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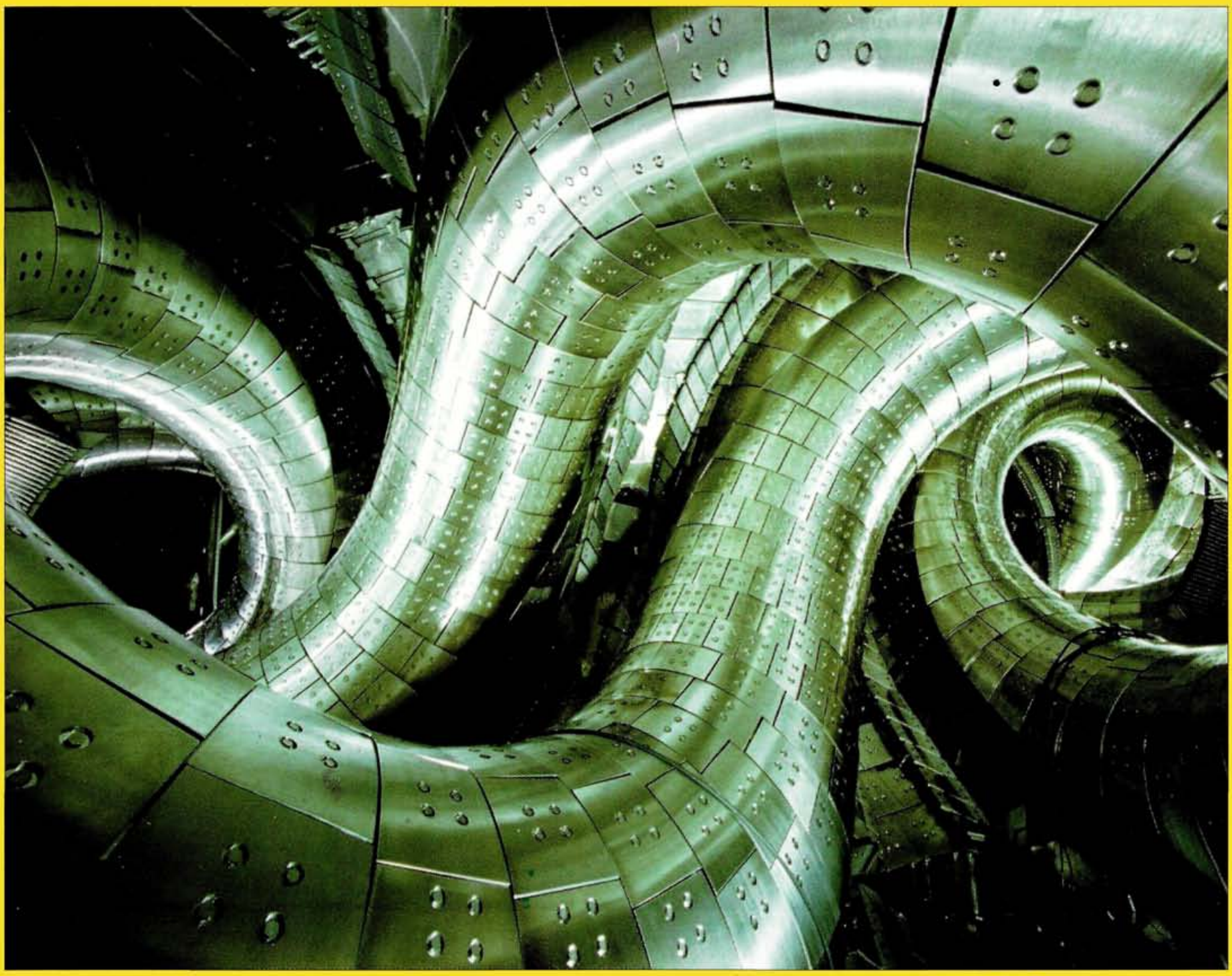

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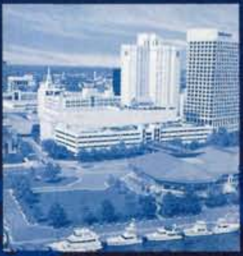

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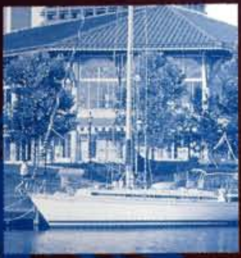

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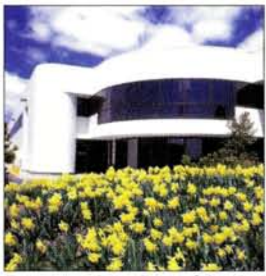
New CERN-US data link p7


Brookhaven's tradition p24


Jentschke reaches 90 p33

Features

Cover: The Large Helical Device at Japan's National Institute for Fusion Science – the world's largest stellarator fusion device – has seen more than 18 000 h of service. It featured in discussions at the 17th International Conference on Magnet Technology, which was hosted by CERN (p12).

CERN

Dipole magnets transfer to industry

The last CERN-assembled dipole magnet for the forthcoming Large Hadron Collider (LHC) left the laboratory on 18 December, bringing to a close one phase in the new accelerator's construction. From now on, all LHC dipoles will be built entirely by industry.

The LHC will use some 1248 superconducting dipole magnets to keep its proton beams on course. Generating an operating field of up to 8.33 Tesla, these are among the most technologically challenging of LHC components. An intensive prototyping exercise concluded in 2000, when an order was placed for 30 magnets each from three potential suppliers. The collared coils of these magnets have since been arriving at CERN for assembly into cold masses. The first cold masses from each supplier were assembled, welded and finished at CERN's magnet assembly facility while the following ones were assembled and welded at CERN and then returned to the suppliers for finishing. Personnel from industry have been stationed at CERN to be trained in this task.

CERN and Ansaldo personnel pose with the last CERN-assembled LHC dipole as it leaves the laboratory on its way to the Italian company.

CERN has developed a unique automatic process for welding the two 15 m long half-cylinders of each magnet's cold mass. This will ensure the quality, precision and uniformity required. To date, a single hydraulic press at CERN has been used. Now the technique has been perfected, however, and the laboratory has invested in three more presses, one for each of the suppliers building the magnets. The first press to become operational is at the French Alstom-Jeumont consortium, where a magnet was assembled, fully welded and finished at the end of 2001. The others began operation at Noell in Germany and Ansaldo in Italy earlier this year.

