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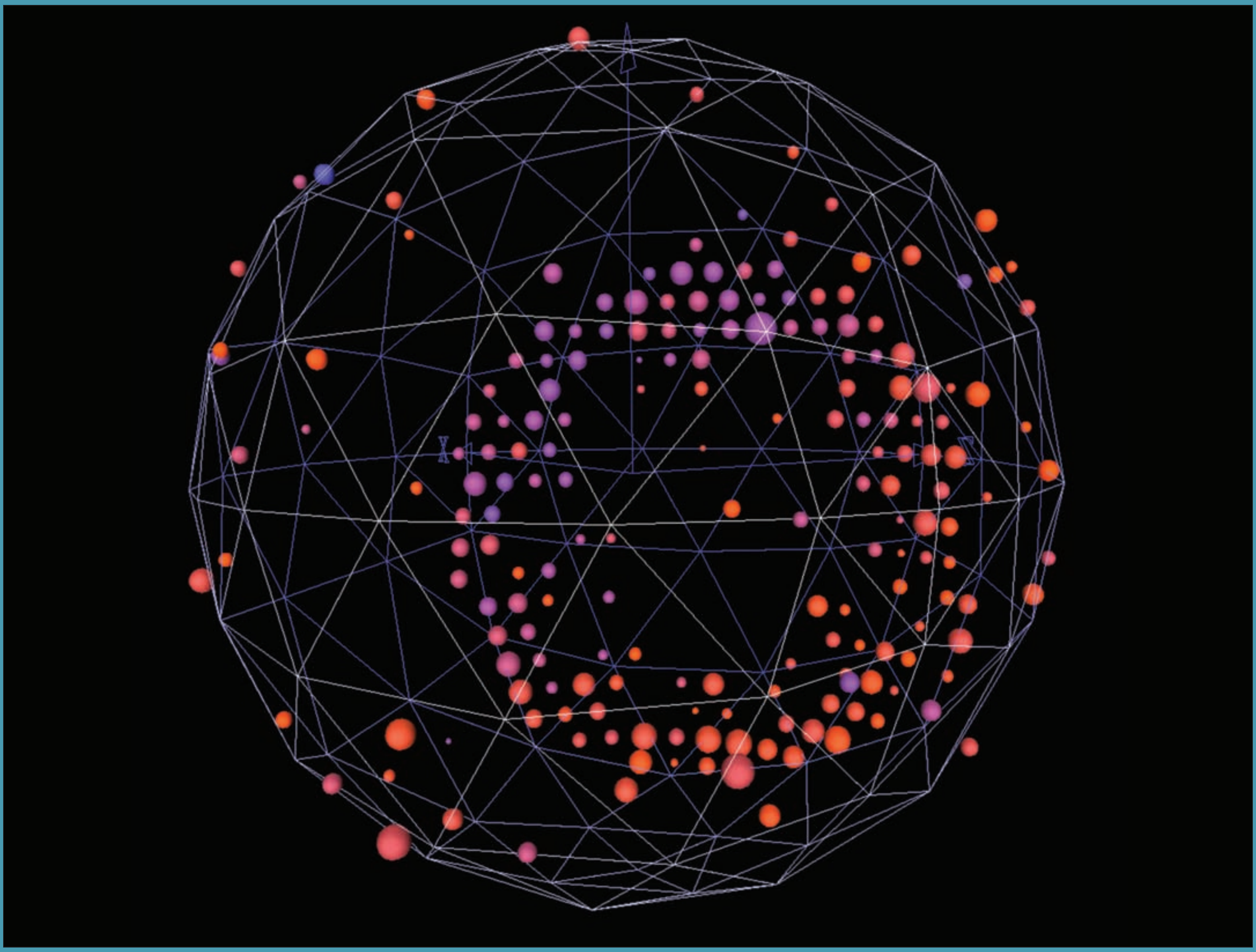

Neutrinos: resolving the mysteries

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Modules

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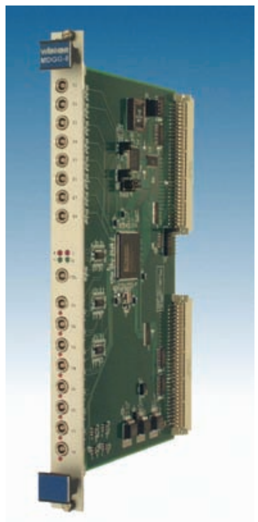

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Editor Christine Sutton
CERN, 1211 Geneva 23, Switzerland
E-mail cern.courier@cern.ch
Fax +41 (0) 22 785 0247
Web cerncourier.com

Advisory board James Gillies, Rolf Landua and Maximilian Metzger

Laboratory correspondents:
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Art director Andrew Giaquinto
Production editor Jonathan Cailes
Technical illustrator Alison Tovey
Advertising manager Ed Jost
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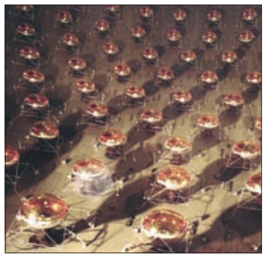
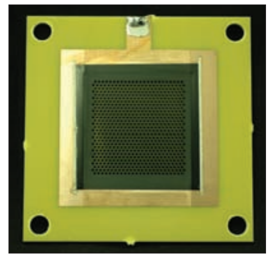


MiniBooNE has the answer p8

Capra shares his vision p15



RETGEM offers higher gain p35

Cover: A neutrino's "footprint" in the MiniBooNE detector. Results recently announced for MiniBooNE have at last resolved questions raised in the 1990s by the LSND experiment (p8). Meanwhile, the Sudbury Neutrino Observatory has come to the end of its studies using heavy water, which enabled resolution of the long-standing solar-neutrino problem (p26). (Courtesy Fermilab Visual Media Services.)

Improved Vacuum Solutions for Research Institutes

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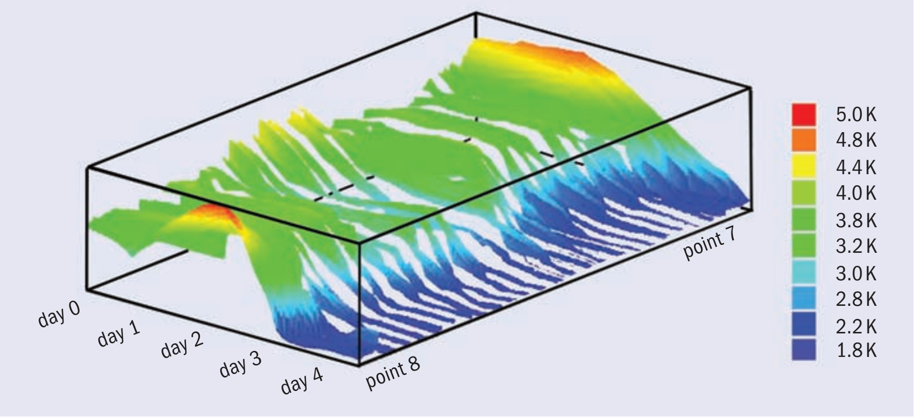
CERN

First LHC sector reaches 1.9 K

The first sector of the LHC to be cooled reached its operating temperature of 1.9 K for the first time on 10 April. Although only an eighth of the LHC ring, this sector is already the world's largest superconducting installation. This achievement marks the end of more than two months of commissioning work, which began in January and was carried out in three stages.

The 3.3 km sector comprises more than 200 dipole magnets and short straight sections, which contain quadrupole magnets, and has a total mass of 4700 tonnes. During the first stage, it was pre-cooled to 80 K, just above the temperature of liquid nitrogen. At this temperature, the material reaches 90% of its final thermal contraction, representing a 3 mm shrinkage for each metre of the steel structures. The total contraction over the sector as a whole is close to 10 m, and special devices (bellows and expansion loops) in the interconnections between the magnets compensate for this.

On 5 March, the teams began work on the second stage, which involved cooling the sector to 4.5 K using the gigantic refrigeration plants (*CERN Courier* May 2004 p15). For the final stage, which began in mid-March, the 1.8 K refrigeration plants came into play. These use a sophisticated pumping system to bring down the heat-exchanger saturation pressure to cool the magnets and the 10 tonnes of helium that they contain to 1.9 K. To achieve a pressure of 15 millibars, the system uses a combination of hydrodynamic centrifugal compressors operating at low temperature and positive-displacement compressors operating at room temperature. At 1.9 K, helium is superfluid, flowing with virtually no viscosity and allowing greater heat-transfer capacity.



The magnet temperature profile along sector 7-8 during the final phase of the cool down.

The complexity and large number of sub-systems to be commissioned for the first time, together with various interface conditions to be managed, account for the time needed to cool the sector. The control system of one sector has to manage approximately 4000 inputs/ouputs and 500 regulation loops that need to be adjusted. In addition, the teams have carried out extensive checks to make sure that the cooling was done with all the necessary caution. This learning phase, which was long but vital, has also enabled the teams to prepare for cooling the other sectors.

While the sector cooling progressed steadily, problems arose in a different sector when a quadrupole magnet, one of an "inner triplet" of three focusing magnets, failed a high-pressure test at Point 5 on 27 March. Each inner triplet set of magnets contains two quadrupole magnets (Q2 and Q3) built at KEK and one (Q1) built at Fermilab. The asymmetric force generated during the test broke the supports, made of the glass cloth–epoxy laminate G-11, that hold the Q1 magnet's cold mass inside the cryostat, and also damaged electrical connections.

CERN and Fermilab now know that this is an intrinsic design flaw that must be addressed in all triplet magnets assembled at Fermilab. Computer-aided calculations after the accident show that the G-11 support structure could not withstand the associated longitudinal forces. Review of engineering designs reveals that the longitudinal force from asymmetric loading was not included in the engineering design or identified as an issue in the four design reviews. An external review committee will analyse how this problem occurred and determine the root causes and the lessons learned.

The goal at CERN and Fermilab is now to redesign and repair the inner triplet magnets and, if necessary, the electrical distribution feed-box without affecting the LHC start-up schedule. Teams at CERN and Fermilab have identified potential repairs that could be carried out without removing undamaged triplet magnets from the tunnel. In the meantime, all three of the pressure-tested triplet magnets at Point 5, plus the associated feed-box, will be removed from the tunnel for inspection and, if necessary, repair.

Sommaire

B-PHYSICS

B-factories yield first evidence for elusive D^0–$\bar{D}^0$ mixing

It is more than 50 years since researchers first observed particle–antiparticle mixing, with the discovery of a second, longer-lived neutral kaon state. This discovery pre-dated the quark model, but the effect became understood in terms of transitions between the quarks (s and d) in these neutral mesons. Thirty years later, scientists found the phenomenon in neutral B_d mesons (b and d quarks), and then last year the D0 and CDF collaborations at Fermilab's Tevatron reported mixing in neutral B_s mesons (b and s). This left the neutral D meson (c and u quarks) as the only system remaining where mixing was possible, but not yet observed.

Now, experiments at the two B-factories, KEKB at KEK in Japan and PEP-II at SLAC in the US, have filled the gap, with reports of the first evidence for D^0–$\bar{D}^0$ mixing. On 13 March at the Rencontres de Moriond in La Thuile, Marko Starič presented results for D^0–$\bar{D}^0$ mixing from the Belle experiment at KEKB. Kevin Flood followed with evidence from the BaBar experiment at the PEP-II storage rings.

As in the kaon and B-meson systems, the D^0 and $\bar{D}^0$ are created in "flavour" eigenstates consisting of a quark and an antiquark, but in each case mixing through weak interactions between the quarks should give rise to two different mass eigenstates that are particle–antiparticle mixtures and have different lifetimes. Mixing should therefore modify the decay times of D mesons by a small but observable amount.

The Belle Collaboration has compared decay times in three decay modes of D mesons: two decays to CP-even eigenstates, K^+K^- and $\pi^+\pi^-$, and a "flavour-specific decay" to a mixed CP state, $D^0 \to K^-\pi^+$. The mass eigenstates are CP eigenstates, assuming no CP violation, one being CP-odd, the other CP-even, so in comparing these decay modes, the team is in effect comparing the lifetimes, τ, of the mass eigenstates, which would be the same in the absence of mixing. They measure the relative lifetime difference, $y_{CP} = \{\tau(K^-\pi^+)/\tau(K^+K^-)\} - 1$ to be $(1.31 \pm 0.32(\text{stat.}) \pm 0.25(\text{syst.}))\%$ (M Starič *et al.* 2007). This differs from zero by $3.2\,\sigma$ after including systematic uncertainties, and so represents clear evidence for D^0 mixing.

The BaBar Collaboration has approached the problem slightly differently by focusing on the decay $D^0 \to K^+\pi^-$, and analysing the data in terms of the parameters, x' and y'. (These are rotations through a strong phase of the mixing parameters $x = \Delta M/\Gamma$ and $y = \Delta\Gamma/2\Gamma$, which depend on the differences in mass (ΔM) and width ($\Delta\Gamma$) of the mass eigenstates, where Γ is the average width.) They find $y' = (9.7 \pm 4.4(\text{stat.}) \pm 3.1(\text{syst.})) \times 10^{-3}$, while x'^2 is consistent with zero – a result that they say is inconsistent with the hypothesis of no mixing at $3.9\,\sigma$ (Aubert *et al.* 2007).

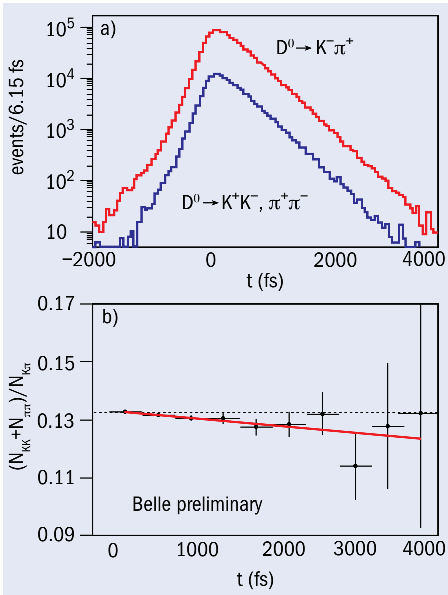


Fig. 1. a) Belle's time distributions measured for $D^0 \to K^-\pi^+$ and the sum of $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$. b) The ratio of the two distributions. The deviation from zero slope in (b) is visual evidence for D^0–$\bar{D}^0$ mixing.

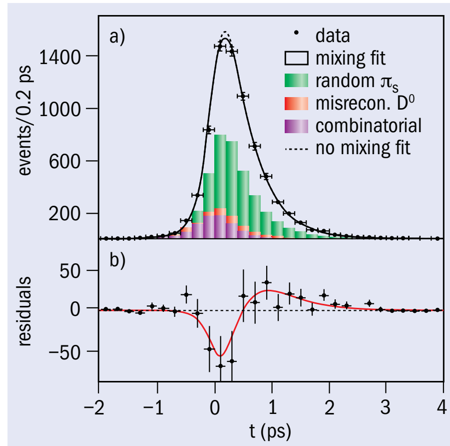


Fig. 2. a) A proper-time distribution of candidates in BaBar for $D^0 \to K^+\pi^-$ decays combined with corresponding decays for $\bar{D}^0$. The solid line shows the fit that allows mixing but not CP violation, while the dotted line is the fit with no mixing. Shaded regions show various backgrounds. b) The difference between the data and the no-mixing fit (points) together with the difference between fits with and without mixing (solid line).

Both collaborations have also analysed the data for CP violation associated with D^0–$\bar{D}^0$ mixing but have found no evidence for this. The new results, meanwhile, can be compared with the Standard Model to search for new physics, as D-meson mixing is particularly sensitive to any contributions from particles or processes that have not so far been observed.

Further reading

For the two presentations at Moriond, see http://indico.in2p3.fr/conferenceDisplay.py?confId=151.
B Aubert *et al.*, the BaBar Collaboration 2007 http://arxiv.org/abs/hep-ex/0703020, submitted to *Phys. Rev. Lett.*
M Starič *et al.*, the Belle Collaboration 2007 http://arxiv.org/abs/hep-ex/0703036, submitted to *Phys. Rev. Lett.*

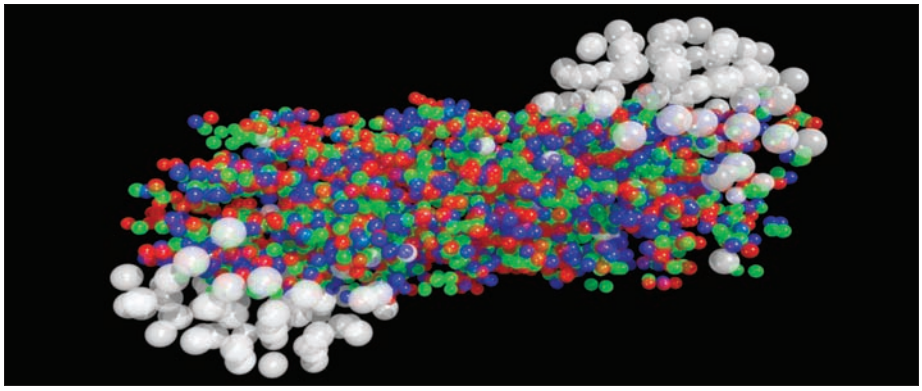
HEAVY IONS

Theory ties strings round jet suppression

The properties of quark–gluon plasma (QGP), where the quarks and gluons are no longer confined within hadrons, lead to intriguing effects that have already been studied in heavy-ion collisions at CERN's Super Proton Synchrotron (SPS) and at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven. However, the hot, dense medium produced momentarily in the collisions is a challenging environment for calculations in quantum chromodynamics (QCD), the theory that describes the strong interactions between the quarks and gluons. Though the medium is hot enough for the hadrons to "melt" into the QGP state, its temperature is still relatively low and the couplings between the quarks and gluons remain too strong to allow the use of perturbative QCD, which relies on the couplings being weak at high energies.

To get to grips with the strong couplings, a small group of theorists has taken inspiration from string theory. Hong Liu and Krishna Rajagopal of MIT and Urs Wiedemann of CERN make use of "gauge-gravity duality", in which a gauge theory and a gravitational theory provide alternative descriptions of the same physical system. They map more complex calculations in a strongly coupled gauge theory onto a simpler problem in a dual gravitational string theory, and have looked at two intriguing effects observed in heavy-ion collisions – "jet quenching" and the suppression of the production of J/Ψ mesons.

Strictly speaking, they are not working directly with QCD as no one yet knows which string theory is dual to QCD. They work instead with a duality that works for a large class of gauge theories that behave similarly to QCD at high temperature. They then conjecture that the effects they find should also hold for QCD, and have made some predictions that can be tested at RHIC and at CERN's LHC.



String theory is helping to untangle the complexity of the hot, dense matter that is created when heavy ions collide and quarks and gluons break free from the hadrons.

Jet quenching is one of the most dramatic pieces of evidence for the strong-coupling nature of the quark–gluon matter produced at RHIC. Here highly energetic quarks and gluons produced in the collisions interact with the matter so strongly that they are stopped within much less than a nuclear diameter, "quenching" the jet of hadrons that would normally materialize from the liberated quark or gluon. Previous attempts using perturbative techniques to calculate the parameter that characterizes this effect produced values an order of magnitude too small. Now, using the dual technique, Liu and colleagues have calculated a quenching parameter that is consistent with the data from RHIC, and had for the first time the right order of magnitude (Liu *et al.* 2006).

In a second calculation, the theorists have turned their attention to the problem of J/Ψ suppression. Screening effects in QGP are sufficient to reduce the attraction between a c and a $\bar{c}$ in the plasma to the extent that they are less likely to bind together to form a J/Ψ. This should lead to a reduction in the number of J/Ψ mesons produced in energetic heavy-ion collisions relative to proton–proton or proton–nucleus collisions. Previous calculations of this effect have depended on the non-perturbative approaches of lattice QCD. However, in lattice QCD the J/Ψ mesons are produced at rest, whereas in reality they will move at high velocities; from the viewpoint of the mesons, they will be in a "wind" of hot QGP.

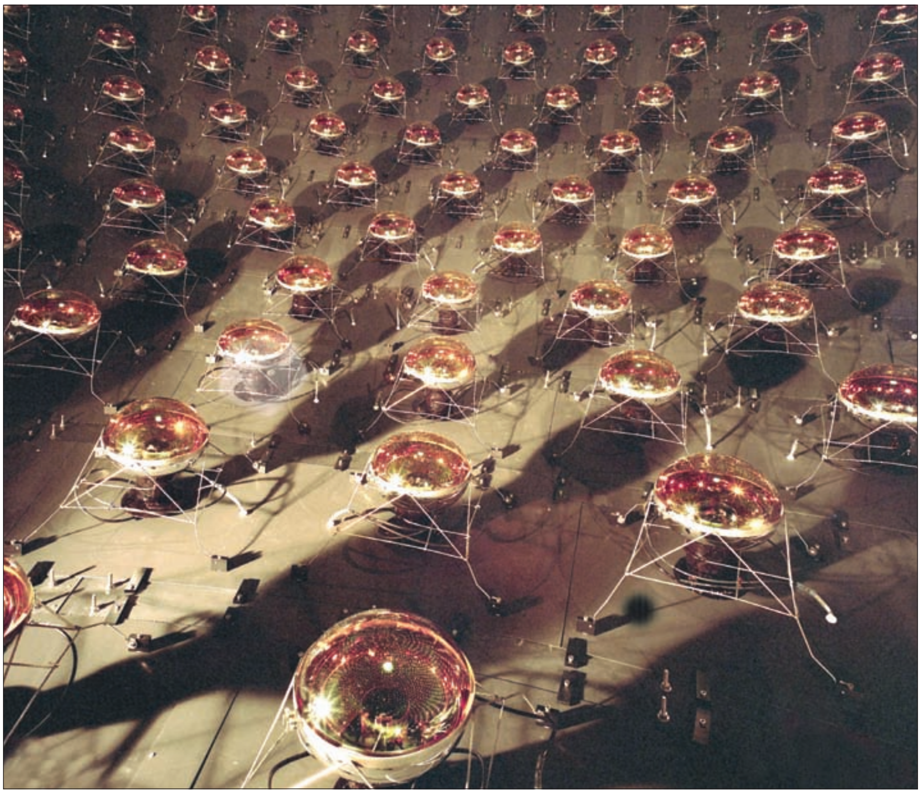
With the aid of the dual approach, Liu and colleagues have calculated the screening effect of such a hot wind, and how it depends on velocity (Liu *et al.* 2007). Assuming that the same effect holds in QCD, the calculations indicate that additional suppression should occur for J/Ψ mesons with higher values of transverse momentum. This should be observable in future in high-luminosity runs at RHIC, and at the LHC, where the temperatures of the QGP may even be high enough to give suppression of the heavier Υ mesons.

