromodynamique quantique – un supermicroscope électronique conçu pour mesurer précisément la structure du proton et les forces qui s'exercent à l'intérieur, en particulier l'interaction forte. Les résultats semblent devoir rester incontestés pendant longtemps. Ici, Rolf-Dieter Heuer et Albrecht Wagner passent en revue la moisson de résultats obtenus grâce à HERA et les perspectives stimulantes ouvertes par l'analyse des données encore en cours.

Rolf-Dieter Heuer and Albrecht Wagner, DESY.

FACES AND PLACES



Antonino Zichichi, left, hands the Science for Peace Erice Prize to the former federal chancellor of Germany, Helmut Kohl, right, with the president of the European Parliament, Hans-Gert Pöttering, centre. The ceremony was held in Strasbourg on 23 October. (Courtesy Photo Service European Parliament.)

AWARDS

Helmut Kohl receives Erice peace prize for his promotion of science

Helmut Kohl, Mikhail Sergeyevich Gorbachev and Pope John Paul II are the 2007 laureates of the Science for Peace Erice Prize.

This prize was instituted in 1988 by the Sicilian parliament at the request of the World Federation of Scientists (WFS) on the occasion of the 25th anniversary of the Ettore Majorana Foundation and Centre for Scientific Culture (EMFCSC). The prize is awarded to world leaders in science and scientific culture, and to those who have played an essential role in promoting and implementing the goals outlined in the *Erice Statement: Science for Peace*, written in 1982 by Paul Dirac, Pyotr Kapitza and Antonino Zichichi, the current president of the EMFCSC.

Kohl, the former federal chancellor of Germany, received his prize on 23 October at a ceremony at the European Parliament in Strasbourg, organized by the parliament's president, Hans-Gert Pöttering. Zichichi praised the value of scientific and cultural activities in an address at the ceremony, entitled: "Neither science nor civilisation could exist without memory". He outlined the role of the WFS in analysing global emergencies and emphasized the importance of political leaders to promote science for peace and progress. He also described the roles of the Erice Centre and CERN. In the spirit of the *Erice Statement*, Kohl helped promote international scientific

collaboration following the fall of the Berlin Wall, which allowed the countries of Central Europe to join CERN.

In his speech, Kohl reviewed the long journey from 1945 to German reunification and to the present. He underlined the role of Pope John Paul II, and that of Gorbachev and other political leaders, in overcoming barriers to allow Europe to become free and enlarged. He encouraged the European parliamentarians to continue their efforts to progress steadily in building a democratic Europe and to promote international scientific collaboration worldwide.

● For more information about the WFS, see www.federationofscientists.org/WFSHist.asp.

Italian Physical Society honours discoveries on weak interactions

Milla Baldo-Ceolin, Ettore Fiorini and Italo Mannelli have won the 2007 Enrico Fermi prize from the Italian Physical Society. The award is for their fundamental contributions to the experimental study of weak interactions, in particular at CERN.

Baldo-Ceolin, of the University of Padua, receives the prize for her early studies on K-mesons, in particular for her experimental evidence of K_L^0 as a mixture of K^0 and \bar{K}^0 , and for the measurement of the mass difference $K_S^0 - K_L^0$. In addition, her further studies on neutrino physics (e.g. on neutral current interactions in muon-neutrino and antineutrino scattering off electrons with the NUC experiment at the PS) provided an essential step towards the initial confirmation of electroweak unification.

Fiorini, of the University of Milan Bicocca, receives the prize for contributing to the discovery of weak neutral currents using the Gargamelle bubble chamber exposed to neutrino and antineutrino beams from the PS. This finding paved the way for the unconfutable success of the electroweak



Left to right: Italo Mannelli, Franco Bassani (president of the Italian Physical Society), Milla Baldo-Ceolin and theoretician Luigi Radicati di Brozolo at the ceremony. (Courtesy André Martin.)

Standard Model. The prize also recognizes other work by Fiorini, including early studies on atmospheric and solar neutrinos with the underground experiments NUSEX at Mont Blanc and GALLEX at Gran Sasso.

Mannelli, of the Scuola Normale Superiore, Pisa, receives his share of the prize for his outstanding contribution to the demonstration of direct CP symmetry



Fiorini, absent from the ceremony, receives the prize for contributions to the discovery of weak neutral currents. (Courtesy CUORE Collaboration.)

violation in K-meson weak decays in the NA31 and NA48 experiments at the SPS. This almost imperceptible but basic effect of symmetry violation has enormous consequences for particle physics and cosmology. The foundations of Mannelli's work on CP violation extends back to his first experimental studies on parity violation in Λ^0 weak decays.

LABORATORIES

JINR looks to its future programme

The latest session of the Committee of Plenipotentiaries of the member-state governments of JINR took place in Dubna, Russia, on 27–28 November. JINR's director Alexei Sissakian presented his report on "Activities at JINR in 2007 and basic trends for strategic development of the Institute".

In addition to summing up the results of the institute's activities in 2007, Sissakian took the opportunity to cast a glance towards 2008 and beyond in the context of the "roadmap" – the strategic programme for development at JINR in fundamental science, innovation and education. Speaking about the main scientific trends at the institute – particle physics, nuclear physics



JINR's director, Alexei Sissakian, left, and the Russian Federation's minister of science and education, Andrei Fursenko, at the exhibition of JINR's achievements in innovation. (Courtesy JINR.)

and condensed-matter physics – he noted the success in the "home" experimental programme. He also spoke about the advanced plans for upgrading the basic facilities at JINR and the programme to

develop a new Nuclotron-based Ion Collider Facility at JINR's Nuclotron accelerator.

Sissakian also informed those at the session about a conference, "Innovation Activity in Special Economic Zones [SEZ]. Public-Private Partnership Technology", held in Dubna on 15–16 November 2007. This was the first event to discuss the SEZ "core". Sissakian also noted that having established an SEZ in Dubna, JINR would have a very profitable scheme for the application of scientific ideas in commodities production.

Introducing the general discussion, Andrei Fursenko, plenipotentiary of Russia to JINR, said: "All the reports presented today are aimed at the process of development, a new gulp of breath for Dubna – the centre that is and will be among leading world centres. We will, and I say it as a minister, support the development of JINR, both in innovation and fundamental trends."

APPOINTMENTS

Persis Drell takes the helm at SLAC

Persis Drell has become the fourth director of SLAC in the laboratory's 45-year history, stepping into the shoes of Wolfgang Panofsky, Burton Richter and most recently, Jonathan Dorfan. She has held a series of senior positions at SLAC since 2002 and has served as acting director from September 2007.

Drell's directorship is the result of an international search by a committee appointed by John Hennessy, president of Stanford University, which operates SLAC on behalf of the US Department of Energy (DoE). The committee began its work in March 2007, when Dorfan announced his plan to step down.

SLAC's activities have gradually changed with the times since 1962, when the laboratory was built to house the world's longest electron accelerator. The linac is now to become the



Drell joined SLAC in 2002. (Courtesy SLAC.)

injector for the world's first X-ray free electron laser, the Linac Coherent Light Source (LCLS), currently under construction. "The science delivered by LCLS, along with programmes in particle physics, photon science and

particle astrophysics and cosmology, will ensure frontier science from the laboratory for decades to come," said Drell on her appointment. "My goal as director is to position the laboratory to make a smooth transition to these exciting future scientific programmes and continue the tradition of outstanding scientific achievement at the lab." Since then, she has already had to confront a major funding crisis in the US (see p6).

Drell has a long association with SLAC, Stanford and the DoE. As a physics professor at Cornell for 14 years, she studied the bottom and charm quarks to measure the parameters of the weak interaction. She also served as the deputy director of Cornell's Laboratory of Nuclear Studies and as chair of the Synchrotron Radiation Committee. She joined SLAC in 2002 as a professor and associate director for the research division, becoming a deputy director for SLAC and director for particle and particle astrophysics in 2005.

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CONFERENCE

Slovakia hosts successful unified conference on hadron structure



Conference participants pose for the traditional photo. Hadron Structure '07 attracted around 50 physicists from 13 countries. (Courtesy S Dubnicka.)

Around 50 physicists from 13 countries participated in the latest Middle European Hadron Structure Conference, held last year in Slovakia. This conference series goes back 35 years; the first meeting was held in 1973 at Smolenice Castle, Slovakia. It arose from the earlier well known Vienna–Budapest–Bratislava “triangle meetings”, organized in the late 1960s. Now it has come together with the Hadron Structure and QCD Conferences organized by the Petersburg Nuclear Physics Institute of the Russian Academy of Sciences in Gatchina, which were previously held in Repino (2004) and St Petersburg (2005). This “unification” was agreed and unambiguously welcomed by more than 30 particle-physics authorities around the world after being first proposed by the physicists at Gatchina.

Hadron Structure '07, the first of the “unified” Hadron Structure International Conferences, was organized by the Institute of Physics of the Slovak Academy of Sciences in Bratislava together with the

Comenius University in Bratislava, the PJ Safarik University in Košice, the Institute of Experimental Physics of the Slovak Academy of Sciences in Košice and the Petersburg Nuclear Physics Institute. The conference took place on 3–7 September at the Comenius University Study and Congress Centre in Modra-Harmonia, some 35 km north of Bratislava, at the foot of the Little Carpathian Mountains. It was also supported by JINR in Dubna, the German Physical Society and the Slovak Physical Society.

From the start, the Hadron Structure Conferences consisted of presentations of invited lectures and short communications, mixed with theoretical talks and experimental reviews. Hadron Structure '07 was no exception, with presentations of new results from almost all of the experimental centres around the world, including Brookhaven, CERN, the DAΦNE facility at Frascati, DESY, Dubna, Fermilab and Protvino. The programme included: talks on the Higgs and beyond the Standard

Model at the Tevatron and ATLAS at the LHC; results on φ radiative decays into scalar and pseudoscalar mesons at the KLOE experiment at DAΦNE; new results from the NA48/2 experiment at CERN; the research programme of the NIS–GIBS spectrometer at the JINR Nuclotron; heavy-quark production at HERA; top and electroweak results from the Tevatron; diffraction and vector meson production at HERA; antibaryon to baryon production ratios at LHC energies; jet studies with the H1 experiment; results from the HERMES experiment; and pion polarizabilities in COMPASS.

Hadron Structure Conferences will be organized every year; the odd years in the Slovak Republic, and in St Petersburg and its surroundings on the even years. The Petersburg Nuclear Physics Institute is already planning Hadron Structure '08, scheduled for the second half of June 2008.

● Contributions to the conference are to be published in an upcoming special issue of *Fizika B* (Zagreb).