Following approval of the dipole magnet contract by CERN Council last December (*CERN Courier* January/February p4), the definitive production schedule is now under discussion with the supplying companies.

BROOKHAVEN

Rare kaon decay tests Standard Model

An experiment at Long Island's Brookhaven laboratory has just reported a long-awaited result: the observation of only the second decay of a positive kaon into a positive pion accompanied by a neutrino and an antineutrino.

The E787 experiment at the laboratory's Alternating Gradient Synchrotron began 12 years ago with the aim of detecting this extremely rare kaon decay. The first sighting was reported four years ago, and some 6 trillion events have since been analysed in the quest for confirmation.

The Standard Model of particle physics forbids the direct decay of positive kaons into positive pions. Instead the decay must proceed via a two-step process involving massive gauge bosons. That's what makes it so rare.

Searching for rare decays: Brookhaven's E787 experiment. (Brookhaven National Laboratory.)

Theory predicts that such two-step decays should occur just a few times for every hundred billion kaon decays. The theoretical uncertainty on rare kaon decays is very small, so measuring them is an important test of the Standard Model, as well as being a sensitive indicator for new physics.

A new collaboration, known as KOPIO, has formed round the core of E787 to study another rare kaon decay – that of the long-lived neutral kaon to a neutral pion accompanied by a pair of neutrinos. KOPIO has support from Canada and Japan and is awaiting congressional approval in the US for National Science Foundation funding.

GRENOBLE

Quantum gravity comes in from the cold

Gravity and quantum mechanics rarely mix in laboratory circles. The weakness of the gravitational interaction makes measuring its effects difficult at the quantum level. However, researchers at the Institut Laue-Langevin (ILL) in Grenoble, France, have now observed quantum effects of gravity on ultracold neutrons trapped in the Earth's gravitational field. Their technique relies on bouncing neutrons off a reflective surface and observing quantization in the height of the bounce.

The key to the experiment was using ultracold neutrons from the ILL reactor. Neutrons do not bounce, except when they strike a surface at very grazing incidence. Instead, they are absorbed or transmitted. However, by firing neutrons with a velocity of less than 8 cm/s over a horizontal mirror, the ILL researchers were able to reduce the vertical component of the neutrons' velocity as they fell under gravity to just 1.7 cm/s. These neutrons bounced along the mirror like flat pebbles across a pond until they were captured by a detector at the far end of the mirror. A neutron absorber could be positioned at varying heights above the mirror, allowing the researchers to identify the lowest-energy neutrons passing through the apparatus.


Quantum states: a team including (left to right) Valery Nesvizhevsky, Hans Boerner and Alexander Petukhov, seen here with their apparatus, has observed energy quantization in a gravitational field.

The ILL apparatus behaved as a neutron trap, bound from below by the mirror and from above by gravity. According to quantum mechanics, neutrons in such a trap should occupy discrete gravitational energy levels just as electrons trapped by nuclei occupy discrete electromagnetic energy levels.

This result shows that the lowest level occupied by neutrons in the trap is 1.41×10^{-12} eV. Comparison with the minimum energy for an electron in a hydrogen atom, 13.6 eV, shows why the quantization of energy in a gravitational potential has not been seen before.

The next step is to use a more intense beam and a trap mirrored on all sides to prolong the period of entrapment and thus improve the resolution of the apparatus. This will allow a precision test of the equivalence between gravitational and inertial mass.

Further reading

Nesvizhevsky *et al. Nature* **415** 297.

NEUTRINOS

Team reports neutrinoless double beta decay

Scientists at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany, have reported evidence of neutrinoless double beta decay. This result comes from members of the long-running Heidelberg–Moscow double beta decay experiment at Italy's Gran Sasso underground laboratory. Neutrinoless double beta decay violates lepton number conservation, a fundamental tenet of particle physics. If confirmed, the consequences for particle physics will be profound.

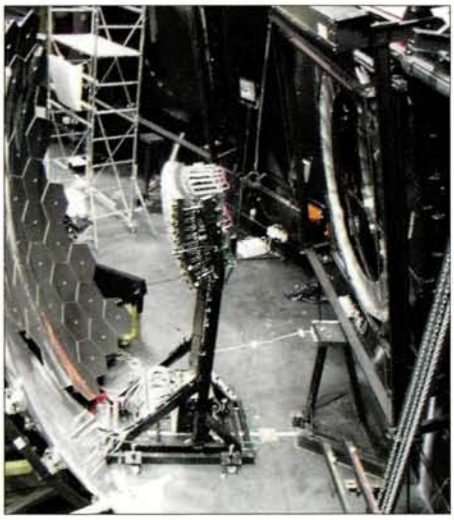
In the conventional picture of particle physics, neutrinos and antineutrinos are distinct. Beta decay proceeds via the transformation of a neutron into a proton with the emission of a neutrino and an electron. However, if the neutrino is its own antiparticle, a rather more exotic process becomes possible. In this case, two successive neutron decays could occur, with the neutrino emitted by the first being absorbed by the second. Two electrons would emerge from the nucleus with no neutrinos, leaving a nucleus that contains two more protons than the original.


The Heidelberg–Moscow double beta decay experiment at the Gran Sasso laboratory.

In the latest paper from the Heidelberg–Moscow collaboration (2001 *Modern Physics Letters A* **16 (37)** 2409–2420), the authors claim evidence for neutrinoless double beta decay with a half-life of around 1.5×10^{25} years from 10 years of running with an enriched sample of germanium-76. This would be compatible with a neutrino mass of around 0.4 eV, which is difficult to reconcile with neutrino mass results from other experiments and would require a special neutrino mass scenario. A previous limit from this experiment was reported in an earlier issue of *CERN Courier* (January/February 2000 p8).

COSMIC RAYS

Pierre Auger Observatory in action



Top: curious cows inspect an Auger surface detector station on the Pampa Amarilla. Left: an Auger fluorescence telescope. The mirror is visible on the left with the camera in the middle and the aperture window to the right. The Auger array combines fluorescence detectors with a large-area array.