Further reading

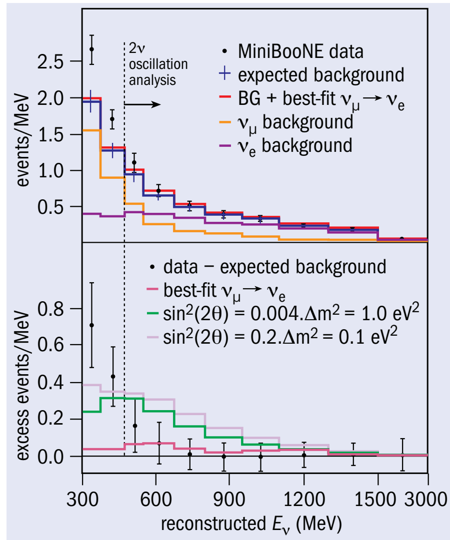
H Liu, K Rajagopal and U Wiedemann 2006 *Phys. Rev. Lett.* **97** 182301.
H Liu, K Rajagopal and U Wiedemann 2007 http://arxiv.org/pdf/hep-ph/0607062, *Phys. Rev. Lett.* in press.

NEUTRINOS

MiniBooNE solves neutrino mystery



Some of the 1280 phototubes that line the inner surface of MiniBooNE, the huge detector that contains 250 000 gallons of ultrapure oil. (Courtesy Fermilab Visual Media Services.)



Data from the MiniBooNE experiment. The bottom plot shows the number of excess events observed after subtracting the background. The solid curves in the bottom plot show two examples of predictions made for electron–neutrino excess according to the two-neutrino oscillation interpretation of the LSND results. The MiniBooNE data rule out such two-neutrino oscillation predictions.

The MiniBooNE Collaboration at Fermilab has revealed its first findings. The results announced on 11 April resolve questions that were raised in the 1990s by observations of the LSND experiment at Los Alamos, which appeared to contradict findings of other neutrino experiments. MiniBooNE now shows conclusively that the LSND results could not be due to simple neutrino oscillation.

The observations made by LSND suggested the presence of neutrino oscillation, but in a region of neutrino mass vastly different from other experiments. Reconciling the LSND observations with the other oscillation results would have required the presence of a fourth, or "sterile" type of neutrino, with properties different from the three standard neutrinos. The existence of sterile neutrinos would indicate physics beyond the Standard Model, so it became crucial to have some independent verification of the LSND results.

The MiniBooNE experiment took data for this analysis from 2002 until the end of 2005 using muon neutrinos produced by the Booster accelerator at Fermilab. The detector consists of a 250 000 gallon tank filled with ultrapure mineral oil, located about 500 m from the point at which the muon neutrinos were produced (*CERN Courier* July/August 2002 p5). A layer of 1280 light-sensitive photomultiplier tubes, mounted inside the tank, detects collisions between neutrinos and carbon nuclei in the oil.

For this analysis the collaboration looked for electron neutrinos created by the muon neutrinos in the region indicated by the LSND observations, using a blind-experiment technique to ensure the credibility of their analysis and the results. While collecting the data, the researchers did not permit themselves access to data in the region, or "box," where they would expect to see the same signature of oscillations as LSND. When the team opened the box and "unblinded" its data, the telltale oscillation signature was absent.

Although this work has decisively ruled out the interpretation of the LSND results as being due to oscillation between two types of neutrinos, the collaboration has more work ahead. Since January 2006, the MiniBooNE experiment has been collecting data using beams of antineutrinos instead of neutrinos and expects further results from these new data.

Future studies also include a detailed analysis of an apparent discrepancy in data observed at low energy, for which the source is currently unknown, together with investigations of more exotic neutrino-oscillation models.

NUCLEAR PHYSICS

Coupled-clusters point to faster computation

Calculations of the structure of heavy nuclei have long suffered from the difficulties presented by the sheer complexity of the many-body system, with all of its protons and neutrons. Using theory to make meaningful predictions requires massive datasets that tax even high-powered supercomputers. Recently researchers from Michigan State and Central Michigan universities have reported dramatic success in stripping away much of this complexity, reducing computational time from days or weeks to minutes or hours.

One way to tackle the many-body problem is first to construct mathematical functions that describe each particle, and then start multiplying these functions together to get some idea of the underlying physics of the system. This approach of making the full configuration-interaction (CI) calculation works well enough to describe light nuclei, but becomes extremely challenging with heavier elements. For example, to calculate wave functions and energy levels for the pf-shell structure of ^{56}Ni, it means in effect solving an equation with around 109 variables.

Researchers face a similar problem in quantum chemistry in studying molecules with many dozens of interacting electrons. For several years, however, they have used a computationally cost-effective alternative to CI known as coupled-cluster (CC) theory, which was originally suggested in nuclear theory, but largely developed by quantum chemists and atomic and molecular physicists. Now the CC method is making its way back into nuclear physics, first in calculations of light nuclei, and most recently in developments for heavy nuclei. The key is correlation, the idea that some pairs of fermions in the system (whether nucleons or electrons) are strongly linked and related.

The researchers first used the Michigan-State High Performance Computing Center and the Central Michigan Center for High Performance Scientific Computing for the several-week-long task of solving the CI equation describing ^{56}Ni, to create a benchmark against which they could compare the results of the CC calculation (M Horoi *et al.* 2007). They found then that the CC theory produced near identical results and that the time spent crunching the numbers – on a standard laptop – was often measured in minutes or even seconds.

This research bodes well for next-generation nuclear science. Because of existing and planned accelerators around the world, the next few decades promise to yield many heavy isotopes for study. Theoretical models will need to keep pace with the expected avalanche of experimental data. To date, many such models have treated the nucleus as a relatively undifferentiated liquid, gas or other set of mathematical averages – all of which tends to gloss over subtle nuclear nuances. In contrast, coupled-cluster theory may be the only manageable and scalable model that takes a particle-by-particle approach.

Further reading

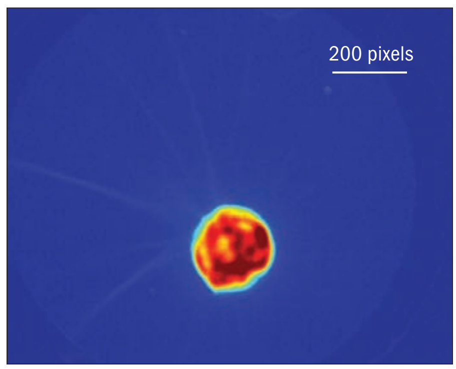
M Horoi *et al.* 2007 *Phys. Rev. Lett.* **98** 112501.

SLAC

Light source gets off to a good start with first electron bunch

Commissioning of the Linac Coherent Light Source (LCLS) at SLAC began on 5 April when physicists and engineers started up the electron-injector system for the first time, and created and accelerated a bunch of electrons. This injector is the first stage in a free-electron X-ray laser that will use the last kilometre of SLAC's 3 km linac to accelerate electrons before they pass through an undulator magnet and emit X-rays of 800 eV – 8 keV.

In the injector facility at Sector 20, a drive laser initiates the process by sending a short burst of UV light to a radio-frequency (RF) gun. The RF gun not only creates a precisely shaped bunch of electrons but also gives the electrons their initial accelerating boost with microwaves. Once they enter the linac, the bunches will pass through compressors that pack them into even shorter bunches before they ultimately pass through the undulator.



The first electron beam produced by the LCLS injector as seen by a diagnostic viewer approximately 80 cm from the gun. The beam energy is 5.5 MeV. (Courtesy SLAC.)

SCIENCEWATCH

Compiled by Steve Reucroft and John Swain, Northeastern University

Symmetry, snakes and snails

The snail-eating Pareas iwasakii *homes in on its prey. (Courtesy M Hoso/Kyoto University.)*

Physicists always find broken symmetries fascinating, and it seems that biologists do too. Masaki Hoso of Kyoto University and colleagues have found specialist snail-eating snakes with more teeth on the right side of the jaw than on the left. Why? Well, it is hard to pull a snail out of its shell, and it turns out that it helps the snakes to extract and eat snails – at least if the snail shells are right-handedly spiralled.

In their studies of the snail-eating specialist *Pareas iwasakii*, the team observed that the snakes could extract snails from right-handed shells much more readily than from left-handed shells. As a side effect, where these snakes are found, snails with left-handed shells tend to do better – evidently a case of an initial small parity violation (even if accidental) that has been amplified by biology and evolution.

Further reading

Masaki Hoso *et al.* 2007 *Biology Letters* **3** 169.

For movies of the snakes in action see http://ecol.zool.kyoto-u.ac.jp/~hoso/E-top.html.

Graphene shows room-temperature quantum Hall effect

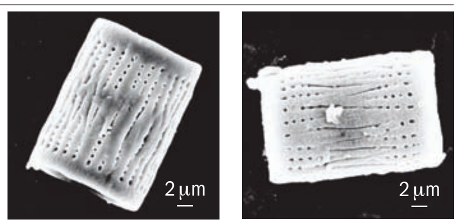
Graphene – a material made from a single layer of carbon atoms – has attracted attention recently because of its many strange properties and the fact that its electrons act in many ways like massless Dirac fermions. The latest amazing finding is that graphene exhibits the quantum Hall effect at room temperature.

KS Novoselov of the University of Manchester and colleagues achieved the feat with an admittedly high magnetic field of 45 T, but have managed to avoid the usual need to go close to or even below liquid helium temperatures. Their work is of particular interest for metrology since the quantum Hall effect can be used to provide a standard reference point for Planck's constant divided by the square of the electron charge.

Further reading

KS Novoselov *et al.* 2007 *Science* **315** 1379.

Researchers replicate nature's nano-architecture



Before and after: secondary electron image of the original silica diatom shell (left) and the final silicon replica (right), showing the same structure with narrow channels.

Nature makes an amazing range of tiny forms out of silica. However, more often than not it is silicon that is useful in a variety of applications, making the work of Zhihao Bao and colleagues at the Georgia Institute of Technology in Atlanta very interesting. They have developed a technique that can take the hard silica cell wall of a diatom, or other small silica structure, and react it with magnesium gas at a relatively low temperature to produce magnesium oxide and silicon. They then etch away the magnesium oxide to leave the original shape of the silica object, but now in more useful microporous silicon.

The process is particularly impressive as it takes place at temperatures less than around 850 °C, whereas the conversion of silica to silicon normally requires temperatures higher than 2000 °C. It could prove useful not only to make novel devices from biological silica but also from silica structures made by other processes. One use that the team has begun to investigate may be in microscale gas sensing.

Further reading

Zhihao Bao *et al.* 2007 *Nature* **446** 172.

Silica nanorods set new record for thin-film refraction

Antireflection coatings play important roles in almost all fields of optics, and could dramatically boost the efficiency of solar cells. It has proven difficult, however, to get materials of very low indices of refraction to have a smooth match between the coating, whatever the type, and air.

Now J-Q Xi of Rensselaer Polytechnic in New York and colleagues have set a new record. Using electron-beam deposition they put two layers of angled silica nanorods onto three layers of angled titanium dioxide nanorods, on an aluminium nitride surface, and reached an index of refraction of just 1.05 – a world record for a thin film.

Further reading

J-Q Xi *et al.* 2007 *Nature Photonics* **1** 176.

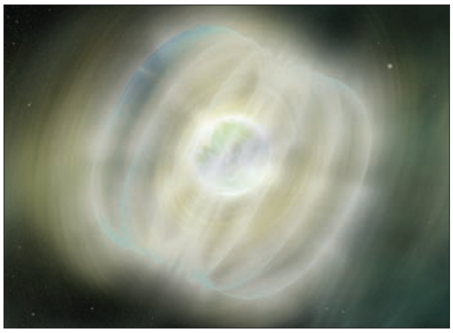
Compiled by Marc Türler, INTEGRAL Science Data Centre and Geneva Observatory

GRB afterglow challenges theory

An extremely bright and long afterglow of a rather common gamma-ray burst (GRB) was observed during four months by the X-ray telescope of NASA's Swift satellite. Such a long-lasting X-ray emission challenges theoreticians who now suggest that some bursts are powered by a neutron star rather than by a black hole.

With the detection of about 100 GRBs each year, NASA's Swift spacecraft – launched in November 2004 – is by far the most efficient hunter of these brief gamma-ray flashes. The strength of Swift is its ability to repoint its X-ray and ultraviolet/optical telescopes to the location of the burst within two minutes. This allows it to study in detail the early phases of the GRB afterglow emission (*CERN Courier* December 2005 p20). From all of these observations, researchers derived a general pattern of the X-ray brightness evolution. The X-ray emission usually starts with a rapid decay extending that of the GRB itself. After a few minutes, the X-ray decay rate slows down and remains moderate for at most a few hours before accelerating again for a final decay at an intermediate rate. After several weeks the source becomes generally undetectable for Swift. In some cases, additional bright X-ray flares have been observed during the first 15–20 minutes after the burst (*CERN Courier* October 2005 p11).

Not all GRBs follow this general trend. Two recent studies describe unusual afterglow emissions. Dirk Grupe from the Pennsylvania State University is leading an analysis of the GRB of 29 July 2006 (GRB 060729). At a redshift of $z=0.54$, this not too remote burst was exceptionally bright in X-rays and, thanks to its slow fading, Swift's X-ray telescope detected it during 125 days: a record for Swift only bettered by the closer "Rosetta stone" GRB of 29 March 2003 (*CERN Courier* September 2003 p15). A phase of very slow X-ray decrease, starting about 10 minutes after the burst and lasting almost half a day, characterized the lightcurve of GRB 060729. This requires continuous energy injection from the central engine over this long period. One possibility is that the collapsed core of the dying star at the origin of the GRB is a magnetar rather than a black hole. The ultra-powerful magnetic field of such a neutron star would force it to spin-down rapidly and the associated energy would be continuously injected into the X-ray emitting blast wave.



Artist's rendering of a magnetar. The rapid spin-down of such extremely magnetized neutron stars is proposed to explain additional energy injection in the afterglow emission of some gamma-ray bursts. (Courtesy Aurore Simonnet SSU NASA E/PO.)

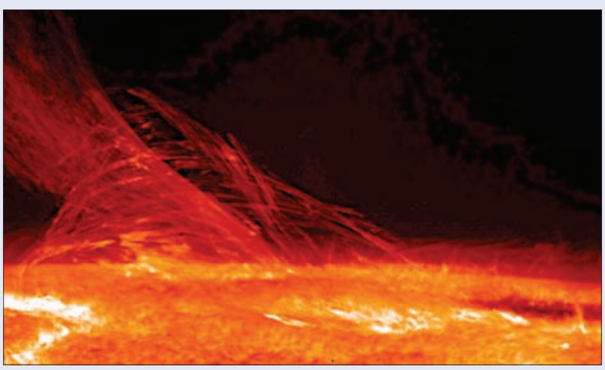
The study of another burst that Swift detected on 10 January 2007 also suggests that magnetars power some GRBs. GRB 070110's afterglow is slightly shorter in duration, but its time evolution shows a plateau of almost constant X-ray flux lasting 5 hours followed by an extremely fast decay before returning to a more typical late afterglow behaviour. This unusual plateau state is again interpreted as being due to a magnetar by an international team led by Eleonora Troja working at the Palermo division of the Italian National Institute for Astrophysics (INAF).

These results shake the general belief that GRBs are always powered by a black hole and less energetic X-ray flashes could be explained by the presence of a magnetar instead of a black hole (*CERN Courier* October 2006 p13). It seems that GRBs are willing to keep some of their mystery and will continue to challenge theoreticians for several years.

Further reading

D Grupe *et al.* 2007 *Astroph. Journal,* in press. See http://arxiv.org/abs/astro-ph/0611240.
E Troja *et al.* 2007 *Astroph. Journal*, submitted for publication. See http://arxiv.org/abs/astro-ph/0702220.

Picture of the month



The first images of the solar limb obtained by the Hinode spacecraft reveal a turbulent magnetic field shaping the surface of the sun. Hinode – meaning sunrise in Japanese – is the new name of the Solar-B international mission led by the Japan Aerospace Exploration Agency (JAXA) and with participation from institutes in the US, the UK and Norway. Launched on 23 September 2006, Hinode is the most advanced observatory for the study of the solar atmosphere from the photosphere, the visible surface of the sun, to the corona, the outer atmosphere that extends into the solar system. This image of the chromosphere – a thin layer between the photosphere and the corona – is a snapshot of the constantly moving plasma filaments connecting regions of different magnetic polarity. (Courtesy Hinode JAXA/NASA/PPARC.)

CERN COURIER ARCHIVE: 1964

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

COMPUTING

Core before Moore

During April it was announced that an order has been signed by CERN for the purchase of an electronic computer of the type CDC 6600, manufactured by the Control Data Corporation, Minneapolis, US. The CDC 6600 is one of the largest computers now available and is capable of carrying out more than a million arithmetical operations every second.

Preceding the decision to place this important order, there had been a year-long study carried out by a committee of European specialists in the field of computers and data processing for high-energy physics. Its conclusion was that the use of computers for high-energy research would continue to develop rapidly in the future and that CERN should acquire a machine of modern design, at least 10 times as powerful as its present one.

In the past year, utilization of the two computers now at CERN has increased by a factor of four, and they are now saturated. The new computer is designed to be used on a "time sharing" basis, that is, it will handle several problems at the same time. This characteristic has become indispensable, particularly because of the development of experimental techniques involving fully automatic operation "on line", or "in real time", in which the experimental apparatus is connected directly to the electronic computer to give immediate results. Part of the capacity of the big new computer will be absorbed by another aspect of this "automation" of experiments in fundamental nuclear physics – the use of automatic devices (such as the HPD and "Luciole") for examining and measuring hundreds of thousands of track-chamber photographs.

The 6600 has a fast [core] "memory" store of 131 000 "words", each of 60 binary units (bits), with an access time of a microsecond, a disc store of 16 million words, and a magnetic-tape memory of 16 units in which 240 000 characters per second can be recorded or found. The initial price of the machine, which has been met by a generous loan from the Swiss Federal Government, is SwFr23 million. The new computer will be installed at the end of this year and will be the most powerful in Europe.

● Extracted from "Last Month at CERN", p54.

OPEN DAY

Around the Lab in four hours

Not the queue at the bar! A throng of visitors on the gallery in the South experimental hall of the proton synchrotron.

As well as firemen, cleaners and transport staff, teachers from the CERN nursery school and girl guides from the international troupe at Ferney-Voltaire helped to look after the children. The Geneva authorities kindly lent the playground equipment.

Saturday 25 April was the occasion of another CERN "open day", when, between 2 pm and 6 pm, all those who work here had been invited to come, with their families and friends, to look around. Most areas of the site were accessible, and neither of the two particle accelerators was in operation during the visit. Special arrangements were made to allow people to see part of the tunnel housing the proton synchrotron and the machine room of the synchrocyclotron. Among the special attractions were the animated model of the PS, health-physics displays, a spark chamber set up to show the tracks of cosmic-ray particles, and demonstrations of glass blowing. Scanning tables for track-chamber films, instruments for the evaluation of photographs (IEPs), the 7090 computer and machines in the workshops could be seen in use.

In spite of the counter-attraction of the France–Hungary football match, some 1100 visitors took advantage of the fine weather to come to CERN and discover more about the work that goes on here. The open day was arranged by the Public Information Office, but thanks are due to very many people who helped to make it a success – the "guides" who posted themselves at strategic points to provide information and explain the exhibits, other members of the staff who exhibited and explained their own equipment, the security guards, health-physics and safety staff, members of the cleaning staff who became guards for the afternoon, those who looked after the children, and all those in every division who helped with the preparations and organization.

● Compiled from "Open Day", p56.

COMPILER'S NOTE

In April 1965, a year after CERN bought the CDC 6600 computer, Gordon Moore published his empirical observation that the number of transistors on an integrated circuit for minimum component cost doubled every 24 months or so; the rest, as they say, is history.

The SwFr23 million needed to buy the CDC 6600 was equivalent to around a thousand years of an average CERN salary at the time and would still buy 20 comfortable homes in the local area. While it is tricky to compare processing power, the PC used to produce this article has 1000 times more fast memory than the CDC and 2000 times the disc storage. Bought a couple of years ago, it cost 10 000 times less, about 10 days of an average CERN salary or the price of an up-market dog kennel.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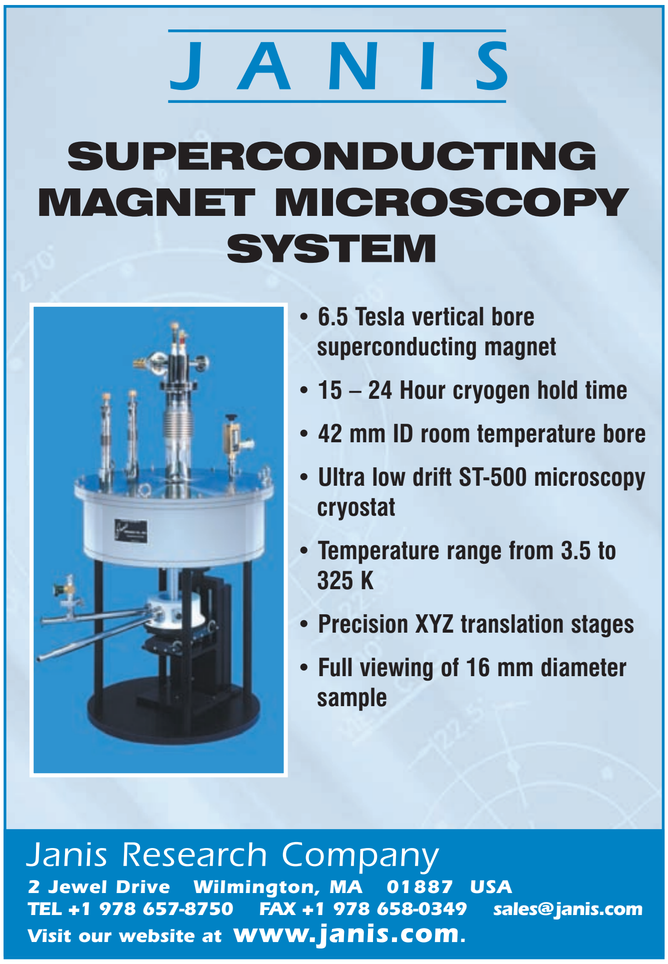
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Theory of unity connects science and social values

The Festival of Science 2006, held in Genoa, Italy, attracted 250 000 visitors. Physicist and systems theorist **Fritjof Capra**, one of the special guests of the event, talked to **Beatrice Bressan** about his vision and objectives for education in sustainable living.