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FACES AND PLACES

Georgian physics conference provides a warm welcome

Georgia's capital Tbilisi is probably best known to particle physicists as the host city of the 1976 International Conference on High Energy Physics, in the Rochester Conference series. What is perhaps less well known is that since then, Georgia has matured to become an enthusiastic player in both experimental and theoretical particle physics, as the 4th International Conference on Physics at the Future Colliders revealed.

This biannual conference, held most recently in 2007 at Tbilisi's I Javakhishvili State University on 22–26 October, aims to bring the community of Georgian particle physicists together with international representatives, with an emphasis on the participation of physicists working at JINR in Dubna and at CERN. Under the substantial support of the Ministry of Education and Science of Georgia and the university administration, some 60 conference participants attended from Armenia, Austria, Azerbaijan, the Czech Republic, Finland, Georgia, Greece, Hungary, Russia, the UK and the US – resulting in informative and lively scientific discussions.

While several review talks highlighted recent achievements in fields as diverse as neutrino physics, energy production and transmutation in subcritical nuclear fission reactors and black holes at the LHC, the conference's main focus was on reports on the readiness for physics at the LHC, due to start operating in 2008. The local authorities noted with satisfaction the strong involvement of Georgian teams in the construction of the ATLAS and CMS detectors. It also stimulated reports by local news media, and the conference chair, Djemal Khubua, found



Gia Dvali during his presentation entitled "Black holes at the LHC". (Courtesy University of Tbilisi.)

himself busily giving interviews and answering questions from journalists.

The conference was complemented by a noteworthy social programme that included a flavour of Georgia's rich cultural heritage, which dates back to several thousand years BC. The contrast between the newly built Cathedral of the Holy Trinity in the centre of Tbilisi and the impressive preserved remains of the ancient city Uplistsikhe, entirely carved out of rock, will long remain in the memory of many participants. Even stronger memories will remain in the minds of foreign visitors of the warm welcome and Georgian hospitality, which spared no effort despite the difficulties that Georgia faces on its path towards a bright and prosperous future.

MEETING

The 3rd CERN–Fermilab Hadron Collider Physics Summer School will be held on 12–22 August at the Fermi National Accelerator Laboratory. The target audience for the school is young postdocs and advanced graduate students with a strong interest in hadron-collider physics. Theorists

and experimentalists alike are encouraged to apply. Applications and references should be received no later than 29 February.

For more information, see <http://hcpss.fnal.gov/hcpss08>; or contact Cynthia Sazama, fax +1 630 840 4102; or e-mail sazama@fnal.gov.

VISITS



Ronald Plasterk, centre, minister of education, culture and science from the Netherlands visited CERN on 25 October and toured the LHC tunnel with CERN's chief scientific officer, **Jos Engelen**, left, and **Herman Ten Kate**, right, ATLAS magnet project leader.

He also visited the ATLAS experiment and met with Dutch researchers who are currently contributing to CERN projects.

Senior vice-minister of the Commission of Science Technology and Industry for the National Defence of China, **Chen Qiufa**, centre, visited CERN on 1–2 November. He toured the AntiMatter Spectrometer detector with spokesperson, **Samuel Ting**, left, and a staff member of the Aerospace Industrial Development Corporation (Taichung) in a special cleanroom for this space-qualified detector.



On 14 November, CERN held a meeting of EIROforum, the partnership of Europe's largest intergovernmental research organizations. Members touring the ATLAS cavern with **Peter Jenni** (left), spokesperson for the ATLAS experiment, included, from right to left, **William G Stirling**, director-general of the European Synchrotron Radiation Facility (ESRF); **Peter Timmins** from the Institut Laue-Langevin; **Manuel Rodriguez Castellano**; and **Jean Susini** from ESRF.

PUBLISHING

CERN chooses *JINST* for the final technical reports of the LHC

CERN has decided to publish the final technical reports of the LHC machine and detectors in *Journal of Instrumentation* (*JINST*), from the International School for Advanced Studies (SISSA) Medialab and IOP Publishing. These reports are all scheduled to appear in April.

The choice reflects confidence in the endeavours by SISSA Medialab – which date back to 1996, more recently in collaboration with IOP Publishing – to provide the scientific community with high-quality journals. The first of these to appear was the pioneering *Journal of High Energy Physics* (*JHEP*); this was followed by the *Journal of Cosmology and Astroparticle Physics* (*JCAP*), the *Journal of Statistical Mechanics* (*JSTAT*), and more recently, *JINST*.

These journals are firmly grounded in the principle that scientific publishing should be run by scientists, with the most-advanced technology available, the smallest-possible impact on the budgets of research institutions and a liberal copyright

policy. The editorial boards of distinguished scientists are entirely responsible for carrying out the peer-review process, for selecting reviewers and for making the final editorial decisions. The crucial role played by the rigorous peer-review system has been decisive in the journals' rapid ranking among the highest impact-factor journals in each of their respective fields.

Collaboration with CERN goes back a long way, and has recently involved participation in a task force on open-access publishing. As a result, all accepted papers – experimental and theoretical – submitted to *JHEP* and *JINST* from CERN are now published according to an open-access scheme. Similar arrangements are also being implemented with the Max Planck Institutes, IN2P3, DESY, Fermilab and SLAC.

● For more information on *JINST*, see <http://jinst.sissa.it>. For scientific matters, please contact *JINST* director and assistant director, Amos Breskin and Peter Krizan, respectively (jinst-eo@jinst.sissa.it).

CORRECTION

Apologies to our German readers for the missing accents in the poem reproduced in the "Archive" section in December 2007. Also, in the Complier's Note the poem's author, Gertrude Weisskopf, was inadvertently given an additional surname, von Desch. This was in fact the name of the publisher of the book *Das Wunder der Wissens*. Here is the corrected version:

DIE GROSSE LAMENTEI

Schönheit vergeht:
 Denn neben jedem Veilchen
 wächst schon sein Gegen-Veilchen.
 Zeit auch verweht:
 Denn neben jedem Weilchen
 bläst schon sein Gegen-Weilchen.
 Raum auch zergeht:
 Denn neben jedem Meilchen
 läuft schon sein Gegen-Meilchen.
 Ding auch zerweht:
 Denn neben jedem Teilchen,
 Ach Gott, da hockt sein
 Gegen-Teilchen.
 Gegenteilchen
 enteil-chen
 Teilchen
 Eilchen ...

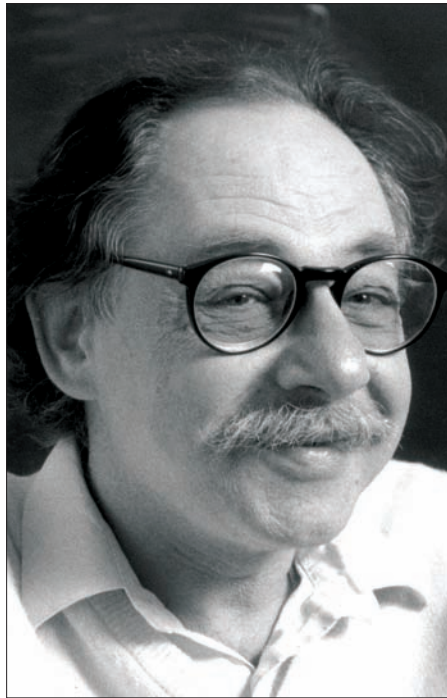
OBITUARIES

Sidney Coleman 1937–2007

Robert Schumann is said to have once remarked about Johann Sebastian Bach: “Let *The Well-Tempered Clavier* be your daily bread, and you will surely attain good musicianship.” Particle physics theorists feel similarly about Sidney Coleman, who died on 18 November, aged 70.

Sidney was a brilliant theoretical physicist. He graduated from the Illinois Institute of Technology in 1957 and went on to graduate school at Caltech, where he studied with Murray Gell-Mann. In the early 1960s, he was a leader in the application of Gell-Mann’s revolutionary idea of approximate SU(3) symmetry of the strong interactions. His work on scale invariance and renormalization in the late 1960s and 1970s paved the way for QCD, leading to the discovery by his student David Politzer and others of asymptotic freedom as well as to his idea of dimensional transmutation. In the late 1970s and 1980s, the results and the techniques from his work on vacuum decay were crucial for the beginnings of quantitative cosmology. Throughout his life, he was the leader in educating high-energy theorists about the field-theoretic and symmetry tools that revolutionized the field in the 1970s and led to the development of the Standard Model.

For 40 years, Sidney was the guru of relativistic quantum field theory. He had about 40 PhD students, many of whom became leaders in the field of high-energy theory. However, his influence extended far beyond his academic progeny. Many hundreds of students from all over the Boston area were inspired by his courses



Coleman was well known for his wit and classic papers. (Courtesy Stu Rosner Photography.)

on quantum field theory, and his notes were used in courses throughout the world. Many more high-energy theorists, both aspiring and established, pored over his classic papers and summer-school lectures. Like the works of Bach, these were simply perfect. Sidney laboured over them until no word was out of place and no explanatory or pedagogical opportunity was missed.

While his first love was the teaching of graduate-level quantum field theory, Sidney

also gave brilliant undergraduate lectures. This was a personal sacrifice, because he was renowned for doing his best work in the wee hours of the morning, and it was never clear whether he was better off getting a few hours of sleep before a late morning undergraduate class, or simply staying up for it. Some of these lectures survive as recordings, such as his colloquium-level lecture, “Quantum Mechanics in Your Face”. His lectures were not only clear, beautifully constructed and delivered, they were always very funny. His sharp wit also shone through in the titles of some of his classic papers, such as *Why There Is Nothing Rather Than Something...* and *Black Holes as Red Herrings...*

Sidney’s wit could be as biting as it was brilliant, and his friends bore the brunt of this – and loved it. They could count on him to keep their head-sizes under control. “Courtesy”, Sidney argued, “is for strangers. Kindness is for friends.”

Not a cloistered academic, Sidney was also a public intellectual in the best sense. He had a deep interest in science fiction, and wrote and published science fiction criticism himself. He served behind the scenes as a science advisor to a number of movies and programmes for Nova.

Health problems bedevilled the end of Sidney’s life and deprived the world of what would surely have been an affectionately irreverent elder statesmanship. He is survived by his wife of 25 years, Diana Coleman, his brother, Robert Coleman, and his many friends around the world.

Howard Georgi, Harvard University.

Philippe Meyer 1925–2007

A prominent figure of French theoretical physics, Philippe Meyer, passed away on 9 November 2007.

Meyer was born in Paris on 22 April 1925. However, at the beginning of the Second World War, his father, the banker André Meyer, left for the US. Philippe was admitted to Harvard in 1941, at the age of 16, but in 1943 he interrupted his studies, went back to

Europe and joined the Free French Forces. He was part of the army that landed in Provence and fought for the liberation of France. He was very discreet and never mentioned that he was decorated with the Croix de Guerre (avec Médaille Vermeil) for his war service.