On a cold, clear night last May the shutters rolled away from the aperture window. The Pierre Auger Observatory's newly completed air-fluorescence telescope was now overlooking a vast expanse of Argentine desert. Experimenters switched on the photomultiplier tubes and moments later they watched as the first cosmic-ray air shower appeared on the event display. The beautiful, nearly noise-free images represented an important milestone for the Auger collaboration in its study of the mysteries of the highest-energy cosmic rays.

Seven months later an even more dramatic event demonstrated the unique strength of the Auger Observatory. By then the first particle detectors of an extensive surface array were in operation. In the early hours of 8 December, the fluorescence detector and the surface array recorded a single shower as it cascaded through the air and splashed into the array below. This shower, captured by two quite different but complementary techniques, was transmitted to collaborators around the world. It demonstrated beyond doubt that the detectors, trigger, timing, data communications and data acquisition systems were working as designed.

However, there could only be a brief moment of celebration. Ahead lay the daunting task of deploying 1600 surface detector stations over 3000 sq. km of desert, and a total of 30 fluorescence telescopes to overlook this array. The observatory needs such a large aperture to gather enough of the very-high-energy cosmic-ray events to probe their origin. At such energies, cosmic -ray particles are extremely rare. Above 10^{19} eV there is just one cosmic -ray particle per square kilometre, per steradian, per year. Above 10^{20} eV there is only one per square kilometre, per steradian, per century.

The quest for the source of the highest-energy cosmic rays is one of the most interesting problems in astrophysics. Following the discovery of the cosmic microwave background in 1965, Greisen and, independently, Zatsepin and Kuzmin realized that this background radiation would make space opaque to cosmic rays of very high energy. Nevertheless, over the past 30 years, several tens of events have been recorded with energies of more than the Greisen, Zatsepin, Kuzmin (GZK) cut-off, which starts at about 5×10^{19} eV, including a number above 10^{20} eV. The cosmic acceleration mechanism for achieving these energies is not known. Because of the GZK cut-off, these particles must come from nearby – less than about 50 megaparsecs. Yet even though particles of these energies are only slightly deflected by galactic and extragalactic magnetic fields, none clearly points to a source sufficiently violent to be a candidate.

The two common detection techniques for cosmic rays both use the Earth's atmosphere, a remarkably effective calorimeter for capturing the great energy of these particles. The traditional means is an array of particle detectors that measure ionizing radiation in a plastic scintillator, or Cerenkov light in a water tank. The other technique was developed in the 1980s by a University of Utah-led group. They used a set of stationary telescopes in their "fly's eye" to record the development of showers by gathering the faint fluorescence produced as the shower passes through the atmosphere. Each of these techniques has its own strengths and limitations. The surface detector array depends on a comparison of the shower density distribution to simulations to obtain the energy scale. On the other hand, the surface array has a well defined aperture and can measure several features of the shower. The shower density, the electromagnetic and muon components, the shape of the shower front and the time structure are all useful in obtaining the composition of the primary particles. The fluorescence detector records the development of the shower and can make a more nearly calorimetric measurement of the energy. It can only be used on dark nights, however, and it depends on very careful calibration and an understanding of the attenuation of light in the atmosphere. The Auger Observatory combines the strengths of both techniques.

Two cosmic-ray air shower detectors are currently active. The AGASA surface array near Akeno, Japan, has been taking data for about 20 years. The other detector is the High Resolution Fly's Eye fluorescence detector in

Utah, US. Although the data from the two experiments seem to agree in many respects, recent results show significant differences in the shape of the high end of the energy spectrum. In the next few years the Auger Observatory should be able to resolve these differences using the power of the hybrid detector system to collect a large number of events around the GZK cut-off.

The Auger Observatory has other new and important features. The fluorescence telescope uses Schmidt optics, which, with their aperture stop and corrector lens, allow greater light collection and reduced coma aberration with a spherical mirror. This aperture is sealed with a window that is also an ultraviolet filter for selecting the nitrogen fluorescence lines. As a result, the camera, mirror and all of the electronics are contained in a clean, controlled environment.

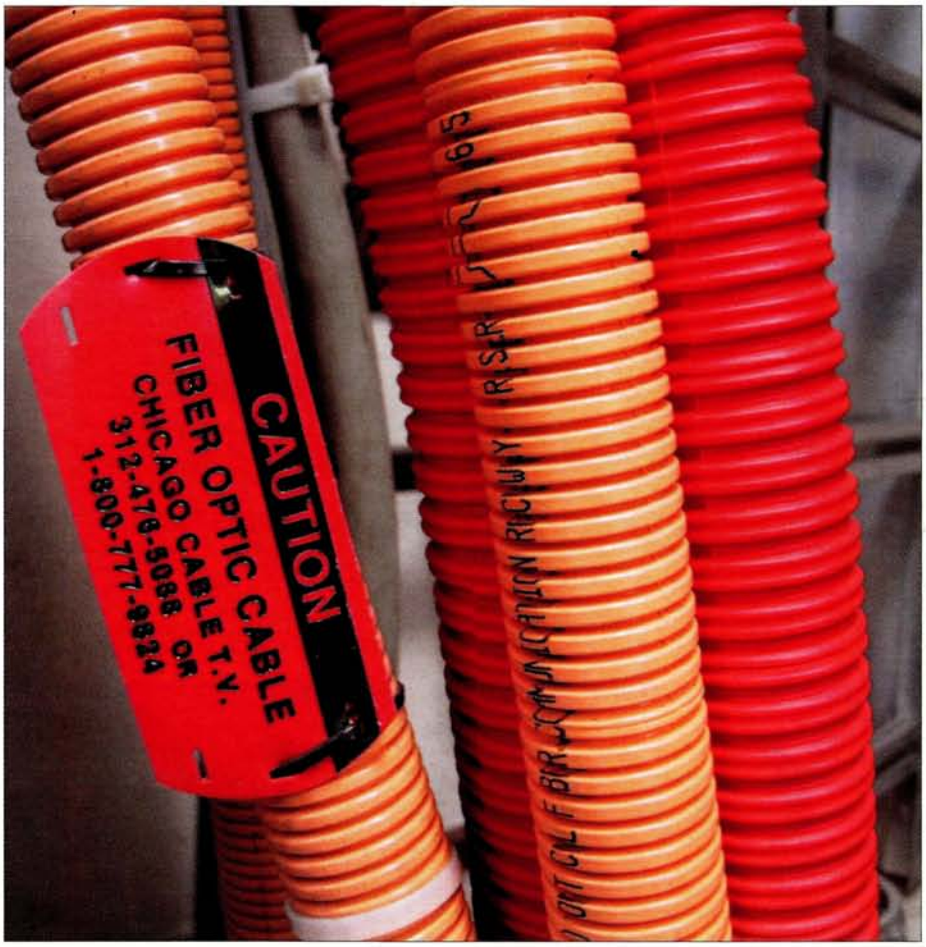
The surface detector stations are 10 000-litre water Cerenkov detectors, each equipped with three 220 mm hemispherical photomultipliers. Each is self-contained, with its own data processing unit, radio transceiver and solar power system. Event triggers indicate the possibility that a large air shower has struck the array. These move by radio to the central data acquisition system, which examines them for interesting events.