For four years, the Genoa Festival of Science, which took place in 2006 on 26 October – 7 November, has been one of the best-attended events in European scientific communication. The aim is to create a crossroads where people and ideas can meet.

One of the many influential speakers at the 2006 festival was Fritjof Capra, founding director of the Center for Ecoliteracy in Berkeley, CA, which promotes ecology and systems thinking in primary and secondary education. Capra is a physicist and systems theorist, who received his PhD from the University of Vienna in 1965 before spending 20 years in particle-physics research. He is the author of several international bestsellers, including *The Tao of Physics*, *The Turning Point*, *The Web of Life* and *The Hidden Connections*, and at the festival he gave a talk entitled "Leonardo da Vinci: the unity of science and art".

Fritjof Capra, founding director of the Center for Ecoliteracy in Berkeley, CA, seeks to help create sustainable communities.

You started your career as a researcher in particle physics and became well known for writing a very popular book in 1975, 'The Tao of Physics', which linked 20th-century physics with mystical traditions. Did you expect such a success when you wrote the book?

During the late 1960s I noticed some striking parallels between the concepts of modern physics and the fundamental ideas in Eastern mystical traditions. At that time, I felt very strongly that these parallels would some day be common knowledge and that I should write a book about it. The subsequent success of the book surpassed all my expectations.

Recently, I was especially gratified to learn that my work as a writer was acknowledged by CERN. When CERN was given a statue of Shiva Nataraja, the Lord of Dance, by the Indian government to celebrate the organization's long association with India, a special plaque was installed to explain the connection between the metaphor of Shiva's cosmic dance and the "dance" of subatomic matter with several quotations from *The Tao of Physics* (*CERN Courier* July/August 2004 p37).

Particle physics can be seen as a reductionist approach, but you moved towards advocating viewing systems as a whole. When did you begin to move into systems theory and what guided your thoughts?

In the epilogue to *The Tao of Physics*, I argued that "the world view implied by modern physics is inconsistent with our present society, which does not reflect the harmonious interrelatedness we observe in nature". To connect the conceptual changes in science with the broader change of world view and values in society, I had to go beyond physics and look for a broader conceptual framework. In doing so, I realized that our major social issues – health, education, human rights, social justice, political power, protection of the environment, the management of business enterprises, the economy, and so on – all have to do with living systems: with individual human beings, social systems and ecosystems. With this realization, my research interests shifted and in the mid-1980s I stopped doing research in particle physics.

This now seems to be becoming a popular approach with increasing interest in the ideas of complexity. Are you pleased to see how complexity is developing? ▷

Yes, I am. I think the development of nonlinear dynamics, popularly known as complexity theory, in the 1970s and 1980s marks a watershed in our understanding of living systems. The key concepts of this new language – chaos, attractors, fractals, bifurcations, and so on – did not exist 25 years ago.

Now we know what kinds of questions to ask when we deal with nonlinear systems. This has led to some significant breakthroughs in our understanding of life. In my own work, I developed a conceptual framework that integrates three dimensions of life: the biological, the cognitive and the social dimension. I presented this framework in my book *The Hidden Connections*.

How did you become involved in the Center for Ecoliteracy at Berkeley?

For the past 30 years I have worked as a scientist and science writer, and also as an environmental educator and activist. In 1995, some colleagues and I founded the Center for Ecoliteracy to promote ecology and systems thinking in public schools. Over the past 10 years, we developed a special pedagogy, which we call "education for sustainable living". To create sustainable human communities means, first of all, to understand the inherent ability of nature to sustain life, and then to redesign our physical structures, technologies and social institutions accordingly. This is what we mean by being "ecologically literate".

How successful would you say your projects are, and how do you measure their success?

I am happy to say that our work has had a tremendous response from educators. There is an intense debate about educational standards and reforms, but it is based on the belief that the goal of education is to prepare our youth only to compete successfully in the global economy. The fact that this economy is not life-preserving but life-destroying is usually ignored, and so are the real educational challenges of our time – to understand the ecological context of our lives, to appreciate scales and limits, to recognize the long-term effects of human actions and, above all, to "connect the dots".

Our pedagogy, "education for sustainable living", is experiential, systemic and multidisciplinary. It transforms schools into learning communities, makes young people ecologically literate and gives them an ethical view of the world and the skills to live as whole persons.

From what you know of education on both sides of the Atlantic, do you think there are major differences between the education systems in Europe and the US, and do you think they can learn from each other?

The educators attending our seminars include people from many parts of the world. These dialogues have made us realize that, although our pedagogy has inspired people in many countries – in Europe as well as in Latin America, Africa and Asia – it cannot be used as a model in those countries in a straightforward way.

The principles of ecology are the same everywhere, but the ecosystems in which we practice experiential learning are different, as are the cultural and political contexts of education in different countries. This means that education for sustainability needs to be re-created each time.

Can physics contribute to the vision of sustainable living?

Absolutely. Ecology is inherently multidisciplinary because ecosystems connect the living and non-living world. Ecology, therefore, is grounded not only in biology, but also in many other sciences, including thermodynamics and other branches of physics.

The flow of energy, in particular, is an important principle of ecology, and the challenge of moving from fossil fuels to renewable energy sources is one in which physicists can make significant contributions. It is no accident that one of the world's foremost experts on energy, Amory Lovins, director of the Rocky Mountain Institute, is a physicist.

You are currently working on a new book about the science of Leonardo da Vinci. In your seminar at the Genoa Festival of Science you explained that what we need today is exactly the kind of science that Da Vinci anticipated. How do you think physics should – or could – evolve in the future? Is there, in your opinion, a future for physics?

Well, you are asking several questions here, all of them very substantial. I'm not sure whether I can do them justice in this short space. We can indeed learn a lot from Leonardo's science. As our sciences and technologies become increasingly narrow in their focus, unable to understand the problems of our time from an interdisciplinary perspective, and dominated by corporations with little interest in the well-being of humanity, we urgently need a science that honours and respects the unity of all life, recognizes the fundamental interdependence of all natural phenomena, and reconnects us with the living Earth. This is exactly the kind of science that Leonardo da Vinci anticipated and outlined 500 years ago.

Physicists have a lot to contribute to the development of such a new scientific paradigm. In modern science, the fundamental interdependence of all natural phenomena was first recognized in quantum theory, and various branches of physics are essential for a full understanding of ecology.

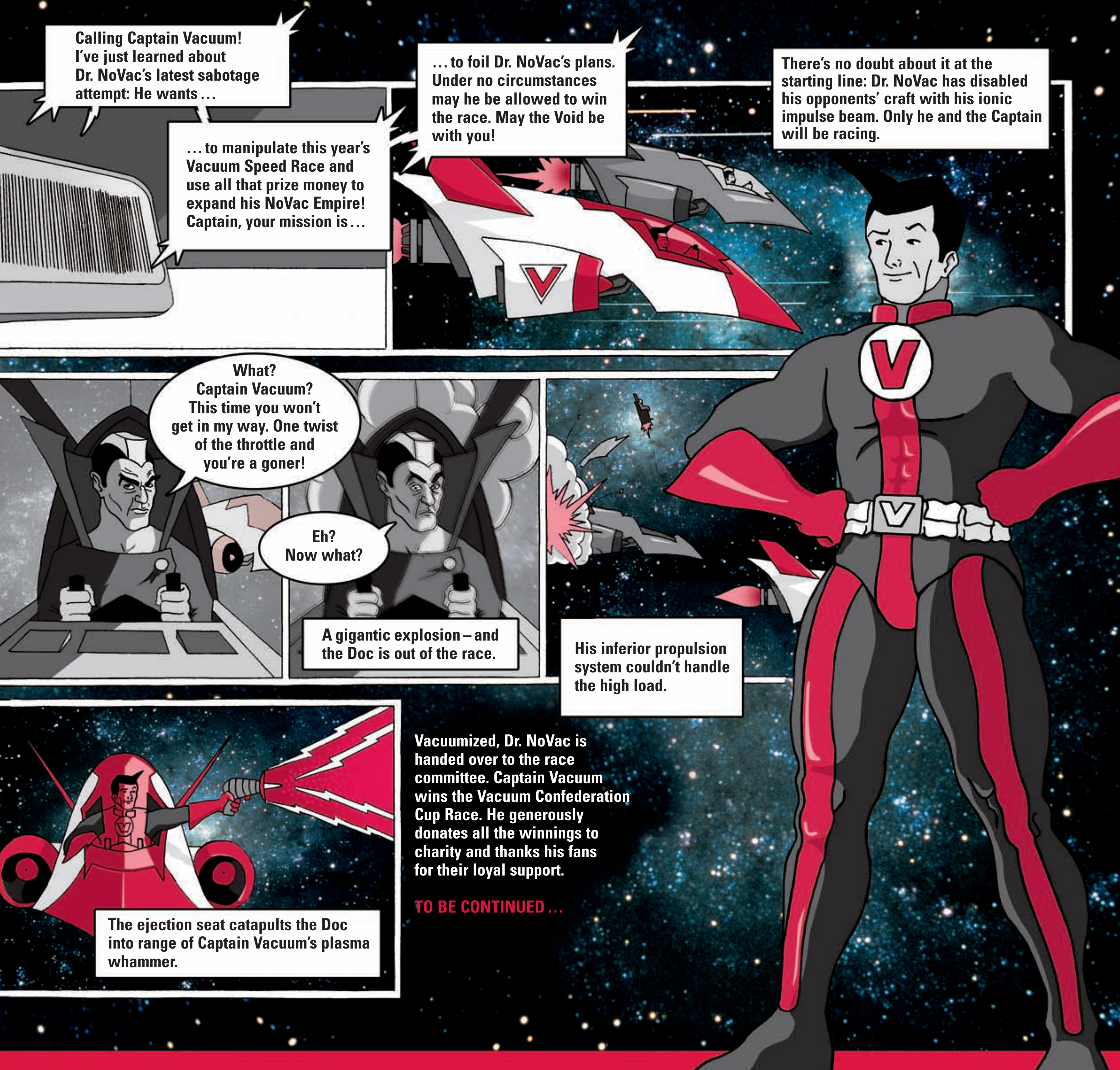
However, to contribute significantly to the great challenge of creating a sustainable future, physicists will need to acknowledge that their science can never provide a "theory of everything", but is only one of many scientific disciplines needed to understand the biological, ecological, cognitive and social dimensions of life.

Résumé

Associer les évolutions scientifiques et les valeurs sociales

Fritjof Capra est un physicien et un théoricien des systèmes qui a consacré 20 ans à la physique des particules avant de se tourner vers d'autres recherches au milieu des années 80. Ecrivain célèbre, il est l'auteur de plusieurs bestsellers, dont Le tao de la physique, Le temps du changement, La toile de la vie *et* Les connexions invisibles. *Capra, qui se décrit aussi comme un éducateur et militant écologiste, est le directeur fondateur du Center for Ecoliteracy de Berkeley (Californie), qui encourage la réflexion sur l'écologie et les systèmes dans l'enseignement primaire et secondaire. Dans cette interview, Capra livre ses conceptions de la physique moderne et de «l'enseignement pour une vie durable».*

Beatrice Bressan, *CERN*.


Calling Captain Vacuum! I've just learned about Dr. NoVac's latest sabotage attempt: He wants …
… to manipulate this year's Vacuum Speed Race and use all that prize money to expand his NoVac Empire! Captain, your mission is …
… to foil Dr. NoVac's plans. Under no circumstances may he be allowed to win the race. May the Void be with you!
There's no doubt about it at the starting line: Dr. NoVac has disabled his opponents' craft with his ionic impulse beam. Only he and the Captain will be racing.
What? Captain Vacuum? This time you won't get in my way. One twist of the throttle and you're a goner!
Eh? Now what?
A gigantic explosion – and the Doc is out of the race.
His inferior propulsion system couldn't handle the high load.
The ejection seat catapults the Doc into range of Captain Vacuum's plasma whammer.
Vacuumized, Dr. NoVac is handed over to the race committee. Captain Vacuum wins the Vacuum Confederation Cup Race. He generously donates all the winnings to charity and thanks his fans for their loyal support.
TO BE CONTINUED …

Canada looks to future of subatomic physics

A recent review by the Canadian subatomic-physics community has identified the main priorites for the coming years for research in nuclear and particle physics in Canada.

The ATLAS Hadronic Endcap Calorimeter (HEC). The HEC was constructed in Canada and assembled at TRIUMF. (Courtesy Roy Langstaff, University of Victoria/TRIUMF.)

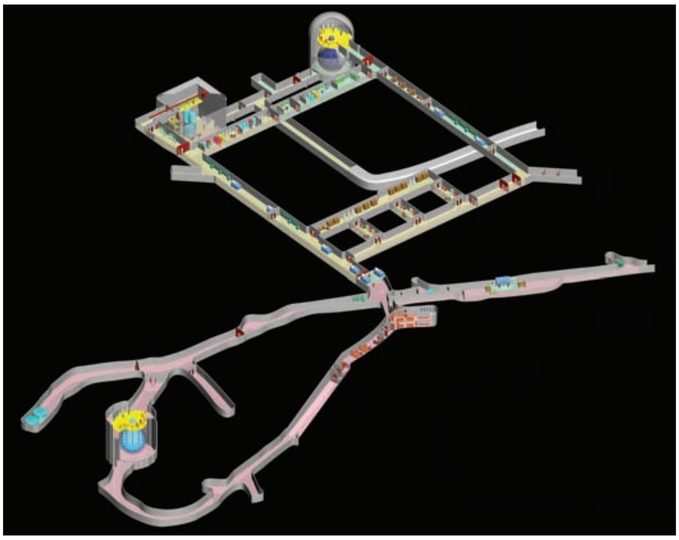
Canada's priorities for subatomic physics

- **Full exploitation of the ATLAS experiment at the LHC, exploring proton–proton collisions at the highest energies available.**
- **Full exploitation of the high-intensity radioactive beams for nuclear physics and nuclear astrophysics at ISAC and ISAC-II.**
- **Completion and full exploitation of SNOLAB, the world's best deep-underground laboratory, including funding for major participation in experiments to be done at the new facility.**
- **Participation in a long-baseline neutrino programme, and in particular, in the T2K experiment at the Japanese J-PARC facility for the first five years of this plan.**
- **Vigorous R&D towards participation in an International Linear Collider, with funding for major participation in 2011–2016.**

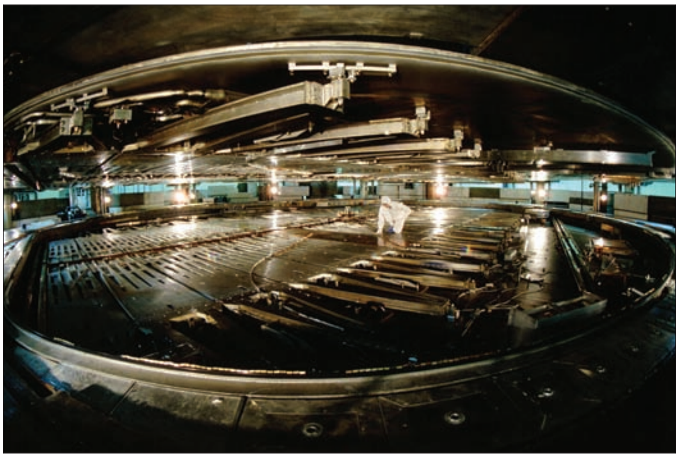
As in many other countries and regions, the Canadian subatomic-physics community has recently completed an in-depth study of its strengths in particle and nuclear physics, and has developed a focused Long Range Plan (LRP) for the coming decade. While primarily focusing on the community's scientific goals, the planning process compiled a list of the economic and training benefits that have resulted from research in subatomic physics and took stock of the extraordinary financial resources that have been available over the past decade. Operating with a budget surplus for much of that time, the Canadian government has invested heavily in all areas of fundamental research, including subatomic physics. Recent studies by the Organisation for Economic Co-operation and Development (OECD) show that these investments have moved Canada to the top of the G8 in public funding *per capita* for scientific research (OECD 2003). Some of this funding has targeted the hiring of top researchers at Canadian universities, but much of it has rejuvenated research infrastructure in Canada – including the construction of the Sudbury Neutrino Observatory (SNO) and the funding of Canada's Tier-1 LHC computing centre.

While there are many similarities between the Canadian LRP and others recently released, there is one important difference. Particle and nuclear physics receive joint funding in Canada not only for university-based researchers – who are funded by the Natural Sciences and Engineering Research Council (NSERC), the sponsor of the LRP process – but also for TRIUMF, the national laboratory for particle and nuclear physics. The LRP balances Canadian priorities for particle and nuclear physics in the coming decade. The five priorities that the plan identifies are seen as crucial if the Canadian subatomic-physics community is to build on its recent successes (see box). These five priorities encompass the main research activities of more than three-quarters of the experimental subatomic-physics community in Canada.

Canadian particle physicists were founding members of the ATLAS experiment at CERN's LHC in the 1990s. In addition to contributing major pieces of the hadronic endcap and forward calorimeters, Canada, through TRIUMF, has made important in-kind contributions to refurbishing the CERN proton-injector complex. Canadians are now leading commissioning efforts for the ATLAS calorimeter and are preparing for *in situ* calibrations using the initial data expected later this year. A growing contingent of recently hired faculty, bringing their experience from Fermilab's Tevatron, are contributing to the ATLAS high-level trigger system – crucial to the extraction of LHC physics. At home, researchers are taking full advantage of the state-of-the-art Canadian computer network infrastructure, integrating the operations of our Tier-1 centre at TRIUMF with those of our Tier-2 centres in Toronto/Montreal and Vancouver/Victoria. The high profile of ATLAS attracts the best graduate students and also serves as a focal point, bringing ▷



A schematic showing the new SNOLAB facility at the Creighton Mine near Sudbury in Ontario. The SNO experiment is in the underground cavern on the far left. (Courtesy SNOLAB.)



The world's largest cyclotron, at TRIUMF, which accelerates negatively charged hydrogen ions. (Courtesy TRIUMF.)

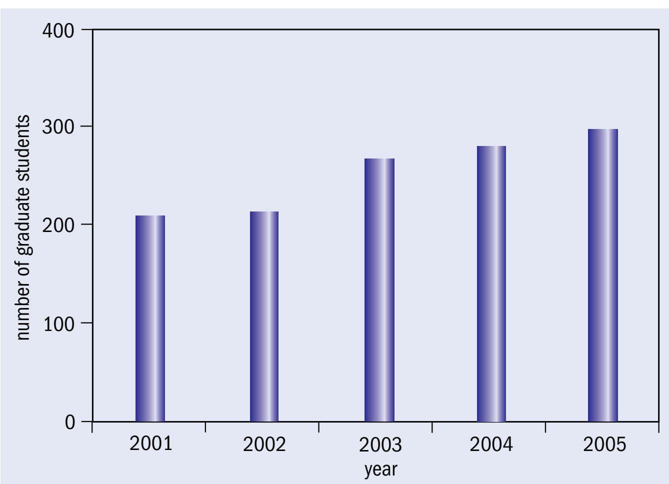


Chart showing the number of students that are enrolled in experimental or theoretical subatomic-physics graduate degree programmes in Canada for 2001–2005. (Courtesy Canadian Long Range Plan committee.)

together Canadian theorists and experimentalists as they prepare to unravel the LHC phenomenology. The LRP prioritizes the support of these researchers to capitalize on Canada's investment in the LHC programme. In addition to preparations for initial ATLAS physics the LRP anticipates a continued involvement and proposes that significant funding be made available for upgrades to the LHC and ATLAS in the second half of the plan.

One of the great Canadian successes of the past decade has been SNO, which has provided unequivocal evidence that electron-neutrinos produced in solar fusion oscillate into muon- and τ-neutrinos at a sufficient rate to explain the long-standing solar-neutrino deficit (p26). As a result of this great success the Canadian government has funded the expansion of the SNO experimental facilities. The new SNOLAB infrastructure is almost complete, nearly tripling the floor space for experiments and generating significant interest from researchers in underground physics from around the world. Out of twenty expressions of interest for SNOLAB experiments, nine are still being vetted for first-round space in the new laboratory.

The main scientific goals include searches for dark matter, neutrino-less double beta decay and the study of lower energy solar and geo-neutrinos. With such a world-class facility in Canada, the LRP prioritizes support for Canadian researchers to lead the construction of one or more major experiments. The SNO+ experiment has an advanced engineering design to replace the heavy water in SNO with liquid scintillator to allow the study of neutrinos from the solar "pep" chain. It may also be possible to dope the scintillator with enriched neodinium, making SNO+ a competitive neutrino-less double beta-decay detector. The DEAP/CLEAN experiment is at prototype stage, exploiting the novel signal properties of dark matter in liquid argon and neon. First-round experiments are expected to begin before the end of the decade.