Meyer returned to Harvard in 1945, obtaining a BS in 1946 and an MS in Physics in 1947. The following year, he

returned to France with his wife and entered CNRS. There were no organized graduate studies in France in those days, and young scientists had to learn modern physics by themselves. He joined the Theoretical Physics Laboratory at the École Normale Supérieure (ENS) in 1953, which had been founded a year earlier by Maurice Lévy. Meyer worked on theoretical nuclear physics and

obtained his Doctorat d'État in 1955 with a study of "Exchange Currents in Deuteron Photodisintegration". He continued work on nuclear physics and published a series of papers on the scattering of fast nucleons on light nuclei. In 1957, he moved to CERN and started working on particle physics, collaborating mainly with Jacques Prentki and Yoshio Yamaguchi on the properties of strange particles. He refused an offer to become a staff member in the TH Division and returned to France where, in 1960, he opted for a faculty position – first at the University of Bordeaux and a year later at the University of Paris at Orsay, where in 1959 the entire theory group from ENS, led by Lévy, had founded a new laboratory.

Together with Claude Bouchiat, Meyer established a very active research group which attracted many young physicists, some of whom became well known theorists and played an important role in building a French school of theoretical physics. The subjects studied included current algebras and K-decays, higher symmetries, dual models, deep inelastic scattering and the parton model, as well as the establishment of the Standard Model. The paper on the anomaly cancellation mechanism among leptons and coloured quarks is a milestone in this field. Meyer directed the Orsay laboratory from 1966 to 1969 after Lévy's departure for Paris. In 1974, he and Bouchiat were invited by Jean Brossel, director of the physics department of ENS, to establish a new laboratory of theoretical physics, which remains a great international success.



Philippe Meyer was a strong patron of the arts, music and literature. (Courtesy J Iliopoulos.)

Meyer never sought positions in the ministry or government. The only exception was a brief period after May 1968 when he became an advisor to Edgar Faure, minister of education. He was at the origin of the law allowing foreigners to become professors in French universities, eliminating a very retrograde French rule.

He was a gifted and dedicated teacher, and a remarkable lab director. Under his leadership, the School of Graduate Studies in

the Paris area, which was initially restricted to high-energy physics, expanded to cover many areas of fundamental physics. Generations of young physicists owe their solid education to his broad and modern views. Occasionally, he helped some of them financially, although he never let them know. He always had a vision of the international role of science and took various initiatives in this direction, many of which survive to the present day. In particular, a yearly Summer Institute gathered the stars of theoretical physics from around the world to Paris every August, and the "Triangular Meetings" initially between the Universities of Paris, Rome and Utrecht, have now become a regular international conference series.

Meyer also patronized art museums in France, following the example of his father who made gifts to the Metropolitan Museum of Art in New York. He helped to buy masterpieces that are now in several museums – in particular the Musée d'Orsay – and donated an entire collection a few years ago. His naturally reserved character did not allow for his name to appear anywhere, and it is only now, after his death, that the Musée d'Orsay plans a special exhibit under his name.

Those of us who knew Meyer well, will remember his natural elegance, charm, and warm and friendly behaviour. His vast cultural good taste in literature, art and music, made him an outstanding person. We are sorry that he left us, but he will not be forgotten *His friends at CERN and École Normale Supérieure.*

Vladimir Murzin 1927–2007

Vladimir Murzin, a pioneer of calorimetry in high-energy physics, and the principal researcher and professor of the Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University (SINP MSU), passed away on 12 June after having a heart attack. Up to his final days he was working actively on textbooks for students and scientists on modern particle physics, cosmic rays and astrophysical phenomena. At celebrations for his 80th birthday on 30 May, he showed copies of the 4th edition of his classic textbook *The Physics of Cosmic Rays*, dedicated to the 250th anniversary of MSU.

Vladimir graduated from the physics faculty of MSU in 1950. His diploma thesis was based on pioneering measurements of the cosmic-ray latitude effect, which he made while on a research ship travelling around the equator. Three years later, he received his PhD and became a senior scientist at SINP MSU. It was while continuing his studies of cosmic rays that he made a significant contribution to particle physics by proposing the ionization calorimeter method for measuring the energy of relativistic particles. Vladimir developed the method together with colleagues Natan

Grigorov and Ilya Rapoport, and produced an analytic description of the nuclear cascade in dense matter and in the atmosphere within the context of the passage of particles through matter. The first such calorimeter was installed in July 1957, in the Pamir mountains, to measure the energy of cosmic-ray particles. Vladimir's skilful analysis of the features of events recorded with the calorimeter allowed the separation of cosmic pions and nucleons as well as the observation of the leading properties of charged and neutral pions in pion–nucleon interactions, similar to the leading effect in

nucleon–nucleon interactions. With these results he became a full doctor of sciences in physics and mathematics in 1967.

At the beginning of the 1970s, Vladimir moved to high-energy physics for studies with large bubble chambers (the 2 m propane bubble chamber, the Mirabelle liquid-hydrogen bubble chamber, and the SCAT and 15 ft heavy-liquid bubble chambers at Protvino and Fermilab, respectively) in collaborations with CERN, JINR and the Institute for High Energy Physics, Protvino. He was an authority among the physics community, with a deep understanding of particle interaction dynamics and a skill in explaining the effects. He was also interested in diffraction processes.

Valdimir's main interest, however, was in neutrinos – both in high-energy physics and cosmic rays. While working with neutrino bubble-chamber projects, he developed the proposal for the BATISS experiment, which was to use a neutrino beam from Fermilab to Lake Issyk-Kul in Asia, passing through the Earth close to its centre. The project was started in 1980 with SINP MSU and the Kazakh University and Nuclear Physics Institute, but later stopped due to dramatic changes in the USSR. He also developed light



Valdimir Murzin. (Courtesy Nikita Murzin.)

but robust gaseous detectors for the neutrino experiment GINES for the planned UNK collider in Protvino.

During the 1990s, Vladimir worked with the E-632 neutrino collaboration on the 15 ft bubble chamber at Fermilab and took part in experiments in SLAC and DESY. He participated in conferences on deep inelastic scattering and wrote books that followed the fast progress of particle physics. He is also a founder of the Laboratory for Neutrino Physics in SINP MSU, and many of his former PhD students are working now on the LHC and other large projects around the world.

Being devoted to physics, for many years Vladimir used his vacations for his other scientific interests – entomology and ecology. He created a large collection of butterflies, and was lucky to find new types, some of which were named after him. He was a member of the Russian Entomological Society and the Moscow Society of Nature Research.

Vladimir had many friends around the world. He was respected for his deep and wide professional knowledge, devotion to scientific research, scientific vision, teaching talent and warm relationships with colleagues. Many of them went to him for clarification, advice and guidance and always received his attention and clear explanations. He was a charming person. We miss him greatly.
His friends and colleagues.

Alexei Zamolodchikov 1952–2007

The theoretical physicist Alexei Zamolodchikov passed away on the night of the 18–19 October 2007.

Alexei was born on 18 September 1952 in Novo-Ivankovo, near Dubna. After finishing high school in 1969, he studied at the Moscow Institute of Physics and Engineering until 1976, and he then worked successively at the JINR, Cybernetics Counsel, and ITEP, Moscow. From 1990 he held a senior CNRS position in the University of Montpellier-2.

His extraordinary journey in theoretical physics was marked by several major discoveries that influenced the work of a whole generation of physicists active in the different domains of quantum field theory and mathematical physics. In particular, he was the first, together with his brother Alexander, to construct exact scattering matrices in two-dimensional quantum field theory. Moreover he demonstrated how these scattering matrices allowed the building up of



Alexei Zamolodchikov contributed to Liouville string theory. (Courtesy Alexander Zamolodchikov.)

a systematic approach to integrable models at finite temperature. He regularly contributed to the development of Liouville string theory – the key model for understanding the most fundamental aspects of string theory and two-dimensional quantum gravity.

Alexei judged his own work by unusually high standards and his published papers reflect only a tiny part of his work. The papers he wrote carried both powerful ideas and mathematical elegance. He left behind a mass of unfinished projects, most of them now lost forever.

All those who knew Alexei closely will remember not only his immense talent as a physicist and the depth of his thought, but also the warmth of his friendship, his radical non-conformism and complete absence of vanity – and finally his incomparable sense of humour, sometimes bitter and fatalistic, but never malicious.
His friends and colleagues.

Turkish air crash is a great loss for physics

The news of the untimely deaths of six Turkish physicists, Engin Arik, Berkol Dogan and Engin Abat from Bogazici University, and Senel Boydag, Iskender Hikmet and Mustafa Fidan from Dogus University, was a shock for many in the physics community. The physicists were killed when their flight from Istanbul to Isparta crashed on 30 November. They were travelling to a workshop on the Turkish Accelerator Centre, a project involving a collaboration of 10 Turkish universities.

Some of those who passed away were world-renowned, while others were young,

talented and just starting their careers. All had connections with CERN. Arik, in particular, was a nuclear physicist with a worldwide reputation. She pioneered Turkish involvement at CERN in experiments such as the Spin Muon Collaboration, the CERN Axion Solar telescope (CAST) and ATLAS. She was also fully engaged in promoting particle physics in Turkey and in getting her country more involved in European science projects.

Arik joined the ATLAS Collaboration early in its beginnings some 15 years ago. With her enthusiasm for physics, she motivated

several generations of young physicists, who worked hard and successfully on the project. Engin Abat and Berkol Dogan were among these young, bright students.

Arik and Dogan were also members of the CAST Collaboration, with Boydag and Hikmet. While Senel and Iskender supported CAST from afar, Arik and Dogan had a strong presence in the work at CERN, active in both data analysis and in the preparation and running of the experiment. Indeed, Berkol had spent two long periods at CERN where he proved himself absolutely sound and 100% reliable.

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Infolytica Corporation has unveiled new MagNet 2D and MagNet 3D low-frequency electromagnetic-field simulation software. Benefits include: faster runtimes for automated mesh refinements in 2D; improved modelling to calculate the dynamic mechanical effects of any two spring-connected components; and vector-controlled circuitry support using the MagNet Plug-In for Simulink. For more information, see www.infolytica.com; or contact Chad H Ghalamzan, tel +1 514 849 8752 ext 300; fax +1 514 849 4239.

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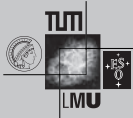
The George Washington University has an opening for an Assistant Research Professor in Experimental Nuclear Physics (three-year term, one course per semester teaching requirement, non-tenure-accruing faculty position). Basic Qualifications: Experience beyond the Ph.D. degree in medium-energy nuclear physics, electromagnetic interactions, and/or few-body nuclei is essential. Preferred Qualifications: Experience with nuclear particle and radiation detectors and data-acquisition systems is valuable.