The central data acquisition system is on the Auger campus, located at the edge of the array in the town of Malargue. The campus also contains the detector assembly building with electronics shops, mechanical shops and a water purification plant. Besides the data acquisition system, the handsome new Auger centre building contains offices for staff and Auger collaborators, and a visitors' centre. For the scientists and engineers from 50 institutions in 18 countries working at the observatory, Malargue has begun to feel like home. At the inauguration of the new office building, the provincial governor, the mayor and a thousand townspeople came to hear speeches and tour the buildings.

In late October, an international review committee chaired by Werner Hoffman of the Max Planck Institute, Heidelberg, Germany, assembled at the Auger Observatory to evaluate progress. Its report was then received by the Auger Project Finance Board in Washington, which voted to proceed to completion. The collaboration hopes to finish the observatory by the end of 2004.

NETWORKS

New high-speed data link between CERN and the US



Optical cables at Chicago's StarLight™ Internet exchange. StarLight is the emerging optical component of the National Science Foundation-funded STAR TAP™ international interconnection point for advanced research and education networks. (Electronic Visualization Laboratory, University of Illinois, Chicago.)

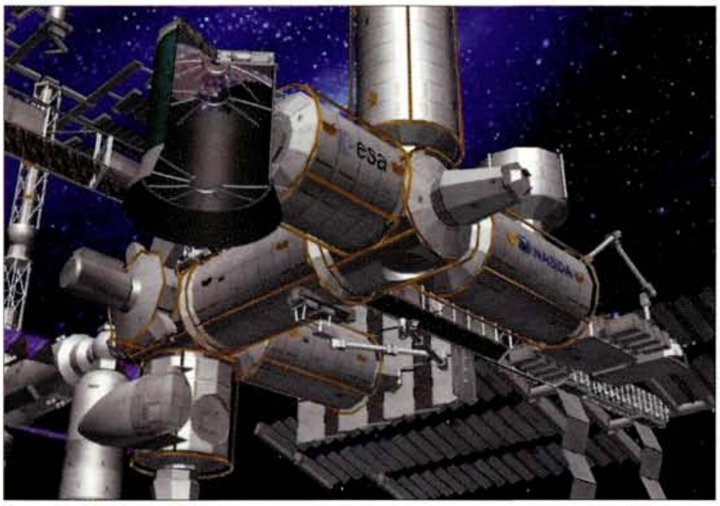
The growth of international collaboration in science was underlined last December by the award of a contract to Dutch telecoms provider KPNQuest for a new transatlantic high-speed data link at 622 Mbps, to replace the existing two 155 Mbps links.

Connecting CERN to StarLight™, the optical component of the STAR TAP™ Internet exchange in Chicago, the new link will be funded by a consortium of the French particle and nuclear physics institute (IN2P3), the US Department of Energy and National Science Foundation, the Canadian high-energy physics community, the World Health Organization and CERN. Research users of transatlantic networking should start to notice the benefits from April 2002.

A second very-high-performance data link operating at 2.5 Gbps, also connecting CERN to StarLight™, is expected to be ordered soon. This is part of the European Union-funded DataTAG (research & technological development for a transatlantic Grid) project, in collaboration with the Department of Energy and National Science Foundation. It will form an important part of the network for the Large Hadron Collider computing Grid (*CERN Courier* November 2001 p5).

EUSO

ESA mission will study ultimate energies



ESA's Extreme Universe Space Observatory, EUSO, will pick up the fluorescence generated by cosmic rays.

Joining the Pierre Auger Observatory (p6) in the long term will be ESA's Extreme Universe Space Observatory (EUSO), which is scheduled to fly on the International Space Station from 2008. Comprising a wide-angle telescope that is sensitive to the ultraviolet region, the EUSO array will look down on Earth, some 400 km below, to pick up the fluorescence that is generated by cosmic rays above the Greisen, Zatsepin, Kuzmin (GKZ) cut-off.

EUSO will take in much larger areas than the Auger Observatory, with its 60° field of view sweeping over 150 000 sq. km of the Earth's atmosphere at every pass. As cosmic-ray showers develop in the atmosphere, light is also generated through the Cherenkov effect, with photons being emitted in a narrow cone that follows the particle trajectories. On reaching the surface this light is reflected, resulting in a terminal flash in the EUSO telescope that will be used to reconstruct the cosmic-ray track.