Canadian subatomic physicists are also at the forefront of the study of nuclear astrophysics and the quest to understand the basic hadronic building block of nature – the nucleus – using radioactive beams at TRIUMF's Isotope Separator and Accelerator Complex (ISAC). The ISAC facility delivers some of the world's most intense rare beams using the world's highest power on target (up to 50 kW). One highlight was an experiment with ^{21}Na that provided incisive measurements, refining our understanding of stellar evolution and modelling nuclear synthesis. The new ISAC-II facility extends the accelerator to 12 MeV for each nucleon using superconducting RF cavities. The first experiment, using ^{11}Li ($t_{1/2} = 8$ ms), was carried out in December 2006: a European, US and Canadian collaboration investigated the unexpected behaviour of this halo nucleus.

The unique capabilities of ISAC and ISAC-II, including state-of-the-art instrumentation, make this the prime location for a worldwide user network; however, it is configured as a single-user facility. There is contention for beam time between the first-rate science programme and the development of new targets and ion sources. To alleviate this, the LRP prioritizes the full exploitation of ISAC and ISAC-II and the development of a second isotope production line.

TRIUMF is also the nexus for Canada's contribution to the Tokai-to-Kamioka (T2K) project in Japan. With its expertise in remote target handling, developed at ISAC, TRIUMF is consulting on the T2K neutrino-beam target station. Canadian researchers are leading the construction of the T2K near detector, building modules of the time projection chamber tracker, as well as the fine-grained calorimeter.

The LRP identified a further future priority, foreseeing a fully fledged Canadian participation in an International Linear Collider. TRIUMF accelerator physicists are already engaged in the ILC Global Design Effort. Members of the Canadian subatomic-physics community are working to identify industrial partners and are encouraging them to become full participants in the North American ILC industrial forum. Canadian university-based researchers have a long history of important contributions to electron–positron collider experiments, including the OPAL experiment at CERN's LEP and more recently the BaBar experiment at SLAC. These researchers have been actively engaged in Canadian detector R&D efforts for ILC detectors.

The Canadian subatomic-physics community has seen significant growth this century. As a result of targeted hiring and replacing retiring faculty, 35% of the subatomic-physics faculty in Canada has been hired in the past six years. A 45% surge in the number of graduate students has accompanied this faculty renewal. Further growth is anticipated as the new faculty members establish their research programmes and recruit their full complement of students and postdoctoral researchers. This growth in subatomic-physics graduate student numbers appears to be counter to the experience in other OECD nations, and bodes well for subatomic physics in Canada.

The LRP Committee has therefore found that subatomic physics in Canada is strong and healthy, but the news is not all good. Despite the significant infusion of capital from the government's novel funding mechanisms, support for traditional sources of subatomic physics in Canada have not kept pace with inflation over the past 10 years. The growth and renewal in the community has put ever increasing pressure on the ongoing operational support. One main goal of the LRP exercise was to identify and quantify these pressures, so as to provide a firmer basis for requests for increased operational support for fundamental research in general and subatomic physics in particular.

Further reading

The LRP report and more details are at www.subatomicphysics.ca.
OECD 2003 *Main Science and Technology Indicators*.

Résumé

Le Canada envisage l'avenir de la physique subatomique

Au Canada, comme dans de nombreux autres pays et régions, les spécialistes de la physique subatomique ont récemment fait le bilan de leurs points forts en physique nucléaire et en physique des particules, puis ont élaboré un plan à long terme ciblé pour les décennies à venir. Parmi les principales priorités figurent: la pleine exploitation de l'expérience ATLAS au LHC, celle des faisceaux radioactifs de haute intensité pour la physique et l'astrophysique nucléaires à ISAC et ISAC II, l'achèvement et la pleine exploitation du laboratoire souterrain SNOLAB, la participation au programme neutrino à long terme (en particulier à l'expérience T2K au Japon) et de vigoureux travaux de R&D en vue de la participation à un collisionneur linéaire international.

Ken Ragan, *McGill University and chair of Canadian subatomic Long Range Plan Committee, and* **William Trischuk**, *University of Toronto and director of Canadian Institute of Particle Physics.*

FAIR builds future for ion and antiproton research

Construction should begin later this year on the new Facility for Antiproton and Ion Research in Darmstadt, and the first experiments could start up in 2012.

Fig.1. Artist's view of the Facility for Antiproton and Ion Research. The synchrotrons on the right will be 10–13 m underground.

In 2001, GSI, together with a large international science community, presented the Conceptual Design Report (CDR) for a major new accelerator facility for beams of ions and antiprotons in Darmstadt (Henning *et al.* 2001). The following years saw the consolidation of the proposal for the project, which was named the Facility for Antiproton and Ion Research (FAIR). During that process high-level national and international science committees evaluated the project's feasibility, scientific merit and discovery potential, as well as the estimated costs. About 2500 scientists and engineers from 45 countries contributed to this effort, which resulted last year in the FAIR Baseline Technical Report (BTR) (Gutbrod *et al.* 2006).

The International Steering Committee has accepted the BTR as the basis for international negotiations on funding for FAIR. The plan is to found a company, FAIR GmbH, as project owner for the construction and operation of the FAIR research facility under international ownership. Currently 14 countries (Austria, China, Finland, France, Germany, Greece, India, Italy, Poland, Romania, Russia, Spain, Sweden and the UK) have signed the Memorandum of Understanding for FAIR, indicating their intention to participate in the FAIR project; the European Union, Hungary and the US have observer status. The investment cost for the project will be about €1000 million, and about 2400 man-years will be required to execute the project. Negotiations at governmental level to secure the funding started in summer 2006. The aim is to complete this process in summer 2007 and begin construction in autumn. The construction plan foresees a staged completion of the facility in which the first experimental programmes commence as early as 2012 while the entire facility will be completed in 2015 (figure 1). ▷

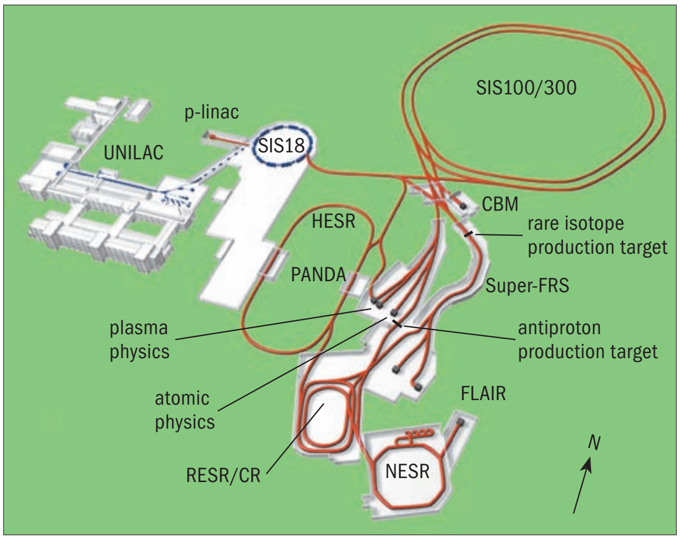


Fig. 2. Layout of the existing (UNILAC, SIS18) and the planned FAIR facility: the superconducting synchrotrons SIS100 and SIS300, the collector ring CR, the accumulator ring RESR, the new experimental storage ring NESR, the super fragment separator Super-FRS, the proton linac, the antiproton production target and the high-energy storage ring HESR. Also shown are the experimental stations for plasma physics, nuclear collisions (CBM), radioactive-ion beams (Super-FRS), atomic-physics experiments, and low-energy antiproton and atomic physics (FLAIR).

The research programme of FAIR can be grouped in the following specific fields:

- Nuclear structure and nuclear astrophysics, using beams of stable and short-lived (radioactive) nuclei far from stability.
- Hadron structure, in particular quantum chromodynamics (QCD) – the theory of the strong interaction – and the QCD vacuum, using primarily beams of antiprotons.
- The nuclear-matter phase diagram and quark–gluon plasma, using beams of high-energy heavy ions.
- Physics of very dense plasmas, using highly compressed heavy-ion beams in unique combination with a petawatt laser.
- Atomic physics, quantum electrodynamics (QED) and ultra-high electromagnetic fields, using beams of highly charged heavy ions and antimatter.
- Technical developments and applied research, using ion beams for materials science and biology.

The BTR lists 14 experimental proposals as elements of the core research programme. However, additional experiments as future options are already being considered and evaluated. In particular, experiments with polarized antiprotons could add an entirely new research field to the FAIR programme. One addition to the core research programme, as presented in 2001, is the Facility for Low-Energy Antiproton and Ion Research (FLAIR), which will exploit the high flux of antiprotons at FAIR. Here cooled beams of antiprotons with energies well below 100 keV can be captured efficiently in charged-particle traps or stopped in low-density gas.

The new SIS100/300 double synchrotron, with a circumference of about 1100 m and with magnetic rigidities of 100 and 300 Tm in the two rings, will meet experimental requirements concerning particle intensities and energies. This constitutes the central part of the FAIR accelerator facility (figure 2). The two synchrotrons will be built on top of each other in a subterranean tunnel. They will be equipped with rapidly cycling superconducting magnets to minimize both construction and operating costs.

For the highest intensities, the 100 Tm synchrotron will operate at a repetition rate of 1 Hz, i.e. with ramp rates for the bending magnets of up to 4 T/s. The goal of the SIS100 is to achieve intense pulsed (5×10^{11} ions per pulse) uranium beams (charge state q = 28+) at 1 GeV/u and intense (4×10^{13}) pulsed proton beams at 29 GeV. A separate proton linac will be constructed as injector to the SIS18 synchrotron to supply the high-intensity proton beams required for antiproton production. It will be possible to compress both the heavy-ion and the proton beams to the very short bunch lengths required for the production and subsequent storage and efficient cooling of exotic nuclei (around 60 ns) and antiprotons (around 25 ns). These short, intense ion bunches are also needed for plasma-physics experiments.

The double-ring facility will provide continuous beams with high average intensities of up to 3×10^{11} ions per second at energies of 1 GeV/u for heavy ions, either directly from the SIS100 or by slow extraction from the 300 Tm ring. The SIS300 will provide high-energy ion beams of maximum energies around 45 GeV/u for Ne^{10+} beams and close to 35 GeV/u for fully stripped U^{92+} beams, respectively. The maximum intensities in this mode will be close to 1.5×10^{10} ions for each spill. These high-energy beams will be extracted over time periods of 10–100 s in quasi-continuous mode, which is the limit that the detectors used for nucleus–nucleus collision experiments can accept.

A complex system of storage rings adjacent to the SIS100/300 double-ring synchrotron, together with the production targets and separators for antiproton beams and radioactive secondary beams (the Super Fragment Separator), will provide an unprecedented variety of particle beams at FAIR. These rings will be equipped with beam-cooling facilities, internal targets and in-ring experiments.

The Collector Ring (CR) serves for stochastic cooling of radioactive and antiproton beams and will allow mass measurements of short-lived nuclei using the time-of-flight method when in isochronous operation mode. The Accumulator Ring (RESR) will accumulate antiproton beams after stochastic pre-cooling in the CR and also provide fast deceleration of radioactive secondary beams with a ramp rate of up to 1 T/s.

The New Experimental Storage Ring (NESR) will be dedicated to experiments with exotic ions and with antiproton beams. The NESR is to be equipped with stochastic cooling and electron cooling and additional instrumentation will include precision mass-spectrometry using the Schottky frequency spectroscopy method, internal-target experiments with atoms and electrons, an electron–nucleus scattering facility, and collinear laser spectroscopy. Moreover, the NESR will serve to cool and decelerate stable and radioactive ions as well as antiprotons for low-energy experiments and trap experiments at the FLAIR facility.

The High-Energy Storage Ring (HESR) will be optimized for antiproton beams at energies of 3 GeV up to a maximum of 14.5 GeV. The ring is to be equipped with electron cooling up to a beam energy of 8 GeV (5 MeV maximum electron energy) and for stochastic cooling up to 14.5 GeV. The experimental equipment includes an internal pellet target and the large in-ring detector PANDA, as well as an option for experiments with polarized antiproton beams.

The design of the FAIR facility has incorporated parallel operation of the different research programmes from the beginning. The proposed scheme of synchrotrons and storage rings, with their intrinsic cycle times for beam acceleration, accumulation, storage and cooling, respectively, has the potential to optimize parallel and highly synergetic operation. This means that for the different programmes the facility will operate more or less like a dedicated facility, without the reduction in luminosity that would occur with simple beam splitting or steering to different experiments.

The realization of the facility involves some technological challenges. For example, it will be necessary to control the dynamic vacuum pressure. The synchrotrons will need to operate close to the space-charge limits with small beam losses in the order of a few per cent; in this respect, the control of collective instabilities and the reduction of the ring impedances is a subject of the present R&D phase. Fast acceleration and compression of the intense heavy-ion beams requires compact RF systems. The SIS100 requires superconducting magnets with a maximum field of 2 T and with 4 T/s ramping rate, while the SIS300 will operate at 4.5 T with a ramp rate of 1 T/s in the dipole magnets – technology that will benefit other accelerators. Lastly, electron and stochastic cooling at medium and high energies will be essential for experiments with exotic ions and with antiprotons.

The past five years have seen substantial R&D effort dedicated to the various technological aspects. This has been funded by the German BMBF and by FAIR member states, as well as by the European Union. The work has made considerable progress and has demonstrated the feasibility of the proposed technical solutions. Now the next stage is underway and prototyping of components has started.

Further reading

W F Henning *et al.* (eds.) 2001 *An International Accelerator Facility for Beams of Ions and Antiprotons*, GSI Darmstadt, www.gsi.de/GSI-Future/cdr/.

H H Gutbrod *et al.* (eds.) 2006 *FAIR Baseline Technical Report*, www.gsi.de/fair/reports/btr.html.

Résumé

FAIR construit l'avenir de la recherche des ions et des antiprotons

La construction de FAIR (l'Installation de recherche sur les antiprotons et les ions) devrait commencer cette année à Darmstadt et les premières expériences pourraient débuter en 2012. Actuellement, 14 pays ont manifesté leur intention de participer au projet, qui nécessite un investissement d'environ un milliard d'euros. L'installation fournira une gamme de faisceaux de particules sans précédent. Elle s'appuiera sur deux synchrotrons supraconducteurs qui seront construits l'un sur l'autre dans le même tunnel et fourniront différents faisceaux d'ions lourds. Un dispositif adjacent d'anneaux de stockage, de cibles de production et de séparateurs fourniront des faisceaux d'antiprotons et des faisceaux radioactifs secondaires.

Ingo Augustin, GSI, FAIR Joint Core Team.

SNO: solving the mystery

Nick Jelley and **Alan Poon** look at the achievements of the experiment that finally solv

The end of an era came on 28 November 2006 when the Sudbury Neutrino Observatory (SNO) stopped data-taking after eight years of exciting discoveries. During this time the observatory saw evidence that neutrinos, produced in the fusion of hydrogen in the solar core, change type – or flavour – while passing through the Sun on their way to Earth. This observation explained the long-standing puzzle as to why previous experiments had seen fewer solar neutrinos than predicted and also confirmed that these elusive particles have mass.

Ray Davis's radiochemical experiment first detected solar neutrinos in 1967, a discovery for which he shared the 2002 Nobel Prize in Physics (*CERN Courier* December 2002 p15). Surprisingly, he found only about a third of the number predicted from models of the Sun's output. The Kamiokande II experiment in Japan confirmed this deficit, which became known as the solar-neutrino problem, while other detectors saw related shortfalls in the number of solar neutrinos. A possible explanation, suggested by Vladimir Gribov and Bruno Pontecorvo in 1969, was that some of the electron-neutrinos, which are produced in the Sun, "oscillated" into neutrinos that could not be detected in Davis's detector. This oscillation mechanism requires that neutrinos have non-zero mass.

In 1985, the late Herb Chen pointed out that heavy water (D_2O) has a unique advantage when it comes to detecting the neutrinos from ^8B decays in the solar-fusion process, as it enables both the number of electron neutrinos and the number of all types of neutrinos to be measured. In heavy water neutrinos of all types can break a deuteron into its constituent proton and neutron (the neutral-current reaction), while only electron neutrinos can change the deuteron into two protons and release an electron (the charged-current reaction). A comparison of the flux of electron neutrinos with that of all flavours can then reveal whether flavour transformation is the cause of the solar-neutrino deficit. This is the principle behind the SNO experiment.

International collaboration

Scientists from Canada, the US and the UK designed SNO to attain a detection rate of about 10 solar neutrinos a day using 1000 tonnes of heavy water. Neutrino interactions were detected by 9456 photomultiplier tubes surrounding the heavy water, which was contained in a 12 m diameter acrylic sphere. This sphere was surrounded by 7000 tonnes of ultra-pure water to shield against radioactivity. Figure 1 shows the layout of the SNO detector, which is located about 2 km underground in Inco's Creighton nickel mine near Sudbury, Canada, so as to all but eliminate cosmic rays from reaching the detector. Figure 2 shows what the detector "sees": the photomultiplier tubes that were hit following the creation of an electron by an electron neutrino.

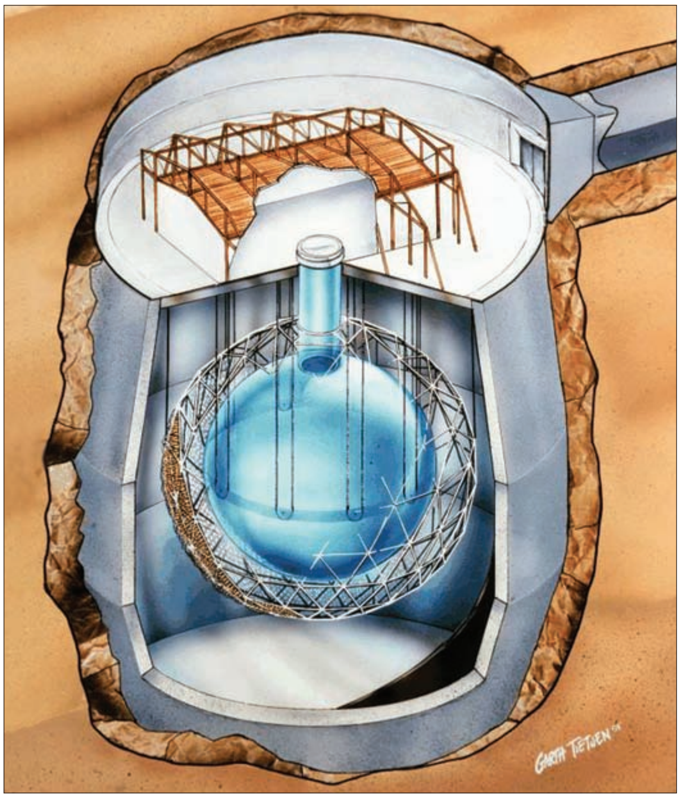


Fig. 1. Artist's impression of the Sudbury Neutrino Observatory. The heart of the detector, which is located 2 km underground in a cleanroom, comprises 1000 tonnes of heavy water.

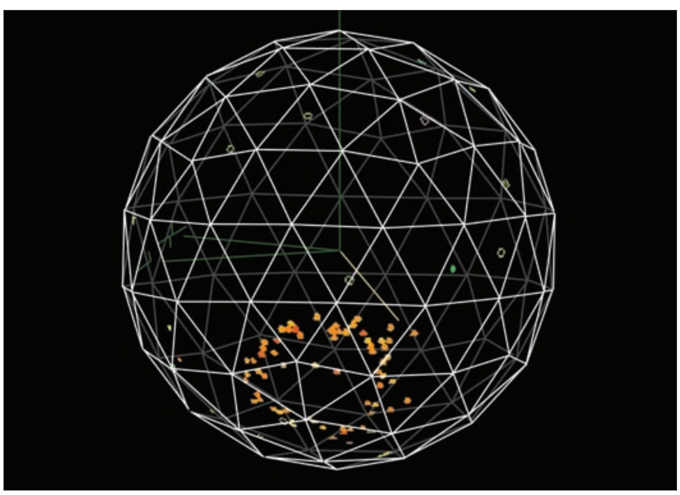


Fig. 2. Event display of a neutrino candidate. Photomultiplier tubes mounted on a geodesic structure detect Cherenkov light from relativistic electrons following a neutrino interaction.

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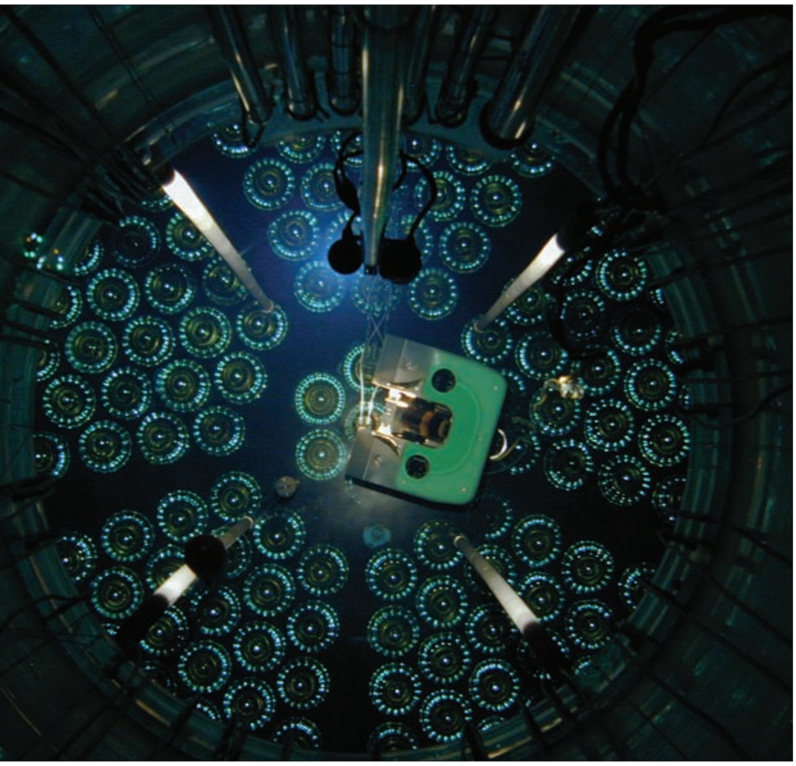
lved the solar-neutrino problem and helped reveal a new world of neutrinos with mass.