Application Procedure: Send a CV, a 1-page statement of research/career goals, and three reference letters to Professor B.L. Berman, Chair, ENP Search Committee, Physics Department, GWU, Washington, D.C. 20052 [fax: (202) 994-3001; e-mail: berman@gwu.edu; website: <http://www.gwu.edu/~ndl/>]. Review Start Date: February 27, 2008. Only complete applications will be considered.

The George Washington University is an Equal Opportunity-Affirmative Action Employer.

The Excellence Cluster for Fundamental Physics

'Origin and Structure of the Universe'



The Cluster of Excellence 'Origin and Structure of the Universe' is a joint research project at the Garching Campus of the Technical University Munich funded by the Excellence Initiative of the Federal Government of Germany. It represents a co-operation by the physics departments of the Technical University Munich and the Ludwig-Maximilians University, four Max-Planck Institutes (MPA, MPE, MPP, IPP) and ESO. The main goal of the Cluster is to solve fundamental questions of astrophysics and cosmology (big bang, dark energy, dark matter, black holes, fundamental forces, nucleosynthesis etc.). The Excellence Cluster Universe provides a unique interdisciplinary research platform for astrophysicists, particle and nuclear physicists to face these challenges and find solutions. We are looking for

- **RESEARCH FELLOWS**
- **POSTDOCTORAL RESEARCHERS**
- **DOCTORAL STUDENTS**

In the **FELLOW PROGRAM** we search for excellent young scientists (experienced postdocs). Fellows are free to choose their own research field although an interest in strong collaboration with existing research groups is expected. The duration for contracts is two years. Fellows receive their own budget for running costs.

POSTDOCTORAL RESEARCHERS will work in specific groups and in well-defined projects, outlined in more detail in the specific job description on our website.

DOCTORAL STUDENTS will be assigned to specific projects and supervisors. The students will be enrolled at the respective supervisor's University that will also award the doctoral degree in physics. Doctoral students will follow a structured PhD program with their scientific progress being monitored by two independent advisors. The duration of the PhD program is three years.

Candidates of all groups are chosen in a competitive manner. They will benefit from the outstanding scientific infrastructure at the Garching Campus and the team-oriented, interdisciplinary work atmosphere. They will also be involved in transregional and international research activities. Furthermore, regular seminars, conferences and our extensive visiting-scientists program offer excellent opportunities for researchers to broaden their scientific horizon and embark upon new collaborations.

The advancement of women in science is an integral part of the Cluster's and the University's policy. Therefore, women are especially encouraged to apply. Persons with disabilities will be given preference to other applicants with equal qualifications.

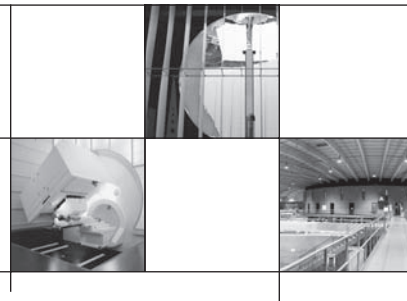
Application:

Details on job vacancies and research of the Cluster can be found on our website <http://www.universe-cluster.de>. Applicants should complete the web-based application form in the respective jobs description (-> **jobs button**). Here you also find further information on deadlines and the application documents required.

Contact:

Technische Universität München · Excellence Cluster Universe
Dr. Andreas Müller · Boltzmannstrasse 2
85748 Garching · Germany

PAUL SCHERRER INSTITUT



The Paul Scherrer Institut is a centre for multi-disciplinary research and one of the world's leading user laboratories. With its 1300 employees it belongs as an autonomous institution to the Swiss ETH domain and concentrates its activities on solid-state research and material sciences, elementary particle physics, energy and environmental research as well as on biology and medicine.

The Ultra-Cold Neutrons (UCN) group is driving the UCN source construction, pursuing a related research and development program, and preparing for important particle physics experiments to be performed at the new source. The flagship experiment will be an improved search for the electric dipole moment (EDM) of the neutron. For the participation in the construction and commissioning of a new Ultracold Neutron Source and related experiments we have a vacant tenure track position for an experienced and outstanding

Research Scientist in Particle Physics

Your tasks

- Characterization of the PSI UCN source, commissioning and measurements of the UCN source parameters
- Enhancement of the PSI UCN source
- Participation in precision experiments in low energy particle physics, e.g., the neutron electric dipole moment ($nEDM$) measurement

Your profile

You have a PhD in experimental physics, preferentially with a strong background in experimental nuclear or particle physics. Experience with ultracold neutrons and/or with precision experiments would be an advantage. You have good knowledge in computing, mathematics, theoretical physics, and basics in electronics. You enjoy working in a highly motivated team in an international environment. A good command of English is required and knowledge of German would be helpful.

We are looking forward to your application.

For further information please contact Dr. Manfred Daum,
ph. +41 (0)56 310 36 68, e-mail: manfred.daum@psi.ch.

Applicants should submit a curriculum vitae, publication list (refereed journals only) and three letters of recommendation to:
Paul Scherrer Institut, Human Resources, Mrs. Hedwig Habersaat,
ref. code 1011-05, 5232 Villigen PSI, Switzerland,
or hedwig.habersaat@psi.ch.

Further job opportunities: www.psi.ch



The Advanced Photon Source facility at Argonne National Laboratory is seeking a skilled manager of high standing within the international particle accelerator community to serve as **Associate Division Director** of its Accelerator Systems Division. The successful applicant will manage and coordinate the R&D efforts of the Accelerator Systems Division in cooperation with other divisions within Advanced Photon Source, Argonne, and other research institutions around the world.

This position requires a high level of expertise in state-of-the-art accelerator science and technology, including superconducting technology, and comprehensive skill in setting priorities and goals for enhancing accelerator systems in support of the Advanced Photon Source (APS) facility. The Associate Division Director must be capable of leading a large group of accelerator scientists and engineers in the development of novel accelerator systems at the APS in order to keep the facility at the forefront of x-ray science. Knowledge of research techniques used in material and condensed matter science desired. The applicant must be able to influence the direction of facility development to achieve maximum scientific results and to evaluate the technical quality and cost effectiveness of designs being developed and implemented by the Division and the APS.

The Associate Division Director will be called upon to demonstrate considerable skill in managing Technical Group Leaders in carrying out their responsibilities, which include safety management, recruiting, scheduling, and effectively allocating financial resources.

Interested candidates should submit a resume through the Argonne career website at <http://www.anl.gov/careers/index.html>, under job openings for **Requisition #312605**.

Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

Argonne is an equal opportunity employer, and we value diversity in our workforce.



Massachusetts Institute of Technology

It takes everyone at MIT to be MIT.

Scientific Administrator

A research group of the Laboratory for Nuclear Science at MIT is currently leading an international collaboration of universities building a scientific detector for deployment on the International Space Station. The present phase of the work is ongoing at the European Center for Nuclear Research (CERN) in Geneva, Switzerland. The group is seeking a candidate to carry out organizational responsibilities including travel arrangements, accounts monitoring, maintaining communications with appropriate offices at CERN and MIT as well as other duties in support of the efficient running of the MIT team. Skills necessary include proficiency with computers, valid driver's license, effective communication skills in English and proficiency in French. Candidate must also be able to travel at short notice to Europe, U.S. and Asia and spend various durations of time at CERN, MIT, the Kennedy Space Center and the Johnson Space Center. Candidate must be able to work long hours and function well under time pressure in a highly technical environment. Weekend work is often required.

Candidate must have at least a Master's degree in engineering or physics.

Applicants should submit curriculum vitae and arrange for at least 3 letters of reference to be sent to: Kenneth Hewitt, Massachusetts Institute of Technology, 26-516, 77 Massachusetts Avenue, Cambridge, MA 02139-4307.

MIT is an Affirmative Action/Equal Opportunity Employer and encourages applications from women and minorities.

<http://web.mit.edu>



UPPSALA
UNIVERSITET

Uppsala University announces a position as

Associate professor/ Senior Lecturer in Experimental Hadron Physics

(with the possibility of being employed as a Professor)
at the Department of Nuclear and Particle Physics,
Uppsala University.

The lectureship is intended to strengthen the present research program at FAIR, Darmstadt, using the PANDA detector, and at COSY, Jülich, using the WASA detector. The holder of the position is expected to engage in either or both of these research projects at a leading level. The position involves research and teaching to the same extent. The holder should also act as doctoral thesis adviser to graduate students involved in the research projects.

Eligibility and Criteria for Ranking the Candidates

To be eligible for the lectureship a candidate must hold a doctoral degree. Grounds for promotion are scientific and pedagogical proficiency, with equal emphasis on both. "Scientific proficiency" refers to the applicant's own research and "teaching proficiency" refers to teaching, supervision and production of teaching materials.

For further information about the position, please contact Prof. Tord Johansson, phone +46 18 4713886, e-mail: tord.johansson@tsl.uu.se

Information about the Department of Nuclear and Particle Physics can be found at <http://www.isv.uu.se>

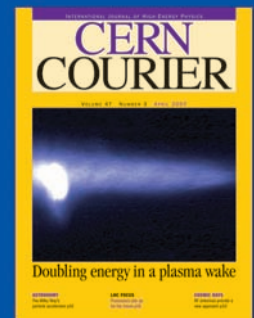
Applications must be sent in before March 3, 2008, UFV-PA 2007/2551.

A full advertisement with information about how to apply can be sent for from anita.ljungstrom@uadm.uu.se and can be found at www.teknat.uu.se/english/index.php



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NATIONAL OBSERVATORY OF ATHENS
NESTOR INSTITUTE for ASTROPARTICLE PHYSICS



TENURED, TENURE TRACK AND POSTDOCTORAL POSITIONS IN NEUTRINO ASTROPARTICLE PHYSICS

The Greek Secretary General for Research and Technology has allocated to the National Observatory of Athens six tenured or tenure track positions to work on the planned Cubic Kilometer Neutrino Telescope at the NESTOR Institute for Astroparticle Physics / NOA, (www.nestor.org.gr).

The NESTOR Institute is inviting interested physicists to enquire. The structure of Research Posts in Greece is RESEARCHER grade A,B,C and D corresponding to the University Posts of FULL, ASSOCIATE, ASSISTANT Professor and LECTURER. The Posts of Researcher A and B are tenured. Researcher C is on a definite tenure track, while Researcher D is for a fixed three year term at the end of which one is considered for promotion to Grade C. All posts are open to nationals of EU member states.