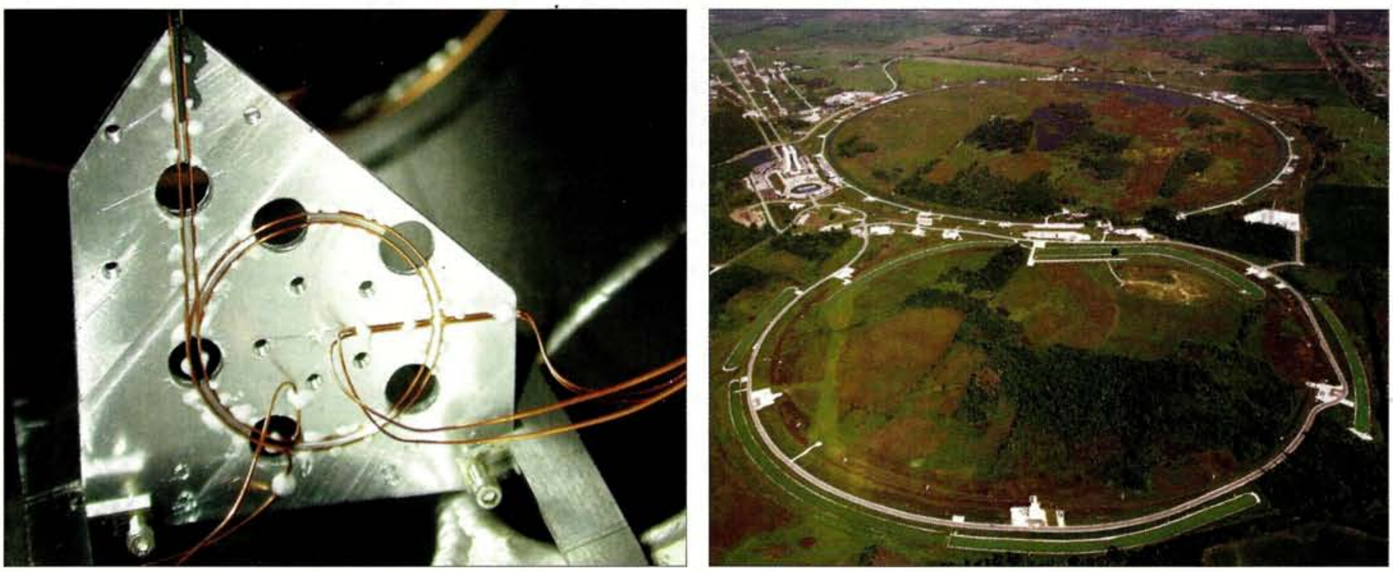
Conceptually simple, the telescope's 2.5 m diameter optics consist of Fresnel lenses that focus light onto a plane surface made up of multinode photomultipliers with 250 000 pixels. Each pixel covers approximately 1 sq. km of the Earth's surface. This resolution is sufficient because at such high energies a cosmic shower can cover dozens of square kilometres when it reaches the Earth.

The total number of excited pixels is governed by the random background noise from residual light on a moonless night. The experiment therefore only takes data when the telescope passes through the Earth's shadow; for the EUSO telescope, night lasts only 45 min and is repeated 16 times every 24 h. In the three years scheduled for the EUSO mission, some 3000 events above the GKZ cut-off are expected.

PHYSICSWATCH

Edited by Archana Sharma

Georgia Tech builds the world's smallest neutral-atom storage ring

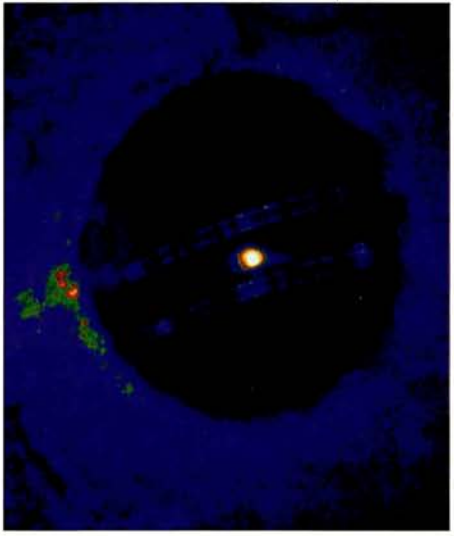


Familiar geometry, different scale: Georgia Tech's Nevatron (left) measures just 2 cm across. Fermilab's Tevatron (right, back), which is more familiar to CERN Courier *readers, has a circumference of nearly 6.5 km. (Georgia Institute of Technology; Fermilab Visual Media Services.)*

Researchers at the Georgia Institute of Technology have demonstrated the first storage ring that is able to confine and guide the flow of ultracold neutral atoms in a circular path. Called the nano-electron-volt neutral-atom storage ring (Nevatron) the ring measures just 2 cm across.

In general, storage rings not only store particles but also serve to define an energy and trajectory in so far as the particles are guided round a prescribed track by some kind of magnet system. Particles with the wrong energy would fly away. Normally the ring's magnets exert themselves by acting on the particles' electric charge. Neutral atoms do not have a net charge but they can possess a net dipole moment that, if the atom is moving slowly enough, is sufficient for guidance. The Nevatron is a circular waveguide that uses magnetic fields from tiny electrical wires to direct low-energy atoms.

In contrast with high-energy particle storage rings, in which the goal is to increase the energy of the confined particles up to and beyond the tera-electron-volt scale, the researchers at Georgia Tech are interested in the opposite – using ultracold atoms with nano-electron-volt energies. Their experiment takes place within a vacuum chamber. First, a standard magneto-optical trap uses a combination of magnetic fields and intense laser beams to confine a few million atoms of rubidium while reducing their speed to a crawl – less than 10 cm/s.



Cold storage: the bright spot in the centre of this false-colour image shows rubidium atoms between the Nevatron's guide wires 840 μm apart.

When the atoms in the trap reach the appropriate temperature – about 3 μK – the magnetic fields and laser beams confining them are switched off. That allows the cold atoms to flow by gravity into a "funnel" made up of two current-carrying wires about 1 mm apart. The funnel guides the atoms into the storage ring where they are confined by magnetic fields created by parallel wires, each of which carries a few amps of electric current.

So far, swarms of 1 million rubidium atoms have made as many as seven circuits around the ring, moving at speeds of 1 m/s. It is early days yet, but the ultimate goal of the Georgia Tech team is to do for uncharged atoms what optical fibre has done for light. In one potential application, the 2 cm storage ring could serve as the foundation for a miniaturized atom interferometer that would improve the accuracy of inertial guidance systems used in commercial aircraft.

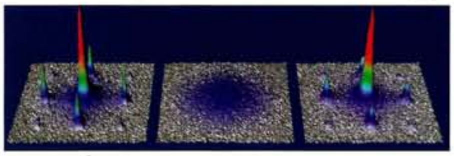
Reference

J A Sauer *et al.* 2001 *Phys. Rev. Letts.* **87** 270401.

Phase transition behaves as quantum switch

German researchers have created a new type of matter by trapping globules of Bose–Einstein condensate in a regular array of indentations. Bose–Einstein condensates are quantum liquids that exist only at very low temperatures where the thermal motion of atoms is small enough to reveal their wave-like properties. By varying the size of the indentations, the team induced a phase transition.