Deployment of the proportional counter array, comprising 36 filled with nd four filled with ^{4}He, with a remotely operated submarine in 2004. Bright ions from four of these proportional counters can be seen in this picture.

On behalf of the SNO Collaboration, SNO director Art McDonald (left) ts the inaugural John C Polanyi Award from the president of NSERC, ne Fortier (middle), and Nobel Laureate John C Polanyi (right).

It was crucial to the success of this experiment to make the components of SNO very clean and, in particular, to reduce the radioactivity within the heavy water to exceedingly low levels. To achieve this aim the team constructed the detector in a Class-2000 cleanroom and entry to SNO was via a shower and changing rooms to reduce the chance of any dust contamination from the mine. The fraction of natural thorium in the D_2O had to be less than a few parts in 10^{15}, roughly equivalent to a small teaspoonful of rock dust added to the 1000 tonnes of heavy water. Such purity was necessary to reduce the break-up of deuterons by gamma rays from natural uranium and thorium radioactivity to a small fraction of the rate from the solar neutrinos. This required complex water purification and assay systems to reduce and measure the radioactivity. Great care in handling the heavy water was also needed as it is on loan from Atomic Energy of Canada Ltd (AECL) and is worth about C$300 million.

SNO's results from the first phase of data-taking with unadulterated D_2O were published in 2001 and 2002, and provided strong evidence that electron neutrinos do transform into other types of neutrino (*CERN Courier* June 2002 p5). The second phase of SNO involved adding 2 tonnes of table salt (NaCl) to the D_2O to enhance the detection efficiency for neutrons. This large "pinch of salt" enabled SNO to make the most direct and precise measurement of the total number of solar neutrinos, which is in excellent agreement with solar-model calculations (*CERN Courier* November 2003 p5). The results to date reject the null hypothesis of no neutrino flavour change by more than 7 σ.

Together with other solar-neutrino measurements, the SNO results are best described by neutrino oscillation enhanced by neutrinos interacting with matter as they pass through the Sun – a resonant effect that Stanislav Mikheyev, Alexei Smirnov and Lincoln Wolfenstein predicted in 1985. To a good approximation, the electron-neutrino flavour eigenstate is a linear combination of two mass eigenstates with masses m_1 and m_2. The mixing angle between these two mass eigenstates, which the ratio (measured by SNO) of the electron-neutrino flux to the total neutrino flux constrains, is found to be large (around 34°) but is excluded from maximal mixing (45°) by more than 5 σ. The matter enhancement enables the ordering (hierarchy) of the two mass eigenstates to be defined, with $m_2 > m_1$ and a difference of around 0.01 eV/c^2. The KamLAND experiment, which uses 1000 tonnes of liquid scintillator to detect anti-neutrinos from Japan's nuclear reactors, confirmed in 2003 that neutrino mixing occurs and is large, as seen for solar neutrinos.

After the removal of salt from the heavy water, the third and final phase of SNO used an array of proportional counters in the heavy water to improve further the neutrino detection. Researchers filled 36 counters with ^{3}He and four with ^{4}He gas. Figure 3 shows part ▷

of this array during its deployment with a remotely operated submarine. The additional information from this phase will enable the SNO collaboration to determine better the oscillation parameters that describe the neutrino mixing. Data analysis is still in progress.

SNO's scientific achievements were marked at the end of data-taking when the collaboration received the inaugural John C Polanyi Award (figure 4, p27) of the Canadian funding agency, the Natural Sciences and Engineering Research Council (NSERC). The completion of SNO does not mark the end of experiments in Sudbury, however, as SNOLAB, a new international underground laboratory, is nearly complete, with expanded space to accommodate four or more experiments (see p19). SNOLAB has received a number of letters of interest from experiments on dark matter, double beta decay, supernovae and solar neutrinos. In addition, a new collaboration is planning to put 1000 tonnes of scintillator in the SNO acrylic vessel once the heavy water is returned to the AECL by the end of 2007. This experiment, called SNO+, aims to study lower-energy solar neutrinos from the "pep" reaction in the proton–proton chain, and to study the double beta decay of ^{150}Nd by the addition of a metallo-organic compound.

As a historical anecdote, SNO was not the first heavy-water solar-neutrino experiment. In 1965, Tom Jenkins, along with other members of Fred Reines' neutrino group, at what was then the Case Institute of Technology, began the construction of a 2 tonne heavy-water Cherenkov detector, complete with 55 photomultiplier tubes, in the Morton salt mine in Ohio. Unlike Chen's proposal, Jenkins had only considered the detection of electron neutrinos through the charged-current reaction as other flavours were not expected, and the neutral-current reaction had not yet been discovered. This experiment finished in 1968 after Davis had obtained a much lower ^{8}B solar-neutrino flux than had been predicted.

Résumé

Le SNO a percé le mystère des neutrinos manquants

Une page s'est tournée lorsque, le 28 novembre 2006, l'Observatoire des neutrinos de Sudbury (SNO) a mis un terme à l'acquisition de ses données après huit années passionnantes. Pendant cette période, le SNO a trouvé des éléments montrant que les neutrinos produits par la fusion de l'hydrogène dans le cœur du Soleil changent de type – ou de saveur – lorsqu'ils traversent le Soleil. Le SNO avait l'avantage sans égal d'utiliser de l'eau lourde, qui a permis de mesurer le nombre des neutrinos de l'électron et le nombre des neutrinos de tous les types provenant de désintégrations du ^{8}B dans le Soleil. Les résultats ont permis d'expliquer pourquoi les expériences précédentes avaient trouvé moins de neutrinos solaires que prévu – c'était jusque-là un mystère – et confirmé que ces particules insaisissables ont une masse.

Nick Jelley, *University of Oxford, and* **Alan Poon**, *Lawrence Berkeley National Laboratory.*

The LHC: illuminating the high-energy frontier

During the next few years, discoveries at CERN's Large Hadron Collider will revolutionize our understanding of matter, forces and space. **John Ellis** looks at what might lie in store.

The principal goal of the experimental programme at the LHC is to make the first direct exploration of a completely new region of energies and distances, to the tera-electron-volt scale and beyond. The main objectives include the search for the Higgs boson and whatever new physics may accompany it, such as supersymmetry or extra dimensions, and also – perhaps above all – to find something that the theorists have not predicted.

The Standard Model of particles and forces summarizes our present knowledge of particle physics. It extends and generalizes the quantum theory of electromagnetism to include the weak nuclear forces responsible for radioactivity in a single unified framework; it also provides an equally successful analogous theory of the strong nuclear forces.

The conceptual basis for the Standard Model was confirmed by the discovery at CERN of the predicted weak neutral-current form of radioactivity and, subsequently, of the quantum particles responsible for the weak and strong forces, at CERN and DESY respectively. Detailed calculations of the properties of these particles, confirmed in particular by experiments at the Large Electron–Positron (LEP) collider, have since enabled us to establish the complete structure of the Standard Model. Data taken at LEP agreed with the calculations at the *per mille* level, and recent precise measurements of the masses of the intermediate vector boson W and the top quark at Fermilab's Tevatron agree very well with predictions.

These successes raise deeper problems, however. The Standard Model does not explain the origin of mass, nor why some particles are very heavy while others have no mass at all; it does not explain why there are so many different types of matter particles in the universe; and it does not offer a unified description of all the fundamental forces. Indeed, the deepest problem in fundamental physics may be how to extend the successes of quantum physics to the force of gravity. It is the search for solutions to these problems that define the current objectives of particle physics – and the programme for the LHC.

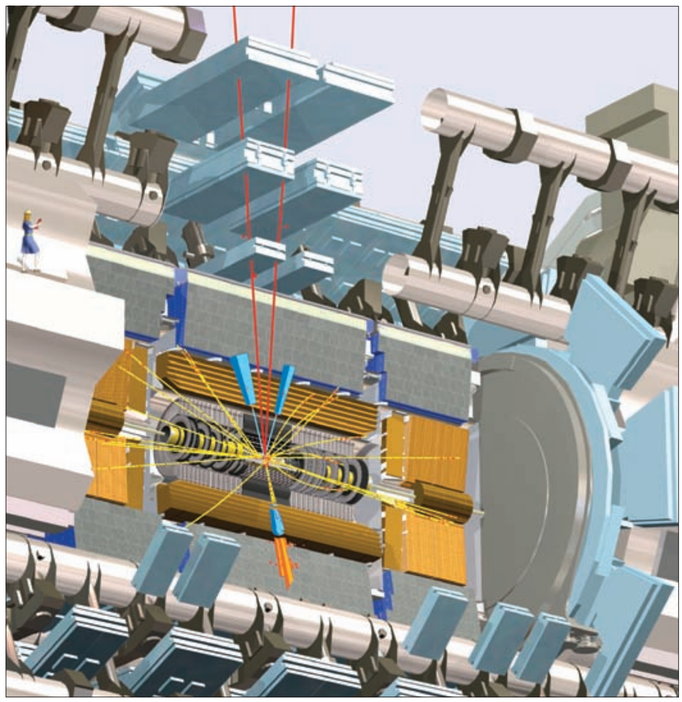


Fig. 1. Simulation of the decay of a Higgs boson in the ATLAS detector. In this case the Higgs has decayed to two Z bosons, one of which decays to a pair of muons (the two red tracks going up through the top of the detector) while the other has decayed to an electron–positron pair, depositing energy in the electromagnetic calorimeter in the opposite direction.

Higgs, hierarchy and extra dimensions

Understanding the origin of mass will unlock some of the basic mysteries of the universe: the mass of the electron determines the sizes of atoms, while radioactivity is weak because the W boson weighs as much as a medium-sized nucleus. Within the Standard Model the key to mass lies with an essential ingredient that has not yet been observed, the Higgs boson; without it the calculations would yield incomprehensible infinite results. The agreement of the data with the calculations implies not only that the Higgs boson (or something equivalent) must exist, but also suggests that its mass should be well within the reach of the LHC.

Experiments at LEP at one time found a hint for the existence of the Higgs boson, but these searches proved unsuccessful and told us only that it must weigh at least 114 GeV (*CERN Courier* November 2005 p23). At the LHC, the ATLAS and CMS experiments will be looking for the Higgs boson in several ways. The particle is predicted to be unstable, decaying for example to photons, bottom quarks, tau leptons, W or Z bosons (figure 1 and ▷

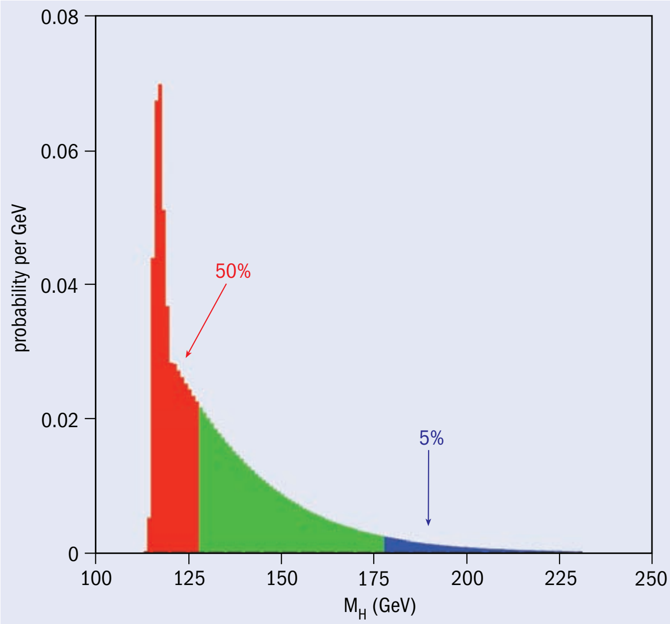


Fig. 2. A graph showing the probability distribution for the mass of the Higgs boson in the Standard Model found by combining direct search information from LEP with an analysis of precision electroweak data (Erler 2007).

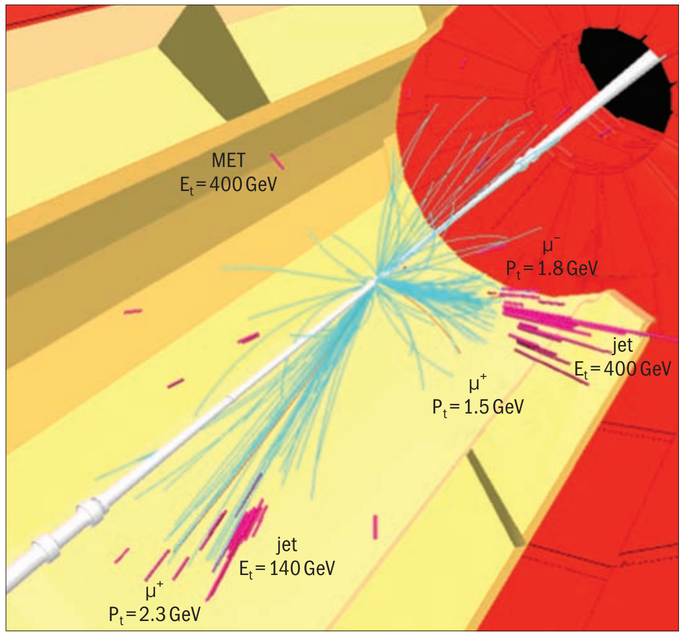


Fig. 3. Simulation of a supersymmetric event in the CMS detector in which a pair of gluinos decay into muons and quark jets and dark-matter particles that carry away a large amount of "missing" invisible energy (MET).

figure 2). It may well be necessary to combine several different decay modes to uncover a convincing signal, but the LHC experiments should be able to find the Higgs boson even if it weighs as much as 1 TeV.

While resolving the Higgs question will set the seal on the Standard Model, there are plenty of reasons to expect other, related new physics, within reach of experiments at the LHC. In particular, the elementary Higgs boson of the Standard Model seems unlikely to exist in isolation. Specifically, difficulties arise in calculating quantum corrections to the mass of the Higgs boson. Not only are these corrections infinite in the Standard Model, but, if the usual procedure is adopted of controlling them by cutting the theory off at some high energy or short distance, the net result depends on the square of the cut-off scale. This implies that, if the Standard Model is embedded in some more complete theory that kicks in at high energy, the mass of the Higgs boson would be very sensitive to the details of this high-energy theory. This would make it difficult to understand why the Higgs boson has a (relatively) low mass and, by extension, why the scale of the weak interactions is so much smaller than that of grand unification, say, or quantum gravity.

This is known as the "hierarchy problem". One could try to resolve it simply by postulating that the underlying parameters of the theory are tuned very finely, so that the net value of the Higgs boson mass after adding in the quantum corrections is small, owing to some suitable cancellation. However, it would be more satisfactory either to abolish the extreme sensitivity to the quantum corrections, or to cancel them in some systematic manner.

One way to achieve this would be if the Higgs boson is composite and so has a finite size, which would cut the quantum corrections off at a relatively low energy scale. In this case, the LHC might uncover a cornucopia of other new composite particles with masses around this cut-off scale, near 1 TeV.

The alternative, more elegant, and in my opinion more plausible, solution is to cancel the quantum corrections systematically, which is where supersymmetry could come in. Supersymmetry would pair up fermions, such as the quarks and leptons, with bosons, such as the photon, gluon, W and Z, or even the Higgs boson itself. In a supersymmetric theory, the quantum corrections due to the pairs of virtual fermions and bosons cancel each other systematically, and a low-mass Higgs boson no longer appears unnatural. Indeed, supersymmetry predicts a mass for the Higgs boson probably below 130 GeV, in line with the global fit to precision electroweak data.

The fermions and bosons of the Standard Model, however, do not pair up with each other in a neat supersymmetric manner. The theory, therefore, requires that a supersymmetric partner, or sparticle, as yet unseen, accompanies each of the Standard Model particles. Thus, this scenario predicts a "scornucopia' of new particles that should weigh less than about 1 TeV and could be produced by the LHC (figure 3).

Another attraction of supersymmetry is that it facilitates the unification of the fundamental forces. Extrapolating the strengths of the strong, weak and electromagnetic interactions measured at low energies does not give a common value at any energy, in the absence of supersymmetry. However, there would be a common value, at an energy around 10^{16} GeV, in the presence of supersymmetry. Moreover, supersymmetry provides a natural candidate, in the form of the lightest supersymmetric particle (LSP), for the cold dark matter required by astrophysicists and cosmologists to explain the amount of matter in the universe and the formation of structures within it, such as galaxies. In this case, the LSP should have neither strong nor electromagnetic interactions, since otherwise it would bind to conventional matter and be detectable. Data from LEP and direct searches have already excluded sneutrinos as

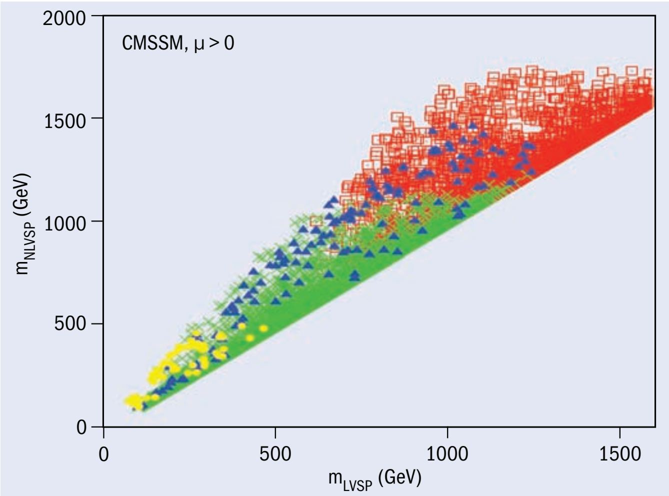


*Fig. 4. Masses of the lightest visible supersymmetric particle (LVSP) and the next-to-lightest visible supersymmetric particle (NLVSP) found in a sampling of parameters (red) of a constrained minimal supersymmetric extension of the Standard Model, including those that produce a suitable amount of dark matter (blue), most of which are detectable at the LHC (green), but perhaps not directly as astrophysical dark matter (yellow) (*Ellis et al. *2004).*

LSPs. Nowadays, the "scandidates" most considered are the lightest neutralino and (to a lesser extent) the gravitino.

Assuming that the LSP is the lightest neutralino, the parameter space of the constrained minimal supersymmetric extension of the Standard Model (CMSSM) is restricted by the need to avoid the stau being the LSP, by the measurements of $b \rightarrow s\gamma$ decay that agree with the Standard Model, by the range of cold dark-matter density allowed by astrophysical observations, and by the measurement of the anomalous magnetic moment of the muon (g_μ–2). These requirements are consistent with relatively large masses for the lightest and next-to-lightest visible supersymmetric particles, as figure 4 indicates. The figure also shows that the LHC can detect most of the models that provide cosmological dark matter (though this is not guaranteed), whereas the astrophysical dark matter itself may be detectable directly for only a smaller fraction of models.

Within the overall range allowed by the experimental constraints, are there any hints at what the supersymmetric mass scale might be? The high precision measurements of m_W tend to favour a relatively small mass scale for sparticles. On the other hand, the rate for $b \rightarrow s\gamma$ shows no evidence for light sparticles, and the experimental upper limit on $B_s \rightarrow \mu^+\mu^-$ begins to exclude very small masses. The strongest indication for new low-energy physics, for which supersymmetry is just one possibility, is offered by g_μ–2. Putting this together with the other precision observables gives a preference for light sparticles.

Other proposals for additional new physics postulate the existence of new dimensions of space, which might also help to deal with the hierarchy problem. Clearly, space is three-dimensional on the distance scales that we know so far, but the suggestion is that there might be additional dimensions curled up so small as to be invisible. This idea, which dates back to the work of Theodor Kaluza and Oskar Klein in the 1920s, has gained currency in recent years with the realization that string theory predicts the existence of extra dimensions and that some of these might be large enough to have consequences observable at the LHC (*CERN Courier* July/August 2003 p21). One possibility that has emerged is that gravity might become strong when these extra dimensions appear, possibly at energies close to 1 TeV. In this case, some variants of string theory predict that microscopic black holes might be produced in the LHC collisions. These would decay rapidly via Hawking radiation, but measurements of this radiation would offer a unique window onto the mysteries of quantum gravity.

If the extra dimensions are curled up on a sufficiently large scale, ATLAS and CMS might be able to see Kaluza–Klein excitations of Standard Model particles, or even the graviton. Indeed, the spectroscopy of some extra-dimensional theories might be as rich as that of supersymmetry while, in some theories, the lightest Kaluza–Klein particle might be stable, rather like the LSP in supersymmetric models.

Back to the beginning

By colliding particles at very high energies we can recreate the conditions that existed a fraction of a second after the Big Bang, which allows us to probe the origins of matter. This may be linked to the question of why there are so many different types of matter particles in the universe. Experiments at LEP revealed that there are just three "families" of elementary particles: one that makes up normal stable matter, and two heavier unstable families that were revealed in cosmic rays and accelerator experiments. The Standard Model does not explain why there are three and only three families, but it may be that their existence in the early universe was necessary for matter to emerge from the Big Bang, with little or no antimatter. It seems likely that the answers to these questions are linked at a fundamental level.

Andrei Sakharov was the first to point out that particle physics could explain the origin of matter in the universe by the fact that matter and antimatter have slightly different properties, as discovered in the decays of K and B mesons, which contain strange and bottom quarks, members of the heavier families (*CERN Courier* June 1999 p22 and October 1999 p24). These differences are manifest in the phenomenon of CP violation. Present data are in good agreement with the amount of CP violation allowed by the Standard Model, but this would be insufficient to generate the matter seen in the universe.