At this moment we are inviting interested experimentalists in the fields of Astrophysics, Particle, Astroparticle and Nuclear Physics to apply by January 31, 2008, for one post of Researcher C and one of Researcher D. We also invite applicants interested for the posts of Researcher A and B to send us expressions of interest including their CV's.

The NESTOR Institute has also several openings for three year Postdoctoral Positions, interested applicants are encouraged to apply.

Further information for all the above positions can be obtained by contacting the NESTOR Institute : secretary@nestor.org.gr

RESEARCH POSITION IN EXPERIMENTAL PARTICLE PHYSICS

UNIVERSITY OF CALIFORNIA, SAN DIEGO (UCSD)

The High Energy Physics Group (<http://hep.ucsd.edu>) at UCSD seeks one or two researchers interested in a long-term leadership position in the group. Our group is playing a leadership role in the DAQ of the CMS experiment at CERN. Our group has been responsible for the development, deployment, and operations of the Event-Builder at CMS, a system comprising several hundred to a few thousand computers, and Myrinet as well as Gigabit networking infrastructure. The candidates are expected to play a key role in all aspects of this effort. Strong technical skills, and an interest in day-to-day operations of computing infrastructure are required in addition to strong written and verbal skills. At least one of the two positions requires a Ph.D. in a data intensive science, e.g. particle physics; postdoctoral experience or equivalent preferred. Title and level of appointment will be commensurate with qualifications and experience. Salary will be based on published UC pay scales. Review of applications will begin on January 31, 2008 and will continue until positions are filled. To apply, candidates should refer to position WPSC-CC and send a CV with names and addresses of references, electronically to daqsearch@physics.ucsd.edu or by mail to: Professor James Branson, UCSD, 9500 Gilman Drive, MC 0319, La Jolla, CA 92093-0319.

UCSD is an equal opportunity/affirmative action employer with a strong institutional commitment to excellence through diversity.



ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Several postdoctoral research positions are available at the Laboratory for High Energy Physics of the Swiss Federal Institute of Technology in Lausanne (EPFL)

in the areas of detector R&D for scintillating fibre tracker with Silicon PMTs, and physics analysis of the LHCb data together with the responsibility to operate a CPU farm at EPFL, or to participate in the Silicon detector operation. We are actively working on Heavy Flavour Physics in the LHCb experiment at CERN, and also starting R&D in the area of FPGA-based readout electronics and precision tracking detectors. Applicants must have a PhD degree in high energy physics or a related field with relevant experience, and be less than 35 years old. The positions are available now and the initial appointment will be for one year, renewable up to a total of four years. Applications will be reviewed upon receipt until the positions are filled. Enquiries and applications, including CV and names of three references, should be sent via e-mail to our secretariat: Erika.Luthi@epfl.ch



TECHNISCHE
UNIVERSITÄT
DRESDEN

At the Faculty of Science in the Institute for Nuclear and Particle Physics we have an opening for a **Research Assistant for Experimental Particle Physics** (E13 TV-L)

on a fixed-term position until 30.6.2013. The period of employment is governed by the Fixed Term Research Contracts Act (Wissenschaftszeitvertragsgesetz – WissZeitVG).

Duties: playing a leading rôle in the analysis efforts of the local ATLAS group in close contact to the ATLAS collaboration at CERN. (Our activities within the BMBF Research Center ATLAS and the Helmholtz-Alliance "Physics at the Terascale" comprise data analysis and tool development for the search for Higgs Bosons beyond the Standard Model as well as commissioning of the ATLAS Liquid Argon Calorimeter.) Participation in the planned research and development of fast readout electronics for the forward calorimeters at the upgraded sLHC and the International Linear Collider ILC will also be possible. The post comprises the usual teaching duties and offers the opportunity for a "habilitation".

Qualification: Ph.D. in Experimental High Energy Physics or equivalent experience, strong commitment to teaching, great potential for outstanding achievements as an independent researcher and for coordination of a research group.

Applications from women are particularly welcome. The same applies to the disabled.

Please submit your application together with your CV, summary of research interests, list of publications with own contributions, a copy of the certificate of your highest academic degree and three names of referees before **February 20, 2008** (Deadlines refer to the date on the postmark of the University's Post Room Service) to **TU Dresden, Fachrichtung Physik, Institut für Kern- und Teilchenphysik, Herrn Prof. Dr. M. Kobel, 01062 Dresden, Germany** or in electronic form to kobel@physik.tu-dresden.de. (Please note: We are currently not able to receive electronically signed and encrypted data).



Vacancy Announcement

Applications are invited for a 36 month post-doctoral position at Forschungszentrum Dresden-Rossendorf (Germany) starting from the 1st of April 2008. The successful candidate will hold a PhD in Physics and has background in solid-state physics or physical metallurgy with experience in atomic simulation and numerical mathematics.

Working field:

- Atomic modelling (e.g. molecular dynamics) of irradiation induced defects in reactor materials and their influence on mechanical properties
- Computer simulation of the interaction of dislocations with irradiation defects
- Model validation using experimental data

Application deadline: March 15, 2008 Ref. No. 02E/2008

Contact: Prof. F.-P. Weiss Tel: +493512603480 f.p.weiss@fzd.de <http://www.fzd.de>



MARIE CURIE FELLOWSHIP POSITION AVAILABLE

A Post-doctoral Research position is offered for a period of 18 months starting March 1st 2008.

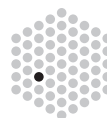
The person must be qualified in electronics & software for the development of high density pixelized semiconductor (CZT, CdTe) imaging instruments.

The position is located in Strasbourg (F) and Freiburg (D).

CONTACT: EURORAD SA 2 RUE E. BUGATTI
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EMBL is a leading international molecular biology research organisation and headquartered in Heidelberg (Germany), with Outstations in Grenoble (France), Hamburg (Germany), Hinxton (U.K.), and Monterotondo (Italy).

Senior Technical Officer Biological Small Angle Scattering

The successful candidate will join the biological SAXS group (within Structural Biology Unit of the EMBL Hamburg), which runs a user-oriented synchrotron radiation X33 beamline on the storage ring DORIS-III. (S)he will provide technical and scientific assistance to the activities at the X33 beamline, participate in collaborative projects with external users, and will work on novel biological SAXS developments in collaboration with the group constructing the EMBL BioSAXS beamline at Petra-III/DESY.

The ideal applicant holds a PhD in a relevant field and has expertise in structure analysis of biological macromolecules using synchrotron X-ray scattering.

For further information please visit www.embl.org/jobs

EMBL is an inclusive, equal opportunity employer offering attractive conditions and benefits appropriate to an international research organisation.

To apply, please send a CV (including names and addresses of referees) and covering letter, by e-mail, quoting ref. no. CC/07/198 in the subject line, to: application@embl.de

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PAUL SCHERRER INSTITUT



ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Professor in Experimental Particle Physics and Head of the Particle Physics Group at PSI

The Paul Scherrer Institute (PSI) and the Physics Department of the Swiss Federal Institute of Technology Zurich (ETH Zurich) have created a joint position. PSI operates the world's highest intensity muon beams and presently constructs the most intense ultra-cold neutron source. The new professor should focus his or her activity on precision measurements at low energies carried out at PSI and, in addition, act as head of the laboratory of particle physics of PSI.

The successful candidate is expected to have an internationally recognized expertise in the field of particle physics experimentation, detector development and construction, and in data analysis. He or she will be required to participate in teaching physics in all departments of ETH, including general introductory physics and specialized particle physics courses up to the level of the ETH Master's degree. Supervision of PhD students will also be requested. Courses at Master level may be taught in English.

Please submit your application, including your curriculum vitae, a list of publications, the names of at least 3 referees, and a short overview of your research interest, to the **President of ETH Zurich, ETH Zurich, Raemistrasse 101, CH-8092 Zurich, Switzerland, no later than February 29, 2008.** Questions referring to this position should be addressed to Prof. A. Rubbia (rubbia@phys.ethz.ch) or Dr. R. Horisberger (roland.horisberger@psi.ch). With a view toward increasing the number of female professors, ETH Zurich specifically encourages qualified women to apply.

cerncourier.com

For information and consultative advice on classified advertising in CERN Courier and the Web options that we offer, please contact