The researchers started with a vapour of Bose–Einstein condensate consisting of about 100 000 rubidium atoms confined to a small volume by a magnetic field and cooled to a few billionths of a degree above absolute zero. All of the atoms in a Bose–Einstein condensate are coherent, acting like a single giant particle. Consequently, the vapour becomes a superfluid. If it moves, it does so en masse. Superfluids have no viscosity because one atom cannot be slowed down without slowing down all of them.



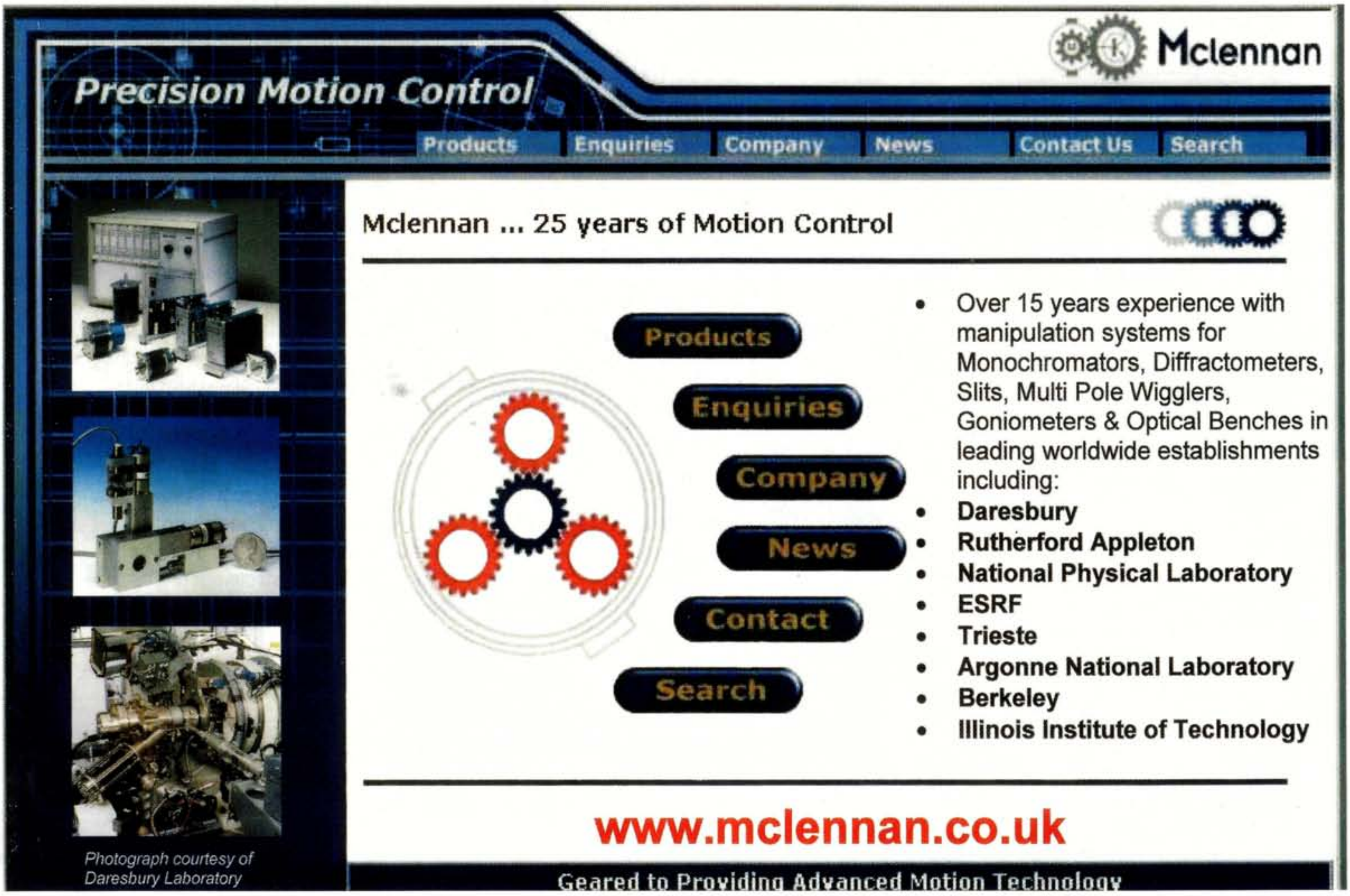
Quantum switch: a phase transition induced in a Bose–Einstein condensate. (Max Planck Institute for Quantum Optics.)

The superfluid was then placed in an optical lattice made up of the interference pattern between several laser beams. The atoms moved easily around the lattice's 150 000 valleys. However, as the lattice was made more intense – with deeper valleys and higher peaks – there came a point at which the fluid became stuck – it ceased to be a superfluid and the localized blobs of rubidium vapour were no longer coherent with one another. This trapped state is called a Mott insulator after the British physicist Neville Mott who first observed a similar effect in semiconductors in the 1960s. Reducing the strength of the optical lattice led to the reappearance of the Bose–Einstein condensate, demonstrating that the transition is reversible.

The sharp change between a coherent condensate and a non-coherent Mott insulator state is loosely analogous to the way a magnet can become non-magnetic when heated, but heat plays no part in the change in the quantum fluid. That is driven by Heisenberg's uncertainty principle, which stipulates that when atoms get trapped in particular valleys, they must lose their coherence. Their wave-like quantum state is no longer like the rippling surface of a single ocean. Instead it is like many independently rippling little lakes. The ability to switch between quantum states in this way is a key ingredient of many proposals for quantum computers.

Reference

M Greiner, O Mandel, T Esslinger, T W Hansch and I Bloch 2002 *Nature* **415** 39–44.



ASTROWATCH

Guest editor Marc Türler

Milky Way reveals new information about the density of baryonic matter in the universe

Ordinary matter composed of baryons – essentially protons and neutrons – is responsible for only a tenth of the gravitation observed in the universe. This result has just been independently confirmed by measuring the abundance of helium-3 ions in our galaxy.