The Standard Model accounts for CP violation within the context of the Cabibbo–Kobayashi–Maskawa (CKM) matrix, which links the interactions between quarks of different type (or flavour). Experiments at the B-factories at KEK and SLAC have established that the CKM mechanism is dominant, so the question is no longer whether this is "right". The task is rather to look for additional sources of CP violation that must surely exist, to create the cosmological matter–antimatter asymmetry via baryogenesis in the early universe. It is an open question whether these may provide new physics at the tera-electron-volt scale accessible to the LHC. On the other hand, if the LHC does observe any new physics, such as the Higgs boson and/or supersymmetry, it will become urgent to understand its flavour and CP properties.

The LHCb experiment will be dedicated to probing the differences between matter and antimatter, notably looking for ▷

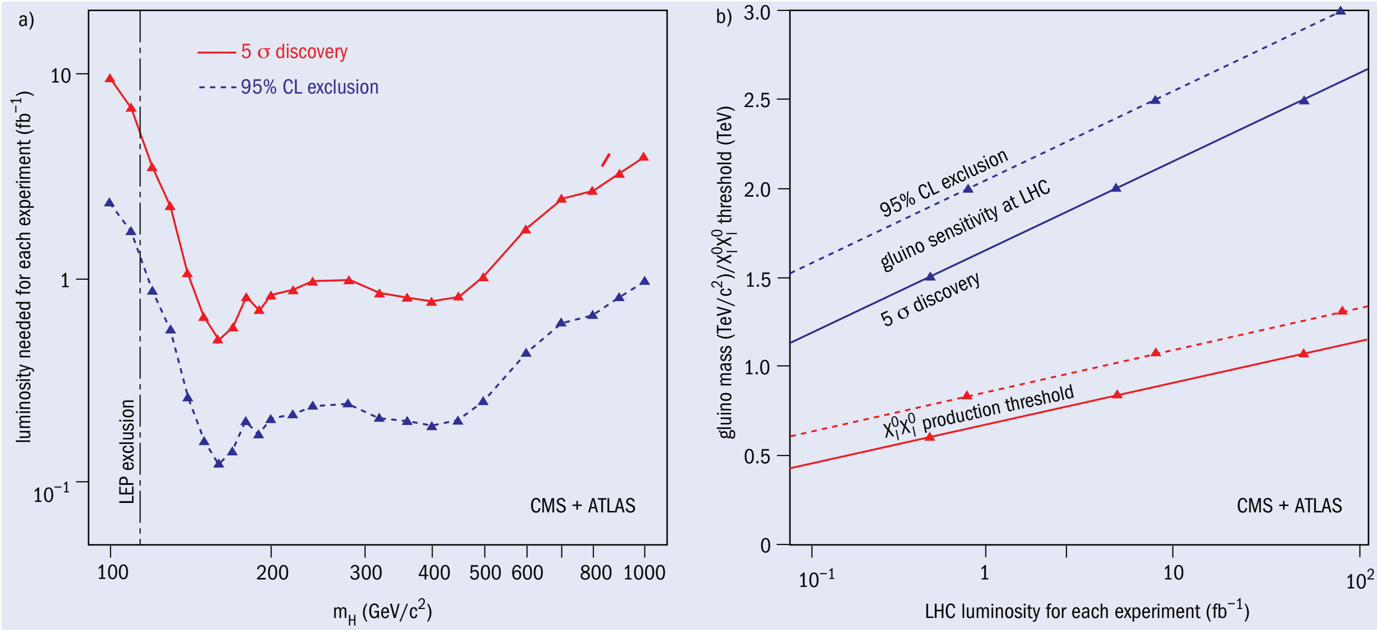


Fig. 5. a) The prospects for discovering a Standard Model Higgs boson in the initial running of the LHC, as a function of the mass of the Higgs. The plot combines the capabilities of the ATLAS and CMS experiments. b) The reach for gluino detection at the LHC and the corresponding threshold for the production of pairs of the lightest neutralinos (X_1^0) at linear colliders, as functions of the LHC intensity for each experiment (Blaising et al. *2006).*

discrepancies with the Standard Model. The experiment has unique capabilities for probing the decays of mesons containing both bottom and strange quarks. It will be able to measure subtle CP-violating effects in B_s decays, and will also improve measurements of all the angles of the unitarity triangle, which expresses the amount of CP violation in the Standard Model. The LHC will also provide high sensitivity to rare B decays, to which the ATLAS and CMS experiments will contribute, in particular, and which may open another window on CP violation beyond the CKM model.

In addition to the studies of proton–proton collisions, heavy-ion collisions at the LHC will provide a window onto the state of matter that would have existed in the early universe at times before quarks and gluons "condensed" into hadrons, and ultimately the protons and neutrons of the primordial elements. When heavy ions collide at high energies they form for an instant a "fireball" of hot, dense matter. Studies, in particular by the ALICE experiment, may resolve some of the puzzles posed by the data already obtained at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven. These data indicate that there is very rapid thermalization in the collisions, after which a fluid with very low viscosity and large transport coefficients seems to be produced. One of the surprises is that the medium produced at RHIC seems to be strongly interacting (p7). The final state exhibits jet quenching and the semblance of cones of energy deposition akin to Machian shock waves or Cherenkov radiation patterns, indicative of very fast particles moving through a medium faster than sound or light (*CERN Courier* March 2007 p35).

Experiments at the LHC will enter a new range of temperatures and pressures, thought to be far into the quark–gluon plasma regime, which should test the various ideas developed to explain results from RHIC. The experiments will probably not see a real phase transition between the hadronic and quark–gluon descriptions; it is more likely to be a cross-over that may not have a distinctive experimental signature at high energies. However, it may well be possible to see quark–gluon matter in its weakly interacting high-temperature phase. The larger kinematic range should also enable ideas about jet quenching and radiation cones to be tested.

First expectations

The first step for the experimenters will be to understand the minimum-bias events and compare measurements of jets with the predictions of QCD. The next Standard Model processes to be measured and understood will be those producing the W and Z vector bosons, followed by top-quark physics. Each of these steps will allow the experimental teams to understand and calibrate their detectors, and only after these steps will the search for the Higgs boson start in earnest. The Higgs will not jump out in the same way as did the W and Z bosons, or even the top quark, and the search for it will demand an excellent understanding of the detectors. Around the time that Higgs searches get underway, the first searches for supersymmetry or other new physics beyond the Standard Model will also start.

In practice, the teams will look for generic signatures of new physics that could be due to several different scenarios. For example, missing-energy events could be due to supersymmetry, extra dimensions, black holes or the radiation of gravitons into extra dimensions. The challenge will then be to distinguish between the different scenarios. For example, in the case of distinguishing between supersymmetry and universal extra dimensions, the spectra of higher excitations would be different in the two scenarios, the different spins of particles in cascade decays would yield distinctive spin correlations, and the spectra and asymmetries of, for instance, dileptons, would be distinguishable.

What is the discovery potential of this initial period of LHC running? Figure 5a shows that a Standard Model Higgs boson could be discovered with 5σ significance with $5\,fb^{-1}$ of integrated and well-understood luminosity, whereas $1\,fb^{-1}$ would already suffice to exclude a Standard Model Higgs boson at the 95% confidence level over a large range of possible masses. However, as mentioned above, this Higgs signal would receive contributions from many different decay signatures, so the search for the Higgs boson will require researchers to understand the detectors very well to find each of these signatures with good efficiency and low background. Therefore, announcement of the Higgs discovery may not come the day after the accelerator produces the required integrated luminosity!

Paradoxically, some new physics scenarios such as supersymmetry may be easier to spot, if their mass scale is not too high. For example, figure 5b shows that $0.1\,fb^{-1}$ of luminosity should be enough to detect the gluino at the 5σ level if its mass is less than 1.2 TeV, and to exclude its existence below 1.5 TeV at the 95% confidence level. This amount of integrated luminosity could be gathered with an ideal month's running at 1% of the design instantaneous luminosity.

We do not know which, if any, of the theories that I have mentioned nature has chosen, but one thing is sure: once the LHC starts delivering data, our hazy view of this new energy scale will begin to clear dramatically. Particle physics stands on the threshold of a new era, in which the LHC will answer some of our deepest questions. The answers will set the agenda for future generations of particle-physics experiments.

● Based on the concluding talk at Physics at the LHC, Cracow, 3–8 July 2006 (http://arxiv.org/abs/hep-ph/0611237).

Further reading

J-J Blaising *et al*. 2006 *Report to CERN Council European Strategy Group*. See the web at http://council-strategygroup.web.cern.ch/council-strategygroup/BB2/contributions/Blaising2.pdf.
J R Ellis *et al*. 2004 *Phys. Lett. B* **603** 51.
J Erler 2007 http://arxiv.org/pdf/hep-ph/0701261.

Résumé

Le LHC fera la lumière aux frontières des hautes énergies

De par son niveau d'énergie sans précédent et son énorme taux de collisions, le LHC sera un microscope capable de sonder la matière à des échelles plus petites que jamais auparavant. Aux énergies et aux distances explorées jusqu'ici, le modèle standard des particules et des forces permet de décrire la matière. Il laisse cependant plusieurs questions fondamentales sans réponse, notamment sur l'origine de la masse, sur la différence subtile entre matière et antimatière, et sur la possibilité d'unifier les interactions fondamentales. John Ellis explique comment le LHC devrait apporter certaines de ces réponses et révolutionner notre compréhension de la matière, des forces et de l'espace.

John Ellis, *CERN*.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Our time is the future.
Technology, experience and team spirit leave their mark.
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Spark-proof GEM gives higher gain

A team from CERN and INFN has developed the resistive-electrode thick GEM, or RETGEM, which offers a high gain while being intrinsically protected against sparks.

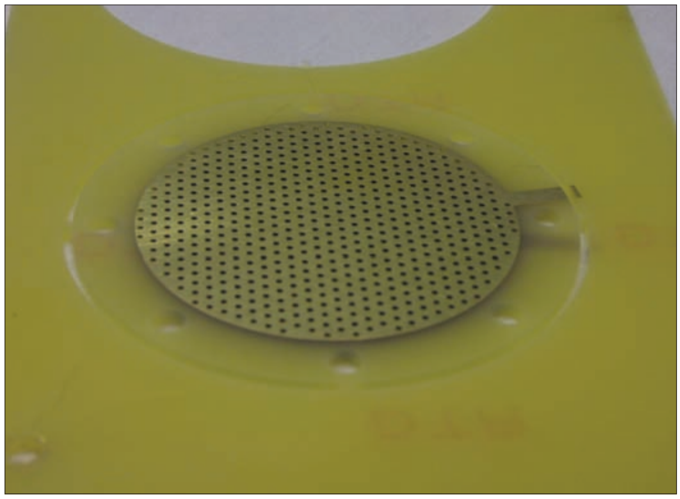


Fig. 1. A photo of a thick GEM showing the array of drilled holes.

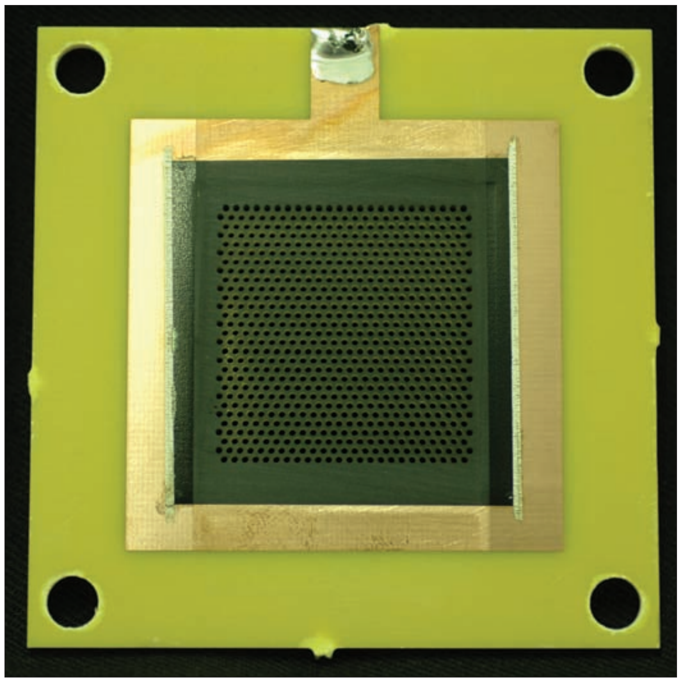


Fig. 2. Photo of the RETGEM with kapton-resistive electrodes.

The gas electron multiplier (GEM) detector developed at CERN by Fabio Sauli has several unique features (*CERN Courier* December 1998 p19). For example, it can operate at relatively high gains in pure noble gases, and can be combined with other devices of the same kind to operate in a cascade mode. Indeed, cascaded GEM structures now feature in several large-scale high-energy physics experiments, such as COMPASS, TOTEM and LHCb at CERN. The basic device consists of a metallized polymer foil chemically pierced to form a dense array of microscopic holes. Applying a voltage across the foil creates a high electric field in the holes which then act as tiny proportional counters, amplifying ionization charge. However, despite great progress in its development and optimization, the GEM is still a rather fragile detector. It requires very clean and dust-free conditions during its manufacture and assembly and it can be easily damaged by sparks, which are almost unavoidable when operating at high gain.

To try to overcome these problems, a few years ago a team of physicists from CERN and the Royal Institute of Technology in Stockholm developed a more robust version of the GEM, which was further improved by a team at the Weizman Institute of Science in Rehovot. Called the thick GEM (TGEM), it is based on printed circuit boards (PCBs) metallized on both sides, with an array of tiny holes drilled through (figure 1). Typically 0.5–1.0 mm thick, it is manufactured using the standard industrial PCB processing techniques for precise drilling and etching. The TGEM has excellent rate characteristics and can operate at higher gains than the GEM, but it can still be damaged by sparks.

Now a small team from CERN and INFN has developed a new, more spark-resistant version of the GEM in which the metallic electrode layers are replaced with electrodes of resistive material. We built the first prototypes from a standard PCB 0.4 mm thick. We glued sheets of resistive kapton (100XC10E5) 50 μm thick onto both surfaces of the PCB to form resistive electrode structures, and drilled holes 0.3 mm in diameter with a pitch of 0.6 mm using a CNC machine. The surface resistivity of the material created in this way varied from 500 to 800 kΩ/□, depending on the particular sample. After the drilling was finished, the copper foils were etched from the active area of the detector (30 mm × 30 mm), leaving only a copper frame for the connection of the high-voltage wires in the circular part of the detector (figure 2). We call this the resistive-electrode thick GEM (RETGEM).

The detector operates in the following way. When a high voltage is applied to the copper frames, the kapton electrodes act as equipotential layers, owing to their finite resistivity, and the same electric field forms inside and outside of the holes as occurs in the TGEM with the metallic electrodes. So at low counting rates the detector should operate as a conventional TGEM, while at high counting rates and in the case of discharges the detector's behaviour should be more like that of a resistive-plate chamber. The ▷

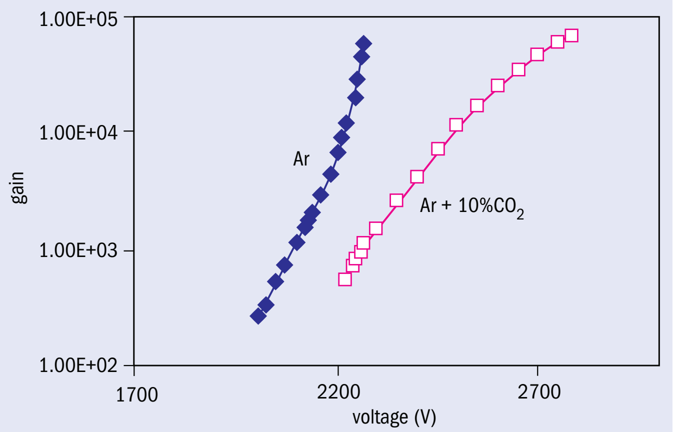


Fig. 3. Graph showing the gain of a RETGEM measured in argon (Ar) and a mixture of argon and carbon dioxide (CO_2).

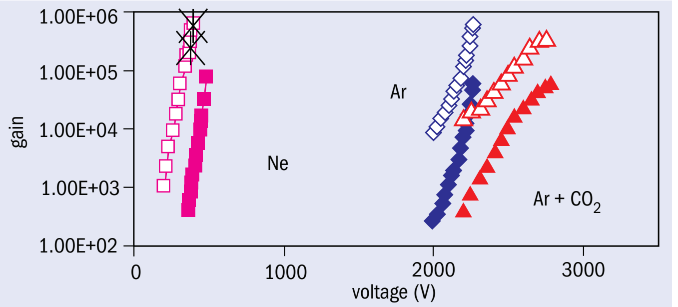


Fig. 4. Graph of the gain for single (solid symbols) and double (open symbols) RETGEM structures, 1 mm thick, measured in various gases. For the double structure, the voltage is given for the bottom RETGEM, with a gap of 7 mm between the two devices. The crosses indicate measurements for a double RETGEM that has been coated with caesium iodide.

RETGEM is only seven times thicker than the conventional GEM structures and could easily be bent to form a semi-cylindrical shape, as is preferred in some cases, such as in the future NA49 experiment at CERN.

We have made systematic studies and further developments of the RETGEM in collaboration with the High Momentum Particle Identification (HMPID) group of the ALICE Collaboration and the ICARUS research group from INFN Padova. These investigations show that the maximum achievable gain before sparks appear in the RETGEM is at least 10 times higher than in the case of the conventional GEM (figure 3). Moreover, when sparks do appear at higher gains, the current in these discharges is of an order of magnitude less than in the case of the TGEMs, so they do not damage either the detector or the front-end electronics.

We have since manufactured RETGEMs 1 and 2 mm thick with active areas of 30 mm × 30 mm and 70 mm × 70 mm in the TS/DEM/PMT workshop at CERN and successfully tested the devices. The maximum gain achieved was 2–3 times higher than with the device that was only about 0.4 mm thick, reaching a value of close to 10^5; as before, sparks did not damage the detector. The RETGEMs could operate at up to 10 kHz/cm^2 without a noticeable drop in the signal amplitude, while at higher counting rates the signal amplitude began dropping, as happens with resistive-plate chambers. We also found that double RETGEMs can operate stably in a cascade mode; we observed no charging-up effect despite the high resistivity of the electrodes and achieved gains close to 10^6 with the double-step RETGEMs.

The most interesting discovery was that if we coat the cathode of the RETGEM with a caesium iodide (CsI) photosensitive layer, the detector acquires high sensitivity to ultraviolet light – an approach that has already been used with the conventional GEM with metallic electrodes. In contrast to these earlier attempts, however, in our case, the CsI was deposited directly onto the dielectric layer, that is, there was no metallic substrate present. Surprisingly enough, this detector worked very stably in the pulse-counting mode, easily achieving gains of 6×10^5 in double-step operation. The measured quantum efficiency was 34% at a wavelength of 120 nm, which is sufficient for some applications such as ring imaging Cherenkov detectors (RICH) or for the detection of the scintillation light from the noble liquids.

These studies have shown that RETGEMs can compete with the GEM in many applications that do not require very fine position resolution. Indeed the RETGEM offers a maximum achievable gain that is 10 times higher, is intrinsically protected against sparks and is thus very robust, can be assembled in ordinary laboratory conditions without using a clean room, and can operate in poorly quenched gases and gas mixtures. Other resistive coatings could also be used and the resistivity optimized for each application.

We believe that the new detector will have a great future and will find a wide range of applications in many areas. In high-energy physics it can be used, for example in RICH, muon detectors, calorimetry and noble-liquid time projection chambers.

● The RETGEM team comprises Rui de Oliveira (CERN TS/DEM/PMT workshop), Paolo Martinengo (ALICE HMPID group), Vladimir Peskov (ALICE HMPID group), Francesco Pietropaolo (INFN Padova) and Pio Picchi (INFN Frascati).

Further reading

R Olivera *et al.* 2007 to be published in *Nucl. Inst. Meth. A* doi:10.1016/j.nima.2007.03.010.

V Peskov *et al.* 2007 Vienna Conference on Instrumentation, http://vci.oeaw.ac.at/2007/.

Résumé

Un nouveau GEM pour gain plus élevé

Le détecteur GEM (multiplicateur d'électrons à gaz), mis au point au CERN par Fabio Sauli, est particulièrement utile dans le cadre des grandes expériences de physique des hautes énergies. Cependant, bien que sa mise au point ait considérablement progressé, le GEM reste un détecteur relativement fragile et peut facilement être endommagé par les étincelles, qui sont presque inévitables à gain élevé. Une petite équipe du CERN et de l'INFN a maintenant développé le RETGEM, un multiplicateur GEM dont les électrodes métalliques ont été remplacées par des électrodes en matériau résistif. RETGEM offre un gain maximal qui est dix fois plus élevé; il est aussi intrinsèquement protégé contre les étincelles et est donc très robuste.

Vladimir Peskov, *École des Mines/CERN.*

US LAB NEWS

SLAC and Jefferson Lab see changing faces




Movers and shakers (from left to right): Jonathan Dorfan, Christoph Leemann, Andrew Hutton and Elke-Caroline Aschenauer.

Jonathan Dorfan, who has been director of SLAC for nearly eight years, has announced that he will step down in the autumn. Dorfan has overseen the laboratory since September 1999. Prior to that, he served as SLAC associate director and as director of the B-Factory Project from 1994 to 1999. He will continue to be involved at SLAC and, once a new director is named, will assist in the transition to the new leadership. Dorfan's achievements during his directorship include creating the Kavli Institute for Particle Astrophysics and Cosmology at SLAC and securing the world's first X-ray free-electron laser, the Linac Coherent Light Source, which is under construction (p9).

At the Thomas Jefferson National Accelerator Facility, Christoph Leemann has announced that he will be stepping down as director after six-and-a-half years at the helm of the research facility. Leemann has served Jefferson Lab for almost 22 years in various leadership positions, after coming to the laboratory from the Lawrence Berkeley Laboratory in 1985, attracted by the opportunity to build a new facility and a new organization on a green site. He was instrumental in the design, technology choice, and construction of the Continuous Electron Beam Accelerator Facility (CEBAF).