Moo Ali

Tel +44 (0)117

930 1264

E-mail moo.ali@iop.org

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MARCH ISSUE

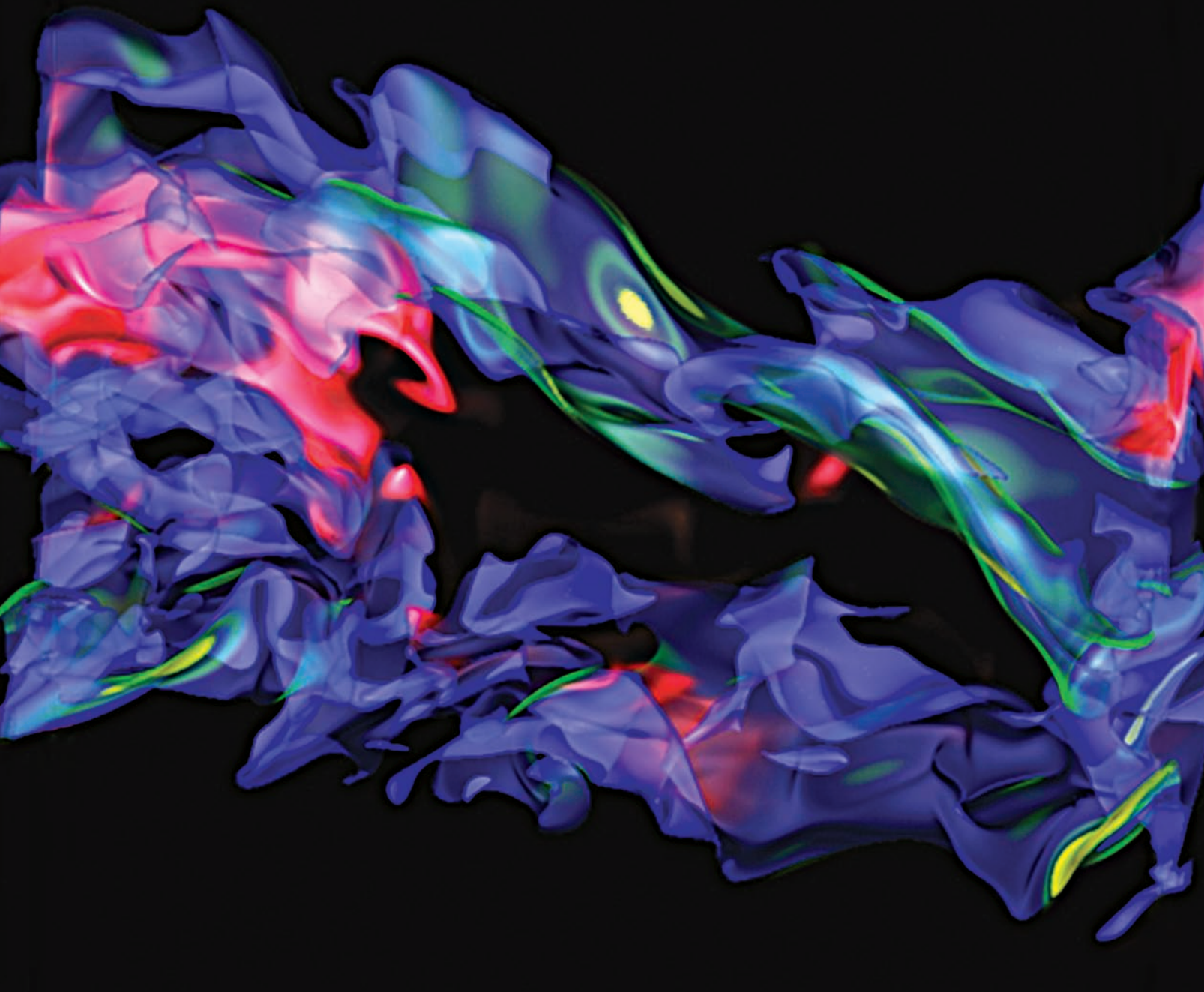
Booking Deadline: Friday 8 February

Copy Deadline: Monday 11 February

Distribution: Wednesday 20 February

Call Moo Ali on +44 (0)117 930 1264 for more details

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Visualization of stoichiometric mixture fraction, scalar dissipation rate, and OH radical mass fraction variables in a turbulent CO/H₂ jet flame
(image courtesy of **H Akiba** and **K-L Ma**, University of California, Davis, USA) **ER Hawkes**, **R Sankaran**, **J C Sutherland** and **J H Chen** 2005 *Journal of Physics: Conference Series* **16** 65–79.

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Warrendale, PA 15086-7573
Tel 724-779-3003
Fax 724-779-8313
info@mrs.org

www.mrs.org/spring2008

Symposia

ELECTRONICS, MAGNETICS, AND PHOTONICS

- A: Amorphous and Polycrystalline Thin-Film Silicon Science and Technology
- B: Materials and Devices for "Beyond CMOS" Scaling
- C: Advances in GaN, GaAs, SiC, and Related Alloys on Silicon Substrates
- D: Silicon Carbide—Materials, Processing, and Devices
- E: Doping Engineering for Front-End Processing
- F: Materials Science and Technology for Nonvolatile Memories
- G: Phase-Change Materials for Reconfigurable Electronics and Memory Applications
- H: Materials Science of High-*k* Dielectric Stacks—From Fundamentals to Technology
- I: Synthesis and Metrology of Nanoscale Oxides and Thin Films
- J: Passive and Electromechanical Materials and Integration
- K: Materials and Devices for Laser Remote Sensing and Optical Communication
- L: Functional Plasmonics and Nanophotonics
- M: Materials and Technology for Flexible, Conformable, and Stretchable Sensors and Transistors
- N: Materials and Processes for Advanced Interconnects for Microelectronics

NANOMATERIALS, FUNDAMENTALS, AND CHARACTERIZATION

- O: Semiconductor Nanowires—Growth, Physics, Devices, and Applications
- P: Carbon Nanotubes and Related Low-Dimensional Materials
- Q: Ionic Liquids in Materials Synthesis and Application
- R: Coupled Mechanical, Electrical, and Thermal Behaviors of Nanomaterials
- S: Weak Interaction Phenomena—Modeling and Simulation from First Principles
- T: Nanoscale Tribology—Impact for Materials and Devices
- U: Mechanics of Nanoscale Materials
- V: Crystal-Shape Control and Shape-Dependent Properties—Methods, Mechanism, Theory, and Simulation
- W: Advances and Applications of Surface Electron Microscopy
- Y: Focused Ion Beams for Materials Characterization and Micromachining
- Z: Materials Structures—The Nabarro Legacy

POLYMERS AND BIOMATERIALS

- AA: Conjugated Organic Materials—Synthesis, Structure, Device, and Applications
- BB: Signal Transduction Across the Biology-Technology Interface
- CC: Designer Biointerfaces
- DD: From Biological Materials to Biomimetic Material Synthesis
- EE: Responsive Biomaterials for Biomedical Applications
- FF: Molecular Motors, Nanomachines, and Active Nanostructures
- GG: Mechanical Behavior of Biological Materials and Biomaterials

ENERGY AND ENVIRONMENT

- HH: The Hydrogen Economy
- II: Heterostructures, Functionalization, and Nanoscale Optimization in Superconductivity
- JJ: Materials Research for Electrical Energy Storage
- KK: Light Management in Photovoltaic Devices—Theory and Practice
- LL: Energy Harvesting—From Fundamentals to Devices
- MM: Health and Environmental Impacts of Nanoscale Materials—Safety by Design
- NN: Actinides IV—Basic Science, Applications, and Technology

GENERAL INTEREST

- X: Frontiers of Materials Research
- OO: The Role of Lifelong Education in Nanoscience and Engineering
- PP: The Business of Nanotechnology

Meeting Activities

Symposium Tutorial Program

Available only to meeting attendees, the symposium tutorials will concentrate on new, rapidly breaking areas of research and are designed to encourage the exchange of information during the symposium.

Exhibit

A major exhibit encompassing the full spectrum of equipment, instrumentation, products, software, publications, and services is scheduled for March 25–27 in Moscone West, convenient to the technical session rooms.

Symposium Assistant Opportunities

Graduate students who are interested in assisting in the symposium rooms during the 2008 MRS Spring Meeting are encouraged to apply for a Symposium Assistant position. By assisting in a minimum of four half-day sessions, students will receive a waiver of the student meeting registration fee, a one-year MRS student membership commencing July 1, 2008, and a stipend to help defray expenses. The application will be available on our Web site by November 1.

Career Center

A Career Center for MRS members and meeting attendees will be offered in Moscone West during the 2008 MRS Spring Meeting.

Publications Desk

A full display of over 950 books will be available at the MRS Publications Desk. Symposium Proceedings from both the 2007 MRS Spring and Fall Meetings will be featured.

Graduate Student Awards

The Materials Research Society announces the availability of Gold and Silver Awards for graduate students conducting research on a topic to be addressed in the 2008 MRS Spring Meeting symposia. All finalists will receive a waiver of the meeting registration fee and a one-year MRS student membership commencing July 1, 2008. The award prizes consist of \$400 and a presentation plaque for the Gold Awards and \$200 and a certificate for the Silver Awards. The application will be available on our Web site by October 1 and must be received at MRS headquarters by December 14, 2007.

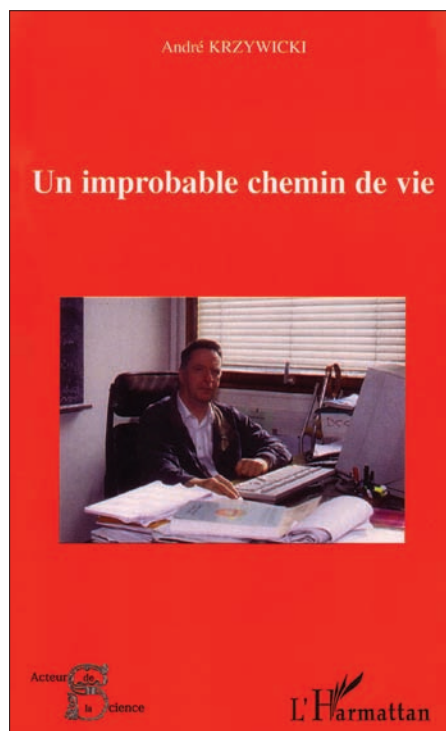
BOOKSHELF

Un Improbable Chemin de Vie par André Krzywicki, L'Harmattan. Broché ISBN 2296011934, €17.50.

André Krzywicki connaît certainement trop bien la théorie des probabilités pour ne pas réaliser que le titre de son autobiographie est une contradiction dans les termes. Un événement envisagé dans le futur peut être probable ou improbable, mais ce qui est déjà arrivé est déjà arrivé, un point c'est tout. Cependant tout le monde comprend très bien ce que veut dire le titre, à savoir que tout ce qui est arrivé était, a priori, très improbable. Improbable qu'il survive à la terreur nazie, comme ce fut le cas pour nos amis du CERN, Georges Charpak, Jacques Prentki et Marcel Vivargent par exemple. Improbable qu'il survive à la poliomyélite. Improbable qu'il s'en tire avec un handicap sérieux mais supportable lui permettant d'avoir une vie sentimentale normale. Improbable enfin de pouvoir s'installer à l'Ouest, à Orsay (près de Paris), où il terminera sa carrière comme physicien théoricien au plus haut niveau. Incontestablement, tout cela valait la peine d'être raconté.

André Krzywicki est né à Varsovie d'un père aristocrate catholique et d'une mère juive, écrivain célèbre déjà avant la guerre. Officier, son père est fait prisonnier par les Russes et exécuté à Kharkov, massacre peut être moins connu que celui de Katyn. L'auteur a un frère aîné, le préféré de sa mère. Cette dernière comprend qu'accepter de porter l'étoile de David est tomber dans un piège. Elle se réfugie avec ses deux enfants sous un faux nom à la campagne. Mais ils se font repérer par les Allemands qui, par chance, s'y prennent à deux fois pour venir les chercher. La seconde fois, la famille avait disparu, cachée par des voisins. Elle retourne à Varsovie. Elle est témoin de l'insurrection du ghetto (de l'extérieur!) et de l'insurrection de Varsovie écrasée à cause du cynisme de Staline.

Ensuite, surviennent la mort catastrophique de son frère aîné, puis l'adaptation au régime communiste. Avec beaucoup d'honnêteté, André Krzywicki reconnaît qu'il s'est lancé à fond dans les jeunesse communistes tandis que sa mère semblait louvoyer avec le régime. Par deux fois, elle est envoyée en mission culturelle dans des ambassades à l'étranger. Il décrit son amour pour le sport brutalement bloqué par la polio dont il risquait de mourir. D'autres,



autour de lui, y resteront par manque de soins. Il parvient à force d'efforts à surmonter une partie de sa paralysie, mais il devra utiliser des béquilles toute sa vie comme le savent ceux qui le connaissent.

C'est peut-être à cause de son handicap qu'il s'oriente vers la physique théorique et atterrit à l'institut de la rue Hoza, sur lequel il porte un jugement un peu trop sévère à mon goût. Il y avait là de bons éléments, par exemple, mon regretté ami Lukaszuk qui, lui, est resté en Pologne et a été exilé sur la Baltique à cause de sa participation à Solidarité.