The abundance of helium-3 is observed by measurements of its 8.665 GHz spin-flip transition. Observations made using the US National Radio Astronomy Observatory's radiotelescope at Green Bank, West Virginia, show that the concentration of helium-3 is almost the same in star-forming regions as in the rest of the Milky Way. This suggests that stars enrich the interstellar medium with helium-3 very little and therefore that the quantity of helium-3 in our galaxy has hardly increased since the Big Bang.

Left: the US National Radio Astronomy Observatory's 140 ft radiotelescope at Green Bank, West Virginia. (NRAO/AUI.) Right: the Milky Way is yielding information about baryonic matter density in the universe. (John Gleason, Celestial Images.)

The abundance of baryons with respect to photons in the universe is linked directly to the concentration of helium-3 relative to hydrogen. Measurements of helium-3 in our galaxy indicate that ordinary matter – in the form of baryons – represents only about 4% of the total matter and energy content of the universe. The rest of the universe appears to consist of non-baryonic dark matter of an as yet unknown nature and "dark energy", the repulsive force that is considered to be responsible for accelerating the rate of expansion of the universe (*CERN Courier* June 2001 p11).

Reference

T M Bania, Robert T Rood and Dana S Balser *Nature* 2002 **415** 54.

Picture of the month

The Chandra satellite reveals hundreds of X-ray sources at the centre of our galaxy 26 000 light-years from the Earth. The Chandra satellite's exceptional resolution has made it possible to separate the contribution of point sources from diffuse X-ray emission. These sources are mostly X-ray binaries consisting of a star and a compact object – a white dwarf, a neutron star or a black hole – that robs the star of matter. This mosaic of 30 images, taken in July 2001, extends over 2° (900 light-years) along the galactic plane. The colours represent the energy of the X-ray radiation, which increases from 1–3 keV (red) to 5–8 keV (blue; Q D Wang, E V Gotthelf and C C Lang 2002 *Nature* 415 148).

CERN hosts major magnet conference

Despite the events of 11 September, 655 out of a record 700 enrolled delegates managed to attend the 17th International Conference on Magnet Technology, MT-17, held that month at the Geneva International Conference Centre. They were rewarded with a varied programme covering topics from particle accelerators to maglev trains.

Inside the Large Helical Device at Japan's National Institute for Fusion Science.

Represented in the MT-17 delegate list were 27 countries, giving an indication of the growing importance of magnet technology. An industrial exhibition at the conference was attended by 30 companies. A busy schedule saw 12 invited papers being delivered in plenary sessions; 34 invited and 79 contributed papers in parallel sessions; and 440 poster presentations. Doing justice to such a wide range of presentations, many of outstanding quality, is an impossible task; so the conference proceedings, which are due to be published in the spring as a dedicated issue of the Institute of Electrical and Electronic Engineers' (IEEE) *Transactions on Superconductivity*, will give the full picture.

High-energy physics and astrophysics

As at previous MT conferences, high-energy physics and fusion dominated the intermediate-field strength (1–10 Tesla) applications. High-energy physics is at present a major user of magnets and it drives their development. Several interesting presentations covered the magnets of CERN's 27 km circumference Large Hadron Collider (LHC), which is currently under construction. The laboratory's Lucio Rossi revisited the basic concepts of superconducting accelerator magnet construction and reported on the progress of the industrial production of LHC dipoles (p4). The machine's insertion magnets, which are being produced at several sites around the world (*CERN Courier* October 2001 p28), were presented by Ranko Ostojic of CERN, Sandor Feher of Fermilab, Toru Ogitsu of Japan's KEK and Erich Willen of Brookhaven. In his plenary talk on the status of the LHC, project director Lyn Evans reported on the successful powering of a complete and final LHC magnet string. Speaking about the LHC experiments, Herman ten Kate, Alain Hervé, Wilfried Flegel and Detlef Swoboda, all from CERN, described good progress in magnet construction for ATLAS, CMS, LHCb and ALICE respectively.

Moving away from the host laboratory, Michael Harrison from Brookhaven in the US discussed the successful magnet performance during the commissioning of the Relativistic Heavy-Ion Collider (*CERN Courier* July/August 2000 p5). Reports on the use of permanent magnets in the Fermilab recycler showed a remarkable progress in solving the problems of strength adjustment, thermal stability and homogeneity. The future for particle accelerators was outlined by several speakers, including Steve Gourlay of the Lawrence Berkeley National Laboratory and Peter Limon of Fermilab, who reported on the different designs and high-field magnet developments for a possible future Very Large Hadron Collider – a project that would dwarf CERN's LHC.

The gradual convergence of particle physics and astrophysics is mirrored in a move towards common technologies. This is certainly true for magnets, as KEK's Akira Yamamoto made clear in his talk about the successful construction of light-superconducting magnets for particle detectors used in stratospheric balloons and in orbiting satellites.

The status and perspectives of magnetically confined fusion were discussed in a plenary talk by Michel Chatelier of the French Atomic Energy Commission. Other interesting presentations on fusion covered tokamak projects in China, Japan and Korea, and the successful test of central solenoid and toroidal field model coils for the

Left: MT-17 saw a record attendance for a magnet technology conference. Right: Maurice Bourquin, president of CERN Council and rector of Geneva University, brought the conference proceedings to a close.

international project for an experimental thermonuclear reactor.

Takashi Satow of the Japanese National Institute for Fusion Science gave a report on 18 000 h of operational experience with the institute's Large Helical Device – a fusion device built around 3–4 Tesla superconducting magnets. He drew particular attention to the stable and reliable performance of the reactor's superconducting magnets fed via flexible superconducting bus-lines. The very-high-field approach to fusion was debated by Bruno Coppi of the Massachusetts Institute of Technology, who discussed proposals for compact devices with fields of up to 21 Tesla.

Magnetic resonance and high fields

Nuclear Magnetic Resonance (NMR) is finding more and more applications in research and industry. Impressive results and forthcoming challenges in high-resolution NMR spectroscopy in the study of protein structures and other biophysics and molecular biology applications were masterfully illustrated by Gerhard Wider of the Institute of Molecular Biology and Biophysics at ETH in Zurich. Considerable advances are promised by the development of high-field NMR systems, which will also benefit magnetic resonance imaging (MRI).