Also at Jefferson Lab Andrew Hutton, the long-time deputy associate director of the Accelerator Division has stepped into the role of associate director. He takes over from Swapan Chattopadhyay who served in that position from 2001, before joining the UK's Cockcroft Institute as its inaugural director in March. Hutton's interest in accelerators dates back to growing up in England, when Hal Gray, after whom the unit of absorbed radiation dose is named, allowed him to go after school to work on a small research electron linear accelerator at the cancer-research institute that Gray led. Ultimately Hutton went on to pursue his interest at CERN at the Large Electron–Positron collider, at the SLAC Linear Collider and at the PEP-II B-factory, before arriving at Jefferson Lab in 1993 to lead the commissioning of CEBAF.

Jefferson Lab has in the meantime welcomed a new face with the appointment of Elke-Caroline Aschenauer as the 12 GeV Upgrade Hall D Leader in December. She is also a member of the 12 GeV Upgrade project team. Aschenauer was previously at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany, and since August 2003 she has served as the spokesperson for the HERMES collaboration (*CERN Courier* April 2006 p26). For HERMES she monitored day-to-day data taking and supervised an analysis of hadron multiplicities in semi-inclusive DIS using the RICH to tune fragmentation parameters in the HERMES Monte Carlo.

PUBLICATIONS

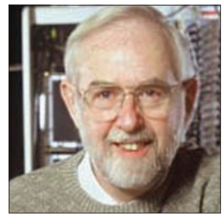
Sprouse takes over at *Physical Review*

The American Physical Society (APS) has appointed Gene D Sprouse, professor of physics at Stony Brook University, as its new editor-in-chief. Sprouse will succeed Martin Blume, who has held the position for 10 years.

Sprouse helped to build the Stony Brook superconducting linac and has been director of the Nuclear Structure Laboratory since 1996. The position of editor-in-chief is one of three co-equal operating officers of the APS, and includes primary responsibility for the *Physical Review* series of physics journals. He will head the APS editorial office located in eastern Long Island, near Brookhaven National Laboratory. With a staff of 150, the office annually receives and processes peer reviews for nearly 30 000 physics manuscripts, two thirds of which originate outside the US. The office also manages an electronic archive of the 400 000 *Physical Review* articles published since 1893.

AWARDS

Franklin Institute rewards Totsuka and McDonald



Yoji Totsuka (left) and Arthur McDonald.

The Franklin Institute in Philadelphia has awarded its 2007 Benjamin Franklin Medal in Physics to Yoji Totsuka and Arthur McDonald for discovering that the three known types of neutrino change into one another when travelling over long distances, and that neutrinos have mass. The institute's awards date back to 1824, when the institute was founded to train artisans and mechanics in the fundamentals of science. McDonald, from Queen's University, Ontario, is director of the Sudbury Neutrino Observatory (SNO) Institute, while Totsuka, from the University of Tokyo, is former director of the Kamioka Observatory, home to the Super-Kamiokande neutrino detector.

The Kamiokande collaboration first reported the detection of a deficit in the number of atmospheric muon neutrinos in 1988. A decade later the Super-Kamiokande collaboration announced the discovery of atmospheric neutrino oscillations. More recently SNO found evidence for oscillation in solar neutrinos, resolving the long-standing solar-neutrino problem (see p26). The Franklin Institute also recognized solar-neutrino physics in 2003, with the award of the Franklin Medal in Physics to John Bahcall, Raymond Davis and Masatoshi Koshiba (*CERN Courier* July/August 2003 p34).

HESS collaboration wins Descartes Prize

Representatives of HESS at the Descartes Prize ceremony, together with Annette Schavan (left), the German research minister, Janez Potočnik (third from right), the Commissioner for Science and Research of EU, and Claudie Haigneré (second from right), chair of the Grand Jury of the Descartes Prizes. (Courtesy European Community.)

The High Energy Stereoscopic System (HESS) collaboration has received the prestigious EU Descartes Prize for Research at a ceremony in Brussels on 7 March. Launched in 2000, the prize rewards teams of scientists for outstanding scientific or technological results achieved through transnational research in any field of science.

The HESS collaboration involves about 100 scientists from Armenia, the Czech Republic, France, Germany, Ireland, Namibia, Poland, South Africa and the UK. It operates an array of four big Cherenkov telescopes in Namibia, which are the most sensitive telescopes in the world for studying very high-energy gamma rays. Since starting operation in 2002, results from HESS have provided a number of breakthroughs, such as the first resolved image of a supernova shock wave acting as a cosmic particle accelerator, the detailed study of high-energy radiation from the centre of our galaxy, and the discovery of a stellar black hole – a "microquasar" – generating gamma rays.

HESS shares the prize with two other projects: Hydrosol, which has developed a way to produce hydrogen from water-splitting using solar energy, and APOPTOSIS, which has made great strides in the understanding of apoptosis (programmed cell death).

NIM rewards two young scientists at Vienna conference

Two young researchers shared the NIMA Young Scientists' Award at the 11th Vienna Conference on Instrumentation held in February. The award, for scientists under 35 who have contributed a paper or poster at the conference, is sponsored by *Nuclear Instruments and Methods in Physics Research, Section A*. This year the International Advisory Committee selected Xavier Llopart from CERN and Nahee Park from Ewha Womans University in Seoul. Llopart, who works on the Medipix project at CERN, won the award "for the development of pixel readout chips for a wide range of instrumentation applications"; Park received her award "for substantial contributions to the CREAM balloon experiment and outstanding presentation of her work".

Nahee Park (left) and Xavier Llopart (right) receive their awards at the conference.

Royal Irish Academy makes Weinberg an honorary member


Steven Weinberg, who receives honorary membership of the Royal Irish Academy.

The Royal Irish Academy has made Steven Weinberg, Nobel laureate and professor at the physics and astronomy departments of the University of Texas, Austin, an honorary member. The academy was founded in 1785, and continues to serve as the national academy of arts and sciences for Northern Ireland and the Republic of Ireland. Weinberg joins just 14 scholars at American universities who are honorary members of this academy.

ANNIVERSARY

Zatsepin celebrates 90 years

George Zatsepin, pioneer of cosmic-ray physics and neutrino astrophysics, celebrates his 90th birthday on 28 May. He is probably best known for the Greisen–Zatsepin–Kuzmin effect, published in the 1970s, which is the subject of many experimental and theoretical studies throughout the world.

In the early 1950s, in work on the nuclear nature of extensive air showers, Zatsepin created the equations for particle propagation through the atmosphere. His "next-generation principle" assumes that the characteristics of secondary particles produced in nucleon–air nucleus interactions depend only on the portion of energy taken away by a secondary particle – an effect found later in experiments on accelerators and named "scaling".

Many experiments have realized Zatsepin's ideas in neutrino physics and astrophysics. He is a leader of the Russian–American gallium germanium experiment, SAGE, which has studied the solar neutrino flux for 15 years at the Baksan Neutrino Observatory. He was the first to suggest measuring the neutrino flux from collapsing stars and was a leading figure in the Baksan neutrino telescope, the 100 tonne scintillator detector in Artyomovsk, and the Italian–Russian Liquid Scintillator Detector under Mont Blanc. He remains a head of the Large-Volume Detector experiment in the Gran Sasso National Laboratory.


George Zatsepin, who turns 90 in May.

Zatsepin has long held the cosmic-ray chair of the physics department of Moscow State University, where he helped to create the emulsion detector group and the international Pamir Collaboration. As head of the neutrino physics and neutrino astrophysics department of the Institute for Nuclear Research of the Russian Academy of Sciences he created an important school of physicists working on cosmic-ray and neutrino physics.

CENTENARY

Dubna symposium honours the memory of Norair Sissakian

The III International Symposium "Problems of Biochemistry, Radiation and Space Biology" took place on 24–28 January in Dubna. This year the symposium was dedicated to the centenary of Norair Martirosovich Sissakian (1907–1966), an eminent researcher and biochemist, one of the founders of space biology, and an outstanding organizer of global scientific cooperation.

For a number of years Sissakian was chief scientific secretary of the Presidium of the USSR Academy of Sciences and academician-secretary of the Department of Biological Sciences. On the global scene he was vice-president of the International Academy of Astronautics, and chair of the committee on bioastronautics of the International Astronautics Federation. In 1964 he was unanimously elected president of the 13th session of the UNESCO General Conference; some 40 years later, the 33rd session decided that the centenary of his birth should be included in the list of anniversaries associated with UNESCO in 2006–2007. He was also an active member of the Pugwash movement of scientists for peace.


Norair Martirosovich Sissakian, 1907–1966.

About 150 scientists, not only from Russia but also from Italy, Canada, the US and CIS countries (Armenia, Georgia, Belarus and Ukraine), attended the symposium. The opening ceremony took place on 25 January at the President Hall of the Russian Academy of Sciences (RAS), with talks from many outstanding scientists and researchers.

● The symposium was organized by the RAS, the RAS Department of Biological Sciences, the Bach Institute of Biochemistry of RAS, the RF State Scientific Centre (SSC) – Institute of Biomedical Problems, the National Academy of Sciences of the Republic of Armenia, Yerevan State University, the Dubna International University of Nature, Society and Man and the Joint Institute for Nuclear Research.

NEW PRODUCTS

HiTek Power has added the OL20K 20 KW family to its range of inherently robust high-voltage power supplies, offering output voltages from 60 kV to 200 kV and beyond. Each consists of a converter in a 6U, 19-inch rack-mounting unit and a separate high-voltage multiplier assembly. The supplies are highly stable, with ripple of less than 0.1% peak-to-peak of rated output. For further information contact sales.uk@hitekpower.com or see www.hitekpower.com.

Lake Shore Cryotronics has introduced the new Model RX-102B-CB ruthenium oxide resistance cryogenic temperature sensor, the first that is commercially available. Calibrated from 20 mK to 40 K, the sensor is monotonic from 10 mK to 300 K, and the calibrations are accurate to ±2.0 mK at 20 mK, ±3.0 mK at 30 mK, ±4.0 mK at 40 mK and ±5.0 mK from 50 mK to 1 K. For further information tel +1 614 891 2244, fax +1 614 818 1600, e-mail info@lakeshore.com or see the website at www.lakeshore.com.

LG Motion Ltd has announced a new compact, low-cost linear positioning stage, available with a manual or motorized drive. Based on a PTFE bearing system with a simple lead-screw drive, the XslideT has repeatability of 2.5 μm per 25 mm and an overall positioning accuracy of 76 μm per 250 mm as standard, or 38 μm per 250 mm in the optional higher precision version. For further information contact Gary Livingstone, tel +44 (0)1256 365600, fax +44 (0)1256 365645 or e-mail g.livingstone@lg-motion.co.uk.

PI (Physik Instrumente) LP has introduced the M-511.HD hybrid nanopositioning translation stage. The new hybrid system combines the resolution (down to 2 nm) and rapid response of a piezo-flexure drive with the long travel ranges and high holding forces of a servo-motor/ballscrew arrangement. Typical applications include surface inspection, laser technology and interferometry. For further information see www.physikinstrumente.com.

Resolve Optics Ltd has developed a comprehensive range of non-browning (radiation resistant) lenses for use in radioactive environments. All the lenses are designed to withstand a total radiation dose of 100 000 000 rads and temperatures up to 55 °C without discolouring. Fixed-focus lenses range from 6 mm to 25 mm focal length with fields of view up to 108°; 6:1 and 3:1 zoom lenses are also available. For further information tel +44 (0)1494 777100, e-mail sales@resolveoptics.com or see www.resolveoptics.com.

Vector Fields has announced a 3D version of its electromagnetic modelling software for simulating permanent magnet characteristics. DEMAG allows optimization of designs by accurately simulating both the magnetization process and subsequent demagnetization effects. Vector Fields has also announced an electromagnetic design tool for coaxial devices such as connectors and attenuators. Concert AS uses 3D drawings imported from CAD software or created by the package's own 3D modelling tool. For more information tel +44 (0)1865 370151 or +1 630 851 1734 or see www.vectorfields.com.

MEETING

The **International School of Subnuclear Physics, Searching for the 'Totally Unexpected' in the LHC Era**, will take place at the Ettore Majorana Foundation and Centre for Scientific Culture, Erice, on 29 August – 7 September. In anticipation of the start-up of the LHC, the school, organized by G 't Hooft and A Zichichi, will be dedicated to a set of "hot theoretical problems" and a series of experimental highlights presented by the directors and experiment leaders of all the major particle-physics laboratories. The programme also includes seminars on specialized topics, such as complexity at the fundamental level, double beta decay, problems with three neutrinos, dark matter and dark energy. The school will be attended by 50 invited "young talents" selected from throughout the world. Diplomas for the best students will be awarded at the end of the school. For more information see www.ccsem.infn.it/ef/emfcsc2007/pdf/ISSP2007.pdf.

OBITUARIES

Simon Peter Rosen 1933–2006

Simon Peter Rosen, 73, died on 13 October 2006 at his home in Rockville, MD, after a battle with pancreatic cancer.

Peter had been senior advisor to the director of the Office of Science in the Department of Energy (DOE) since 2003. From 1997 to 2003, he was associate director of the Office of Science, with responsibility for high-energy and nuclear physics. Highlights of his tenure include the discoveries of neutrino oscillations and dark energy, construction of the B-Factory and the Relativistic Heavy Ion Collider, and the signing of a US–CERN agreement for US participation in the LHC.

An authority on neutrino oscillations and neutrinoless double beta decay, Peter was also a gifted spokesman for particle and nuclear physics. Even while undergoing three years of intensive cancer therapy, he continued his efforts, writing and speaking about the importance of physics and finding DOE support for two NOVA programmes. In September 2006, one month before his death, *CERN Courier* published Peter's eloquent tribute to Ray Davis, whom he called "discoverer and grand pioneer of the solar-neutrino problem" (*CERN Courier* September 2006 p32).

Peter was born in August 1933 in London, UK, and became a US citizen in 1972. Earning a PhD in physics at Oxford in 1957, he began his career at Washington University in St Louis, MO, where he became well known for his work with Henry Primakoff on the theory of double beta decay. Peter then moved to Midwestern Universities Research and spent a year as a NATO Fellow at Oxford.

In 1962, he joined Purdue University as an assistant professor and rose rapidly,

Simon Peter Rosen, who died in October.

promoted to associate professor in 1963 and to professor in 1966. His research focused heavily on implications of various symmetry principles for the weak interactions. These included the application of unitary symmetries to non-leptonic hyperon decays and tests of lepton number conservation in semi-leptonic decays. Following the discovery of neutral weak currents in the mid-1970s, Peter co-authored a series of papers with Boris Kayser, Gerry Garvey, Ephraim Fischbach and others on tests to determine the space–time structure of the neutral current using data from reactions such as elastic neutrino–proton scattering.

At Purdue and throughout his career, Peter returned many times to the theory of double beta decay, a problem that became increasingly important as the evidence for massive neutrinos grew. Peter's work helped connect experimental bounds to physics beyond the Standard Model: constraints placed on the neutrino mass matrix, on right-handed couplings of Majorana neutrinos, and on exotic processes such as Majoron emission.

Peter also found time to serve on both the university and the School of Science promotion committees and as president of the Purdue chapter of the American Association of University Professors. He enjoyed tennis and squash and was a tenacious competitor – a trait also apparent in his physics, where he relished debate with friends and colleagues.

On leave from Purdue, Peter served as a theoretical physicist at two federal agencies: ERDA (1975–77) and the National Science Foundation (1981–83). He moved from Purdue to the Theoretical Division of Los Alamos National Laboratory (1983–90), where he helped to organize an unsuccessful proposal to mount a US gallium solar-neutrino experiment. He also collaborated with James Gelb on the implications of the newly discovered Mihkeyev–Smirnov–Wolfenstein mechanism for matter-enhanced neutrino oscillations. In anticipation of the Superconducting Supercollider, Peter left Los Alamos to become dean of science at the University of Texas at Arlington (1990–96), establishing a high-energy-physics group in the physics department.

Peter was a fellow in the American Physical Society and the American Association for the Advancement of Science. In 2000 he became professor emeritus of the University of Texas at Arlington and in 2004 received an honorary degree from Purdue University.

Peter is survived by his wife Adrienne, his son Daniel and his daughter Sarah.

Ephraim Fischbach, Sandip Pakvasa, and Wick Haxton.

Willy van Neerven 1947–2007

Willy van Neerven died on 15 February 2007. He held a position at the Lorentz Institute of Leiden University and a special professorship at the Vrije Universiteit Amsterdam, working as a theoretical particle physicist.

Willy was born at Weert in the Netherlands on 3 May 1947. He received his PhD at Nijmegen University in 1975, carrying out thesis studies under the supervision of R P Van Royen and J J de Swart. As a postdoctoral fellow and during long-term visits he worked at CERN, NIKHEF, Dortmund University, ETH Zurich, Tallahassee, YITP Stony Brook and DESY. From his early years at CERN and NIKHEF onwards he performed groundbreaking calculations within perturbative quantum field theory.

He was involved in developing important

aspects of quantum electrodynamics (QED), quantum chromodynamics (QCD) and the Standard Model. He developed specific calculation technologies and performed a large number of complete calculations at the one- and two-loop level, including those with different mass scales and polarized initial states.

Willy played a leading role in calculating the two-loop QED-corrections for the Large Electron–Positron collider, which were instrumental in establishing all precision measurements at the Z peak. His pioneering work on the QCD-Wilson coefficients for the deeply inelastic structure functions, also including those for heavy flavours, formed a milestone in QCD and was instrumental for interpreting the experimental data at HERA. He performed one of the first calculations of the polarized next-to-leading-order anomalous dimensions. His work in collider physics covered the celebrated two-loop calculations of the cross-sections for the Drell–Yan process and for Higgs production, which are of central importance for the physics at the Tevatron and the LHC. He also calculated the next-to-leading QCD corrections to the top-quark cross-section. Without his efforts much of the precision analysis of the data would have been impossible.


Willy van Neerven, who died in February.

Willy was a driven teacher to the benefit of his students and collaborators. He was equipped with a fabulous encyclopaedic knowledge of many facets of quantum field theory, and also of scientific literature, often down to the volume number, as well as of historic facts down to dates. We all remember conversations with him, especially on walks, during which he enjoyed a good cigar; besides being pleasant they offered a great way to analyse current scientific problems with his collaborators. In his reasoning he was strict but not at all dogmatic. His aim was to understand a physics problem to the very end, whenever possible. Willy understood physics thoroughly as quantitative science and therefore only accepted theories that could be tested by experiment.

He will be greatly missed by friends and colleagues alike.

P van Baal, J Blümlein, P Mulders, A Schellekens, J Smith and J Vermaseren.

RECRUITMENT

For advertising enquiries, contact CERN Courier recruitment/classified, Institute of Physics Publishing, Dirac House, Temple Back, Bristol BS1 6BE, UK.
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Max Planck Institute for Physics
(Werner Heisenberg Institute)

MAX-PLANCK-GESELLSCHAFT

Postdoctoral Position within the ATLAS Inner Detector Group

The Max Planck Institute for Physics is one of the world's leading research institutes focused on particle and astroparticle physics from both an experimental and a theoretical perspective. One main research activity in elementary particle physics at accelerators is the participation in the ATLAS experiment to operate at CERN's Large Hadron Collider (LHC) starting this year. The scientific focus of the ATLAS collaboration is the search for the Higgs boson, precision measurements of top- and b-quark physics, and the search for new physics beyond the Standard Model.

The ATLAS Inner Detector Group at the Max Planck Institute for Physics has contributed to the design, construction and commissioning of the Semiconductor Tracker (SCT). The data analysis program pursued in our group concentrates on the alignment of the Inner Detector with particle tracks and precision measurements within the Standard Model in the area of top-quark physics, namely the determination of the top-quark mass and the top anti-top production cross-section.

We invite applications for a postdoctoral position in experimental elementary particle physics to strengthen our group mainly for the commissioning of the SCT as well as for data analysis in the areas outlined above. In addition, participation in a newly started R&D project towards a novel pixel detector concept for the upgrade of the ATLAS Inner Detector to be operated at the high luminosity period at the LHC (SLHC) would be encouraged.

Initially, the position is limited to two years, with the possibility of extension within the scope of the German Hochschulrahmengesetz. Salary is according to the German federal pay scale (TVöD). The Max Planck Society is committed to increasing the participation of women wherever they are underrepresented. Applications from women are particularly welcome. The Max Planck Society is committed to employing more handicapped individuals and especially encourages them to apply.

For questions concerning the position offered please contact Dr. Richard Nisius (nisius@mppmu.mpg.de). Interested scientists should send their application in writing, including a CV and list of publications until May 31, 2007. Applicants should also arrange for three letters of recommendation to be received by the same date at the following address:

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

Deutsches Elektronen-Synchrotron
Bibliothek und Dokumentation

DESY

DESY ist eines der weltweit führenden Beschleunigerzentren zur Erforschung der Struktur der Materie. Die Schwerpunkte der Forschung reichen von der Elementarteilchenphysik über vielfältige Anwendungen der Synchrotronstrahlung bis zu Bau und Nutzung von Röntgenlasern.

Die DESY-Dokumentation betreut das DESY Open-Access Repository und erstellt in Kollaboration mit der Bibliothek des Stanford Linear Accelerator Center (SLAC) eine Literaturdatenbank, die Teilchenphysikern/-innen weltweit den Zugriff auf benötigte Fachliteratur ermöglicht. Zur Verstärkung unseres Teams suchen wir zum nächstmöglichen Termin eine/-n

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Wir erwarten von Ihnen ein abgeschlossenes Hochschulstudium der Physik, vorzugsweise mit Promotion. Sie haben fundierte und breit gefächerte EDV-Kenntnisse, Fachkenntnisse in experimenteller und instrumenteller Physik und möchten Ihr umfangreiches Wissen in der Literaturdokumentation und Bibliotheksdatenverarbeitung einsetzen. Wenn Sie zudem noch über gute englische Sprachkenntnisse verfügen, freuen wir uns auf Ihre vollständigen Bewerbungsunterlagen unter Angabe der Kennziffer in unserer Personalabteilung. Fachliche Fragen beantwortet Ihnen gerne Herr Schmidt unter Telefon 040/8998-2560.