Lors d'une première escapade à l'Ouest, à Copenhague, André Krzywicki invite son ami Ziro Koba qui lui présente son élève, l'excentrique mais génial Holger Nielsen que nous connaissons bien au CERN. Ensuite, pour des raisons idéologiques et scientifiques, il part à l'Ouest définitivement. Au CERN, dont il fait beaucoup d'éloges, il bénéficie de l'aide de Jacques Prentki, alors que Léon Van Hove essaie de le persuader de retourner à Varsovie (un peu comme Van Hove avait réexpédié Martin Veltman à Utrecht, ce qui valut à ce dernier de reconstruire Gerard 't Hooft avec lequel il partagea le prix Nobel!). Finalement, avec l'aide de Louis Leprince-Ringuet et de Maurice Lévy, il s'installe à Orsay. J'admire qu'il ait réussi ce prodige car ces deux personnalités

marquantes du monde scientifique français n'avaient pas d'atomes crochus.

Ses témoignages de la vie scientifique parisienne sont très intéressants. Il y décrit, avec un œil critique, le fonctionnement de la recherche et de l'enseignement et surtout, il dresse une peinture impitoyable des événements de Mai 1968. Il raille la veulerie de la plupart des enseignants et des chercheurs. Il décrit la séquestration de Jean Nuyts accusé d'"élitisme" parce qu'il enseignait la théorie des champs. Pour lui, Mai 1968 a été surtout l'occasion pour les médiocres de se pousser en avant! Dans l'ensemble, c'est vrai. Mais il y avait parmi les meneurs, des gens qui avaient fait d'excellents travaux avant (par exemple, Jean Marc Lévy-Leblond). Nous avons aussi droit à une description réaliste du milieu scientifique où, il n'y a pas que des saints, mais parfois des voleurs, agissant de différentes façons, dont nous avons tous été victimes un jour ou l'autre. Ce qui rend la compétition entre les physiciens pire que celle entre les hommes d'affaires, disait un ancien ingénieur du CERN, Pierre Amiot, c'est que les hommes d'affaires luttent pour l'argent tandis que les physiciens se battent pour la gloire. Roy Glauber (bien avant de recevoir le Prix Nobel), lui fait une intéressante remarque: "Vers 50 ans les gens souffrent de ne pas recevoir la considération qu'ils méritent". Il explique aussi le pour et le contre du système des citations qui "rapporte" surtout aux plus connus.

Sur son œuvre personnelle André Krzywicki est relativement discret. C'est un mérite du livre qu'il ne contienne pas de formules. Tout au plus, on lit "nucléon, quark, couleur". L'homme peut être d'une très grande modestie: "il n'est pas exclus que cet ouvrage (de mathématiques pour la physique) soit la seule chose qui reste de moi" (p117). Mais il ne résiste pas à l'envie de répéter les compliments (et les emprunts) que lui ont fait les grands de ce monde comme Ken Wilson et Dick Feynman.

Sur sa vie sentimentale complexe, l'auteur est très honnête, donnant même des détails d'ordre sexuels. Mais on voit bien que parmi toutes les femmes qu'il a rencontrées, il n'y en a qu'une qui a été le grand amour. Il s'agit d'Ela, décédée d'un cancer à Orsay. C'est un peu comme Feynman qui a eu beaucoup d'aventures, mais un seul grand amour, Arlene, morte de la tuberculose à Albuquerque, alors qu'il travaillait à Los

Alamos. Une dernière remarque : alors qu'il conserve un attachement viscéral à la Pologne, on comprend qu'il se sent vraiment chez lui en France.

Ma conclusion est que ce livre vaut vraiment la peine d'être lu, non seulement par des physiciens, mais aussi par des personnes connaissant le milieu de la physique, par exemple des époux ou épouses de physiciens ou des membres non scientifiques du personnel du CERN. Je pense qu'il serait très souhaitable qu'une traduction en Anglais en soit faite.
André Martin, CERN.

Entropy Demystified: The Second Law Reduced to Plain Common Sense by Arieh Ben-Naim, World Scientific. Hardback ISBN 9789812700520, £28 (\$49). Paperback ISBN 9789812700551, £17 (\$29).

Arieh Ben-Naim, professor at the Hebrew University of Jerusalem, has been teaching thermodynamics and statistical mechanics for many years. He is therefore well aware that students learn the second law but do not understand it, simply because it cannot be explained in the framework of the continuous systems considered by the classical thermodynamics. They do not usually understand why entropy is always increasing (it is left as a principle in classical thermodynamics), and wonder what is the source of such an ever-increasing quantity.

The author shows that if we identify the entropy with the concept of "missing information" of the system at equilibrium, following the work by Claude Elwood Shannon (1916–2001) in 1948, then we obtain a well defined and measurable quantity. This quantity, apart from being a multiplicative constant, has the same behaviour as entropy – for every spontaneous process of an isolated system it must increase until the equilibrium state is reached. The missing information, rather than the disorder, is the key concept to understanding the second law. I should add here that this is not a widespread idea among physicists, so that many people may not appreciate this point. However, the arguments in this book are quite convincing, and different opinions are also taken into account and commented upon.

The author goes on to explain how the mystery of the ever-increasing entropy can be explained if we realize that matter is not continuous, but discrete. The author

follows the work of Josiah Willard Gibbs (1839–1903), who developed the statistical mechanical theory of matter based on a purely probabilistic approach. First, one has to accept the fact that macroscopic measurements are not sensitive enough to distinguish microscopic configurations when they differ for thousands or even millions of atoms, just because the total number of particles is usually of the order of 10^{23} . Then, under the hypothesis that each microscopic state is equally probable, one can group indistinguishable micro-states into measurable macro-states. The author shows that, for ordinary systems, the probability to have any measurable fluctuation away from the equilibrium state is so low that the age of the universe is negligible compared with the time we should wait to observe such a fluctuation. From this point of view, the second law is far more "absolute" than the other laws of physics, for which we could at best state that they are valid since the beginning of the universe.

The book makes very good reading for all students of thermodynamics, as well as for more-advanced people who do (or do not) feel comfortable with the fascinating concept of entropy. Ben-Naim is also author of the more technical book *A Farewell to Entropy: Statistical Thermodynamics Based*

on Information (World Scientific, in press), in which these guidelines form the basis for a more detailed treatment of statistical mechanics. Because we usually learn things much better when following a sequential approach, I encourage readers to start with *Entropy Demystified* and then consider seriously going deeper into the details of statistical mechanics with the forthcoming book by Ben-Naim, of which I was delighted to read the draft.

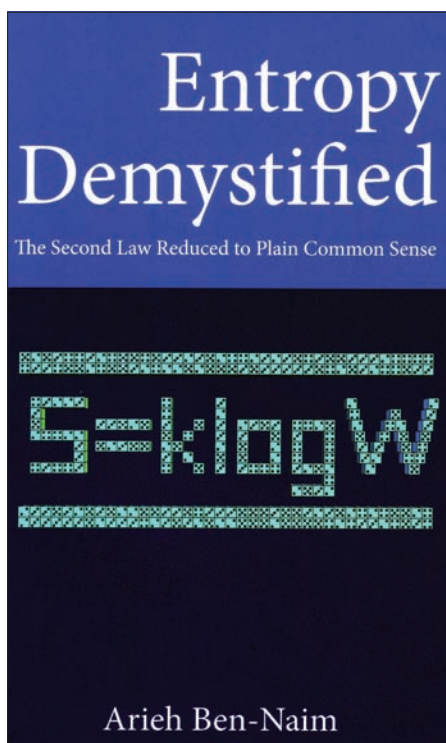
Diego Casadei, New York University and CERN.

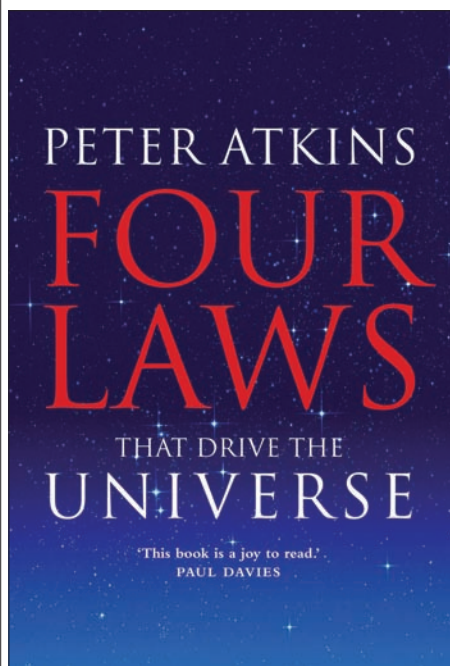
Four Laws That Drive The Universe by Peter Atkins, Oxford University Press. Hardback ISBN 9780199232369, £9.99 (\$19.95).

When looking at the starry cover and the title of this book, it is impossible not to think that it will deal with the four fundamental forces that are so invaluable to particle physicists and cosmologists. However, Peter Atkins, who is well known for his efforts in writing popular science books, is a chemist. So the universe turns out to be the most notable absentee in this latest book, and the four laws that drive it are in fact the ones of thermodynamics, which govern all questions about energy. Thus, Atkins presents the important concepts of temperature, heat, entropy, free energy and so on.

The content and form are quite classical, but the way the book is written is enjoyable; the words that Atkins uses and the explanations that he gives are accessible to everyone but never simplistic. Moreover, a large number of analogies will help novices to grasp concepts that are sometimes quite abstract. We must also keep in mind that thermodynamics is essential for experiments at CERN, which use huge cryogenic systems and calorimeters to measure the energy left by the particles produced in the collisions. So the author is right in claiming that the four laws of thermodynamics concern not only the steam engines of the 19th century, but "almost everything". However, readers will still feel hungry for more about the relationships between thermodynamics and the story of the universe, or even with daily life.

On the other hand, the book provides interesting historical points of reference about some of the greatest people in the field. It also gives a different perspective, showing how the ideas in this area evolved. In conclusion, it is certainly not a bedside book,





but it will suit anyone who is looking for a good and easy introduction to thermodynamics. *Arnaud Marsollier, CERN.*

Books received

Supersymmetry: Theory, Experiment, and Cosmology by Pierre Binétruy, Oxford University Press. Hardback ISBN 9780198509547, £49.95 (\$100).