Die Vergütung und sozialen Leistungen entsprechen denen des öffentlichen Dienstes. Schwerbehinderte Menschen werden bei gleicher Eignung bevorzugt berücksichtigt. DESY fördert die berufliche Entwicklung von Frauen und bittet Frauen deshalb nachdrücklich, sich um die zu besetzende Stelle zu bewerben. DESY verfügt über einen Betriebskindergarten.

Deutsches Elektronen-Synchrotron DESY
in der Helmholtz-Gemeinschaft
Kennziffer: 49/2007 • Notkestraße 85 • 22607 Hamburg
Telefon 040/8998-3392 • www.desy.de
E-Mail: personal.abteilung@desy.de

Bewerbungsschluss: 21.05.2007

SCUOLA NORMALE SUPERIORE

Professorship in Experimental Elementary Particle Physics

The Scuola Normale Superiore of Pisa invites expressions of interest from qualified physicists in the field of experimental elementary particles, in view of a forthcoming vacancy in its Classe di Scienze at the full professor level.

We are seeking candidates with a proven record of achievements and a clear potential to promote and to lead research at the frontier of high energy physics and to contribute to the teaching of physics, at graduate and undergraduate level, and to the general activities of the Scuola Normale Superiore.

As a result of this enquiry the Scuola Normale Superiore will either issue an official vacancy declaration and carry out the procedure for filling a tenured position, or otherwise will offer a suitable temporary contract.

The expressions of interest should be addressed not later than May 18th 2007 to:

Prof. Fulvio Ricci
Preside Classe di Scienze,
Scuola Normale Superiore
Piazza dei Cavalieri 7, PISA I-56126

European Organization for Nuclear Research

European Laboratory for Particle Physics

With 2500 staff members and some 8000 scientific users from 80 countries, the European Organization for Nuclear Research, CERN, an Intergovernmental Organization with its seat at Geneva, Switzerland, is the leading international Laboratory for fundamental research in particle physics. The annual Budget of presently about 1 billion Swiss francs is funded by 20 Member States. CERN is presently constructing the Large Hadron Collider, LHC, the world's most powerful particle accelerator that will provide new insights into the origin and the structure of matter and into the forces governing the Universe.

The Director-General is the Chief Executive Officer and legal representative of the Organization. He/she is directly responsible to, and shall execute the decisions of, the CERN Council, the Organization's governing and decision-making body composed of the representatives of the Member States.
The term of office of the present Director-General, Dr Robert AYMAR, ends on 31st December 2008. The Council is therefore inviting applications for the appointment of a

Director-General

for a five-year term of office starting on 1st January 2009.

THE POSITION The successful candidate will • provide scientific and managerial leadership to the Organization • lead the implementation of the approved scientific programme, with emphasis on the full exploitation of the scientific potential of the LHC • develop strategic options for the long-term scientific programme of the Organization as an integral part of the European Strategy for Particle Physics • maintain and develop collaboration with the European national laboratories and institutes in the field as an integral part of the European Strategy for Particle Physics • maintain and develop close relations with Member States and non-Member States, and with the world-wide scientific user community of CERN.

REQUIREMENTS • Capacity for providing scientific and managerial leadership for CERN, for representing the Organization in dealings with governments and other bodies in and outside the Member States and for effective building of consensus within the Organization, the Member States and internationally • Outstanding expertise and a high reputation in particle physics and/or closely related fields • Communication and negotiation skills in accordance with the level of the position.

Applicants are requested to address a letter of interest, with a detailed curriculum vitae, to the Chairperson of the Search Committee and to send it to the CERN Council Secretariat*, before 31st May 2007. The Council is scheduled to make the appointment in December 2007. To allow the Director-General Designate sufficient time for consultation and familiarisation with CERN, a position within the Organization can be arranged for the year 2008. Additional information may be obtained from the Chairperson of the Search Committee; please contact the Council Secretariat. An appropriate remuneration and benefits package will be offered.

For general information about CERN: http://www.cern.ch. In line with CERN's equal opportunities policy, both men and women are encouraged to apply.

*Mrs Brigitte Beauseroy, Council Secretariat, CERN, CH-1211 Geneva 23, Switzerland Tel. +41 22 767 28 34 Fax. +41 22 782 30 11 e-mail Brigitte.Beauseroy@cern.ch

EUDET Detector R&D towards the International Linear Collider

TRANSNATIONAL ACCESS TO DETECTOR R&D INFRASTRUCTURES

EUDET is a project supported by the European Union in the Sixth Framework Programme (FP6) structuring the European Research Area. The project aims at creating a coordinated European effort towards research and development for the next generation of large-scale particle detectors. EUDET comprises 23 European partner institutes and 24 associated institutes working in the field of High Energy Physics.

EUDET provides in the framework of the Transnational Access scheme travel support for groups from the EU and countries associated to FP6 for using the following infrastructures:

TA1: Experiments at DESY testbeam (http://testbeam.desy.de)
TA2: Experiments using infrastructure developed within the EUDET project: high precision beam telescope; large, low mass TPC field cage; silicon based TPC readout system; support for the development of SI-Stripdetectors; support for the development of granular calorimeters.

TO APPLY FOR EC FUNDED ACCESS

visit our web site http://www.eudet.org to obtain more information about the modalities of application.

Director

Stanford Linear Accelerator Center at Stanford University

Stanford University seeks nominations and applications for the position of Director of the Stanford Linear Accelerator Center (SLAC). Stanford University manages SLAC under contract with the U.S. Department of Energy (DOE) and funding for the laboratory comes primarily from the Office of Science of the DOE.

The Director of SLAC oversees a $250M per year scientific program with a staff of 1600. The Director is responsible for leading the Laboratory's programs, including key efforts in photon science, accelerator physics, particle physics and particle astrophysics. This world-class facility is an integral part of Stanford University. The SLAC Director is a member of the Stanford faculty and reports jointly to the President and Provost, as well as serving as a member of the University's Cabinet.

Candidates should be outstanding scientists with an extensive record of scientific and technical accomplishments and demonstrated success in leading and managing large scientific programs or organizations. This position requires an individual with a proven track record of exemplary, senior-level leadership, and a vision to foster a culture of innovation and collaboration. Ability to communicate effectively and establish rapport with faculty, researchers, government officials, and the press is essential. Considerable understanding of the DOE and previous experience in a research university setting would be helpful. The appointment will be effective on or about September 1, 2007.

Applications, accompanied by current resumes, or nominations may be sent to:

Director Search Committee
Stanford Linear Accelerator Center
2575 Sand Hill Road M.S. 60
Menlo Park, California 94025
Email: directorsearch@slac.stanford.edu

The deadline for nominations and applications is June 1, 2007

"Stanford University has a strong institutional commitment to the principle of diversity. Applications from women, ethnic minorities, veterans and individuals with disabilities are encouraged. AA/EOE.

http://slac.stanford.edu

DESY

The Deutsches Elektronen-Synchrotron (DESY), location Zeuthen, in a common call with the **University of Potsdam, Faculty of Mathematics and Natural Sciences,** invites applications for the position of a

Professor of Theoretical Astroparticle Physics (W3)

The position is combined with that of a leading scientist at DESY.

The neutrino astrophysics group in Zeuthen is one of the leading partners of the IceCube project, a neutrino telescope just under construction at the South Pole. The group has a long, successful experience from the Baikal neutrino telescope and from IceCube's predecessor AMANDA. It has close working connections to the H.E.S.S. group at Humboldt University, Berlin, to the MAGIC collaboration, and to astronomers and astrophysicists in Potsdam.

Applicants are expected to be internationally recognized experts in theoretical astroparticle physics. Their expertise should include fields like cosmic acceleration mechanisms, cosmology, particle physics beyond the standard model, or neutrino physics. Applicants are expected to integrate into the collaborative activities of the institutions mentioned above and to support their work in experimental and observational astroparticle physics. The work at DESY also opens possibilities to cooperate with DESY theoreticians on fields like phenomenological particle physics, electro-weak theory, quantum chromo-dynamics, lattice gauge theory, and cosmology.

Within the cooperation agreement with the University of Potsdam, the applicant will have teaching responsibilities on the field of particle/astroparticle physics of two semester hours. Beyond his/her activities in Zeuthen, he/she should also establish a working group localized in Potsdam.

Prerequisites for the application are a doctoral degree and a record of research equivalent to the German "Habilitation". Scientific qualifications achieved in the private sector, outside Germany, or as Junior professor will also be considered.

Appointment will be made according to the laws of Brandenburg (Brandenburgisches Hochschulgesetz of 6 July 2004 Bbg. GVBl. I, page 394 ff). According to state law (§ 40 Abs. 1 BbgHG) the contract will be limited, in case it is the first appointment of the successful applicant as university professor, with the possibility of tenure after 5 years. Exceptions are possible, in particular if foreign applicants or applications from outside Universities cannot be acquired otherwise. When the appointment will be transformed into a permanent one later, there is no need for a new appointment procedure.

Potsdam University is an equal opportunity employer. The goal is to enhance the percentage of women in the areas where they are underrepresented. Women, therefore, are particularly encouraged to apply. Applications of disabled persons will be preferred in cases of equal qualification.

Applications by **15 June 2007** to: **Präsidentin der Universität Potsdam, Am Neuen Palais 10, 14469 Potsdam, Germany**

Florida Institute of Technology

Postdoctoral Research Associate Position & Ph.D. Student Research Assistant Position

in Micropattern Gas Detector Development for Muon Radiography

The **Department of Physics & Space Sciences at Florida Institute of Technology in Melbourne, Florida** seeks to fill openings for a Postdoctoral Research Associate and a Doctoral Student Research Assistant in a project exploring muon radiography of nuclear contraband using advanced Micro Pattern Gaseous Detectors, such as GEM detectors. In the initial phase detailed detector simulations will be performed as a basis for subsequent prototype detector development and experimental radiography tests. Applications for the **post-doctoral research associate** position are welcome from candidates with a Ph.D. degree in experimental high-energy or nuclear physics. A successful candidate has experience with simulation of particle detectors in GEANT4 and with construction, commissioning, and operation of particle detector systems and associated electronics - preferably MPGDs such as GEM and MICROMEGAS detectors. Experience with simulations in a Grid computing environment is considered an asset. The successful candidate is expected to organize and lead graduate and undergraduate students participating in the project. Candidates for the **Ph.D. student research assistantship** should hold an M.S. degree or equivalent in nuclear or particle physics. They should have a strong interest in particle detector development work and must be admitted to the Department's Ph.D. program before a Research Assistantship can be awarded. Interested candidates for either position are requested to submit their CV, a list of publications, contact information for three references, and a description of relevant research experience to **Prof. Marcus Hohlmann** by e-mail ONLY at **hohlmann@fit.edu**. Florida Institute of Technology (www.fit.edu) is a leading private academic research institution in the Southeastern United States located near NASA's Kennedy Space Center and is an Equal Opportunity /Affirmative Action Employer.

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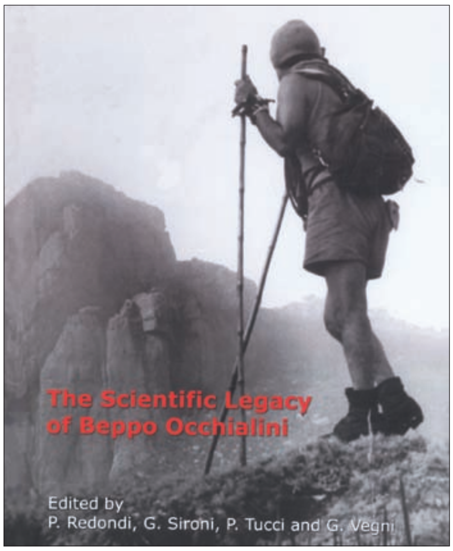
BOOKSHELF

The Scientific Legacy of Beppo Occhialini
by P Redondi, G Sironi, P Tucci and G Vegni (eds), Springer. Hardback ISBN 9783540373537, £54 (€74.85).

Giuseppe Paulo Stanislao Occhialini, or Beppo to his many friends across the world, was a charismatic, dynamic leader of discovery in particle and astrophysics for more than 50 years from the 1930s. These essays and reminiscences, by 30 colleagues and others who knew him, review his life to celebrate the centenary of his birth in 1907.

The early years of Occhialini's career were remarkable for two close encounters with the Nobel Prize: through his work on cosmic rays with Patrick Blackett and a decade later with Cecil Powell. His interest in cosmic rays began while studying at the Institute of Physics at Arcetri, part of the University of Florence, where he learnt to use new coincidence circuitry for Geiger–Muller counters from its developer, Bruno Rossi. After graduating in 1929 Occhialini stayed in research and in 1931 Rossi sent him to Cambridge to learn about Wilson cloud chambers from Blackett – who in turn learnt from Occhialini the advantages of using counters in coincidence to trigger the chamber. Soon, although unluckily a week or so after Carl Anderson at Caltech, they saw their first "positive electrons", but, unlike Anderson, they observed e^+e^- pairs and recognized that Paul Dirac's new relativistic quantum theory predicted this. Occhialini was a keen member of the "Kapitza Club" at Cambridge's Cavendish Laboratory, where he met Dirac.

Returning to Arcetri in 1934, Occhialini found that things had changed. Facism was taking power in Italy so he left for an appointment at the University of Sao Paulo in Brazil where he stayed throughout the Second World War. He built a strong group there using counters in cosmic-ray research before leaving at the end of 1944 for England at the invitation of Blackett, who thought that his help would be valuable in the work on an atomic bomb. Since Occhialini was Italian, this was not allowed and in autumn 1945 he went to Bristol to join Powell, who was using photographic emulsions to study low-energy nuclear reactions. Occhialini was immediately intrigued and impressed by the elegance and power of the method, but saw the need to improve the emulsions' sensitivity. So he contacted the technical staff at Kodak and Ilford to add his influence. Ilford then



produced the C2 emulsion, with eight times the silver halide concentration, which Powell and Occhialini "warmly welcomed", according to Ilford's man in charge, Cecil Waller.

Occhialini proposed exposing C2 plates to cosmic radiation at the top of the Pic du Midi (2800 m) in the Pyrenees, and did so in summer 1946. In January 1947 Occhialini and Powell published in *Nature* the first of a series of papers from the Bristol group establishing the discovery of the π-meson, its decay to the μ-meson and, after Kodak produced the first emulsions able to detect minimum ionization, the μ's decay to an electron.

It was at Bristol that Beppo met Connie: Constance Charlotte Dilworth, who was born in 1924 in Streatham, London. She started postgraduate studies in theoretical solid-state physics at Bristol in about 1946, then switched to join Powell's group. Together with Occhialini and others, she contributed significantly to processing thick photographic emulsions. In 1948, when Occhialini was invited to Brussels to start a new nuclear emulsion group, Connie went with him. They were married in 1950 and their daughter, Etra, who contributed to this book, was born the next year. Connie and Beppo became a very effective team, a formidable duo who would provide strong leadership in Italian and European science. Beppo's excitable Italian temperament was complemented by the calm, organized approach of Connie, a notable scientist herself who always understood how Beppo's aspirations could be realized.

In 1950 the Occhialinis moved to Genoa and in 1952 to Milan University where Beppo was director until he retired in 1974. He built up a strong emulsion group at Milan, making major contributions to the "G-stack" and other collaborations flying emulsions on balloons. He was always looking for new challenges in physics and advances in experimental techniques. On returning from a visit to Rossi at MIT in 1960, he showed his group a new detector made of silicon, saying "think what you can do with this". They did, and established an expertise that later became the basis for Milan's major contribution to the central detector for the DELPHI experiment at LEP.

As machines replaced cosmic rays as a source for particle physics, and while maintaining a major presence for his group at CERN, Beppo turned to other techniques to continue his interest in cosmic rays, first with balloon-borne spark chambers and then adapting these to flights on satellites. Both Beppo and Connie were influential members of advisory and scheduling bodies for the European Space Research Organisation and together, as one contributor puts it, they pushed Italy into a leading position in astronomy. Milan was a "power house" for space research, with leading roles in two satellite experiments that mapped the sky for X-ray and gamma-ray sources: COS-B launched in 1975 and Beppo-SAX in 1996. Beppo maintained his interest in the design of the latter until his death in 1993, when it was named after him. Connie died in 2004.

Research into the origins of intense gamma-ray bursts (GRBs) – by far the brightest events known – is a scientific legacy of Beppo still very much alive. Until Beppo-SAX made the first accurate locations in 1997, no GRB had been associated with a visible galaxy. His most long-lasting legacies, however, are the young scientists who entered research in his care: his irrepressible enthusiasm inspired them; his lateral, dialectical probing tested their ideas; and his quick wit, wide cultural interests in art, literature and thoughts on "the film I saw last night" entertained them. This collection of essays portrays a complex personality for whom life was never dull, who was always ready to "brain storm" with colleagues, and who experienced the excitement of discovery in his research.

One question remains: why didn't he share one of the two Nobel prizes, Blackett's in 1948 or Powell's in 1950?
John Mulvey, Oxford.

VIEWPOINT

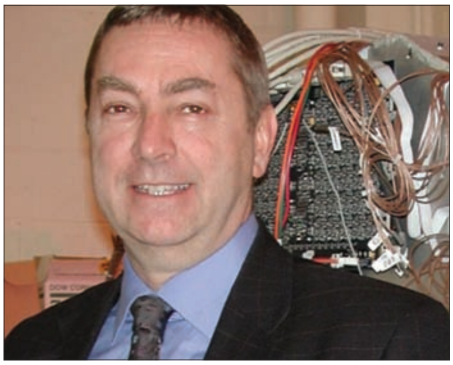
A new challenge for particle physics

TRIUMF's new director **Nigel Lockyer** looks to the future of co-operation in particle physics, and Canada's role in this increasingly global adventure.

Particle physics often describes itself, and correctly so, as having brought countries and people together that previously had been unable to co-operate with each other. In Europe, CERN was born out of a desire for co-operation. This was evident later, for example, when Russian and Chinese scientists worked well together within the US throughout the Cold War. This spirit of connection across national boundaries led to success for our science – and for us all as scientists. The strong innate desire to understand our universe transcends our differences. Our field was in many ways, or so we like to say, the first and most successful model in modern international relations. CERN embodies this co-operation.

Nowadays, however, we cannot rest on our laurels. This co-operation is happening in almost every other field of research; international facilities and multinational teams of researchers are no longer unique to particle physics. So what is the next level of co-operation for us? To some it might be obvious. We should continue to strive for a seamless global vision of science projects, and we should distribute those projects around the world so as to maximize the benefits of science in all countries, large or small, rich or poor. The ITER and LHC projects perhaps exemplify global projects: the world unites to select, design, build and operate a project. Particle physicists, as everyone knows, are considering another one, an International Linear Collider (ILC).

The Global Design Effort (GDE) for an ILC is not "flat" globally, but is a merging of regions. The world has been divided into three geographical areas: Asia, the Americas and Europe. In this mixture, Canada is an interesting case study. TRIUMF, Canada's National Laboratory for Particle and Nuclear Physics is located in Vancouver, on the Asia–Pacific rim, yet only a few miles north of the US border. TRIUMF, though a small laboratory, hosts more than 550 scientists, engineers, technicians, postdoctoral fellows



and students, and more than 1000 active users from Canada, the US and around the world. Historically, TRIUMF and the Canadian particle-physics community have made significant intellectual contributions to the major projects – both on the accelerator side and detector-physics side – in Europe at DESY with HERA and ZEUS, LHC and ATLAS at CERN, and most recently in Japan with T2K at JPARC. Canadian particle physicists have also been active in experiments in the US, such as SLD and BaBar at SLAC, CDF and D0 at Fermilab and rare-kaon experiments at Brookhaven National Laboratory.

TRIUMF also has a world-leading internal radioactive-beam programme using the ISOL technique, familiar at CERN's ISOLDE. TRIUMF's nuclear physicists are collaborating with China and India and have strong ties to France (Ganil), Germany (GSI), the UK and Japan. TRIUMF is truly global, reflecting that Canada is close to Europe in culture, close to the US geographically and culturally, and is on the Asia–Pacific rim. Canada also continues to merge the culture of nuclear and particle physics, just as CERN is doing at the LHC with ALICE, ATLAS and CMS. A good example is the Sudbury Neutrino Observatory (SNO; p26), where particle and nuclear physicists came together and did great science. SNOLAB will also merge nuclear and particle physics to pursue neutrino and dark-matter searches (p19). TRIUMF's infrastructure and technical resources allowed Canadian physicists to help build SNO and will be important in the future for experiments at SNOLAB.

TRIUMF is not yet fully engaged in the ILC effort. Given its history, it is obvious that it will want to participate significantly. Canadian particle physicists are big proponents of an ILC and believe that it is a great opportunity and that it has tremendous discovery potential. However, the area of TRIUMF's involvement and with which regions it will partner is under discussion.

One fact remains: involvement in any international science project must also feed back to help the internal national programmes. Advances in accelerator technology and detector development for the LHC help the entire national science programme, including nuclear physics, life sciences and condensed matter physics. ILC and superconducting radio-frequency (SRF) development will also be important for Canada and TRIUMF's internal programmes. The latest ILC technology will bootstrap other vanguard technical developments in each country just as we hope that the globally distributed computing for the LHC, such as TRIUMF's Tier-1 centre, will have a similar impact.

A strong national science programme supports educational advances and is necessary for innovation and economic prosperity. We should keep this in mind as the world considers the ILC and other large projects, such as next-generation neutrino observatories or underground laboratories. TRIUMF's and Canada's strategy is to develop niches of national expertise while participating in exciting international science projects such as the LHC and ILC. The development of such niches is essential to the future prosperity of our field.

All of this will require strategic regional and global planning in particle and nuclear physics. Surely, we are up for this challenge!

After investing in ATLAS and LHC for many years, Canada and TRIUMF are looking forward to a decade or more of great discoveries.

Nigel Lockyer, TRIUMF director from 1 May.