This book describes the basic concepts of supersymmetric theories and is aimed at theorists, experimentalists and cosmologists interested in supersymmetry. The topics include a discussion of the motivation for supersymmetry in fundamental physics, a description of the minimal supersymmetric model, grand unification and string models. The book features a presentation of the main scenarios for supersymmetry breaking, including the concepts and results of dynamical breaking. On the astrophysics/cosmology side, the book discusses supersymmetric dark-matter candidates, inflation, dark energy and the cosmological constant problem.

The Theory of Open Quantum Systems

by Heinz-Peter Breuer and Francesco Petruccione, Oxford University Press. Hardback ISBN 9780198520634, £63 (\$125). Paperback ISBN 9780199213900, £37 (\$69.50).

Breuer and Petruccione focus on the central physical concepts and mathematical techniques used to investigate the dynamics of open quantum systems. The text begins with a survey of classical probability theory and an introduction into the foundations of quantum mechanics, looking at statistical interpretation in particular. Special attention is paid to the theory of environment-induced decoherence, its role in the dynamical description of the measurement process and the experimental observation of decohering Schrödinger-cat states. It includes the modern formulation of open quantum systems in terms of stochastic processes in Hilbert space, and also expounds the relativistic theory of quantum measurements from a unified perspective (e.g. non-local measurements and quantum teleportation).

Exotic Smoothness and Physics: Differential Topology and Spacetime Models

by Torsten Asselmeyer-Maluga and Carl H Brans, World Scientific Publishing. Hardback ISBN 9789810241957, £42 (\$77).

The rich panoply of new differentiable structures that lie in the unexplored region between topology and geometry forms the subject of this book. Just as physical geometry was thought to be trivial before Einstein, physicists have continued to work under the tacit – now shown to be incorrect – assumption that differentiability is uniquely determined by topology for simple four-manifolds. Since diffeomorphisms are the mathematical models for physical co-ordinate transformations, Einstein's relativity principle requires that these models be physically inequivalent. This book provides an introductory survey of relevant mathematics, presents preliminary results and makes suggestions for further applications to space-time models.

Lectures on QED and QCD: Practical Calculation and Renormalization of One- and Multi-Loop Feynman Diagrams

by Andrey Grozin, World Scientific Publishing. Hardback ISBN 9789812569141, £32 (\$56).
The increasing precision of experimental data in many areas of elementary-particle physics requires an equally precise theoretical description. In particular, radiative corrections (described by one- and multi-loop Feynman diagrams) must be considered. Although a growing number of physicists are involved in such projects, multi-loop calculation methods can only be studied from original publications. With its coverage of multi-loop calculations, this book serves as an excellent supplement to the standard textbooks on quantum field theory. Based around postgraduate-level lectures given by the author, the material is suitable for both beginners and graduate students.

Pairing in Fermionic Systems: Basic Concepts and Modern Applications

edited by Armen Sedrakian, John W Clark, and Mark Alford, World Scientific Publishing. Hardback ISBN 9789812569073, £54 (\$98).

Cooper pairing of fermions is a profound phenomenon that has recently become important in many different areas of physics. This book brings together experts from various fields that involve Cooper pairing, at the level of BCS theory and beyond, and includes the study of novel states of matter such as ultracold atomic gases and quark matter with application to neutron stars. The book's emphasis is on novel issues beyond ordinary BCS theory, such as pairing in asymmetric systems, the polarization effect and higher-spin pairing. The book also considers new techniques used widely in current research that differ significantly from the conventional condensed-matter approaches described in the standard literature. Cross-disciplinary in nature, the book will be of interest to physicists in many specialities, including condensed-matter, nuclear and high-energy physics.



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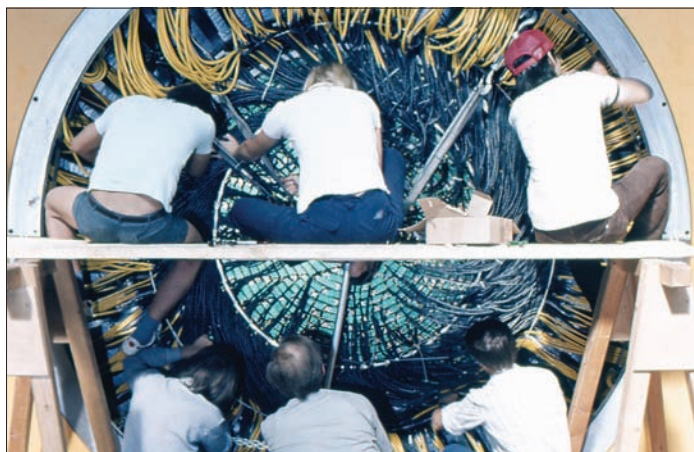
When ARGUS led to new physics

Frank Lehner on the DESY “ARGUS Fest” celebrating 20 years of B-meson mixing.

Twenty years after the groundbreaking observation of B-meson mixing by the ARGUS experiment in 1987, around 150 physicists, many former ARGUS collaborators, gathered at DESY on 9 November to celebrate the anniversary of this landmark for B physics.

The measurement of B-mixing by ARGUS in 1987 was a big surprise to the community. Common belief at the time was that the top quark would be light, meaning that B-mixing would be small, if not negligible. However, ARGUS observed a substantial B-meson mixing rate, indicating that the top quark must be much heavier than researchers had previously believed. The observed large mixing rate suddenly opened the door for CP-violating measurements in B physics. The discovery started to pave the way towards the design and construction of the precision experiments in B physics pursued with BaBar and Belle at SLAC and KEK, respectively, which will be continued with LHCb at CERN and other experiments in the future.

Herwig Schopper, former director of DESY and director-general of CERN, opened the symposium with some pertinent recollections. He had recognized the importance of heavy-flavour physics early on and established a programme of B physics at the DORIS storage ring at DESY immediately after the discovery of the b quark in 1977 by Leon Lederman's team at Fermilab. “At a time when most efforts



Top: 1982 was a busy time for preparations on the ARGUS detector. Bottom: Participants at the “ARGUS fest”, 25 years later. (Photos courtesy DESY.)

at DESY were devoted to getting PETRA into operation, DORIS and ARGUS were in the shadow of this large sister,” recalls Schopper. “To the surprise of most of us, ARGUS was able to open up a new domain of particle physics.”

Walter Schmidt-Parzefall, one of the founding fathers and long-time spokesman of ARGUS, described the story of the experiment and the meandering path that finally led to a clear signature of B-meson mixing. He had formed a team of young physicists to draft a concept for a new detector at DORIS.

Officially, the acronym ARGUS indicated the origin of the founding institutions: a Russian/German/United States/Swedish collaboration. However, the founders also knew about Argus, the legendary giant in Greek mythology, famous for having many eyes so that nothing could escape his view.

The ARGUS experiment took data from 1982 to 1992, and during that decade the collaboration contributed substantially to various fields of high-energy physics. Its 150 publications in high-energy physics have been cited nearly 10 000 times. Other speakers at the symposium, including David Cassel from Cornell University, a former member of the competing CLEO collaboration, stressed that the ARGUS discovery had “a profound effect on heavy quark physics and the CLEO programme”.

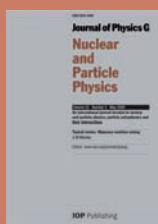
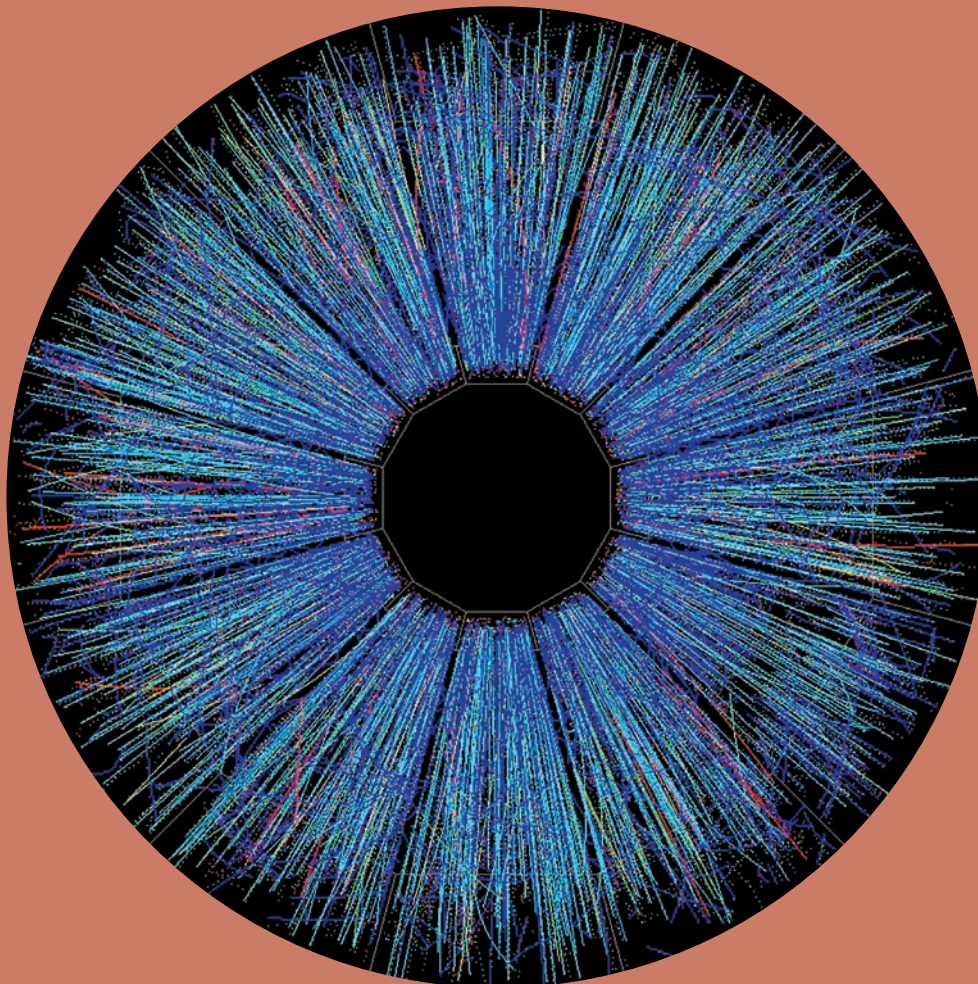
The speakers at the symposium did a wonderful job of recalling this exciting period in heavy-flavour physics. They covered not only the physics but also the sociology of the experiment, showing slides of black-and-white photographs from the past and creative log-book entries made during ARGUS shifts. It was altogether an excellent opportunity to meet old friends and to exchange pleasant memories of “the good old days”.

● For more information about the symposium, see <http://argus-fest.desy.de>.
Frank Lehner, DESY.

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Image: End view of a collision of two 30-billion electron-volt gold beams in the STAR detector at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. Courtesy of Brookhaven National Laboratory

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