Alan Street of Oxford Instruments discussed the development of a 900 MHz, 21.1 Tesla system. Hitoshi Wada and Tsukasa Kiyoshi of the Japanese National Institute for Materials Science reported that, in the quest for higher-resolution 1 GHz, 23.5 Tesla systems, the Tsukuba magnet laboratory at the institute has already experimentally generated a 23.4 Tesla field using inserts of the high-temperature superconductor Bi-2212 inside a 21.7 Tesla magnet. An NMR magnet with low-temperature superconductor outer coils and an inner coil with a $(NbTi)_3$ Sn conductor is operational at 21.6 Tesla in a persistent mode. The inner coil will be replaced soon by a Bi-2212 coil, which is currently being manufactured and is expected to raise the field to the 23.5 Tesla target.

MRI is already widely used in medical diagnostics and it is finding important new applications with the increased precision and resolution provided by higher magnetic fields. Functional MRI (fMRI) has become the leading research tool for the non-invasive acquisition of physiological and biochemical information. The most striking example is the mapping of brain function – monitoring neuronal activity by measuring the concentration of oxygen and other molecules related to neuron activity. Yuri Popowski of Geneva University Hospital described a novel use of precision MRI monitoring during surgical and radiation cancer therapy, leading to the more accurate destruction of tumours with no, or reduced, damage to nearby healthy tissues.

Progress in the generation of extremely high magnetic fields for research were outlined by Walter Joss of the Grenoble High Magnetic Field Laboratory, for resistive magnets, and by Alessandro Bonito Oliva of Oxford Instruments, for hybrid magnets. Mark Bird, on behalf of the director of the US National High Magnetic Field Laboratory (NHMFL), Jack Crow, reviewed world facilities and future possibilities: DC fields of 40 Tesla are already available at NHMFL's Tallahassee site. Charles Swenson, also of NHMFL, discussed the limitations, achievements and prospects found in the generation of pulsed high fields. Last year, the long pulse, 60 Tesla magnet at NHMFL's Los Alamos site underwent a catastrophic failure, but the cause is now known and a successor magnet is already planned. A pulsed magnet generating fields of up to 60 Tesla for 15 ms is at present in operation at the Grenoble High Magnetic Field Laboratory. Ambitious plans were also presented for an 80 Tesla pulsed magnet in Europe to be financed by the European Union and to be installed at the Laboratoire National des Champs Magnétiques Pulsés in Toulouse as well as for a 100 Tesla non-destructive magnet to be installed at NHMFL in the US.

Magnets in society

An area that attracts much interest from industry is magnetic levitated (maglev) transport. Eisuke Masada of Tokyo University and Marcel Jufer of the Swiss Ecole Polytechnique Fédérale de Lausanne discussed the present state of projects, the different technologies available and the economic aspects. Construction costs for maglev systems are currently estimated to be about 20% higher than for conventional railways, but this has to be weighed against the advantages of higher speeds – 400–600 km/h – and improved comfort for passengers that are offered by maglev systems. The speakers presented the status of maglev train projects under construction or proposed in China, Germany, Japan, Switzerland and the US.

One session was devoted to the status and development of power applications of superconductors around the world. Three speakers – Risto Mikkonen of Tampere University of Technology, Shirabe Akita from the Central Research Institute of the Electric Power Industry of Japan and Christopher Rey of DuPont Superconductivity – outlined the picture in Europe, Japan and the US respectively. The first commercial application is superconducting magnetic-energy-storage, which currently uses low-temperature superconductors for the magnet windings and high-temperature superconductors for the current leads to reduce heat intake into the cryogenic system. However, in a review, Alex Malozemoff of American Superconductor (ASC) pointed out that, although several significant prototypes of transformers, current limiters, motors, generators and power cables fabricated with low-temperature superconductors have worked perfectly well, it will be only through the use of high-temperature super- ▷

Magnet technology at the LHC

As the Large Hadron Collider is the world's largest single superconducting magnet project, CERN was a logical host for MT-17. Some 230 delegates went on a post-conference visit to the laboratory's magnet assembly and test facilities, where they could see cutting-edge magnet technology in action.

The main lattice of CERN's new accelerator (*CERN Courier* June 2001 p15) will be composed of 1248 superconducting dipoles accompanied by 392 sections containing focusing quadrupoles. As well as these main magnets there is an array of sextupole, octupole and decapole corrector magnets. In addition, many specialized magnets, known as insertions, will be used. These will perform specific tasks, such as injecting and ejecting beams, and providing the final focus before the collision points (*CERN Courier* October 2001 p28).

The LHC's experiments – notably ATLAS and CMS – will also be shining examples of magnet technology in action. ATLAS is building an air-cored toroid system of unprecedented proportions (*CERN Courier* December 2000 p6), while CMS is built round the world's largest superconducting solenoid (*CERN Courier* November 1999 p7).

conductors operating at temperatures of 30–80 K that superconducting components will find applications in the power grids. For this the high-temperature superconductor wire industry has still much to do to improve performance and reduce cost.

David Larbalestier from the University of Wisconsin and Geneva University's René Flukiger outlined development perspectives for low-temperature and high-temperature superconductors respectively. Juergen Kellers and Larry Masur of ASC spoke of the next technological and economic targets, and milestones to be met in the industrial production of high-temperature superconductors.

The conference included contributions too numerous to discuss here that dealt with magnetic and structural design and measurement; superconducting, resistive, structural and magnetic materials; and cryogenics. Well known experts from academia and industry took part in a panel discussion on superconducting materials to identify the main medium-term development needs for applications. Their conclusions will appear in a report that is currently being prepared.

Highlights of the conference included opening addresses by Carlo Lamprecht, president of the Geneva State Council, and CERN director-general Luciano Maiani, as well as the presentation of the IEEE Council on Superconductivity award to Peter Komarek for a lifetime's contribution to the science and applications of superconducting magnets (*CERN Courier* November 2001 p29). The conference was brought to a close by Maurice Bourquin, president of CERN Council and rector of Geneva University.

Morioka, Japan, was confirmed as the site of MT-18 – the next International Conference on Magnet Technology – which will be held in October 2003 and chaired by Hitoshi Wada. MT-19 will be held in 2005 in Genoa, Italy.

Romeo Perin, *MT-17 chairman.*

Climbing out of the nuclear valley

With nuclear physics largely confined to a narrow band of stable isotopes, a new US machine aims to provide a wider nuclear perspective.

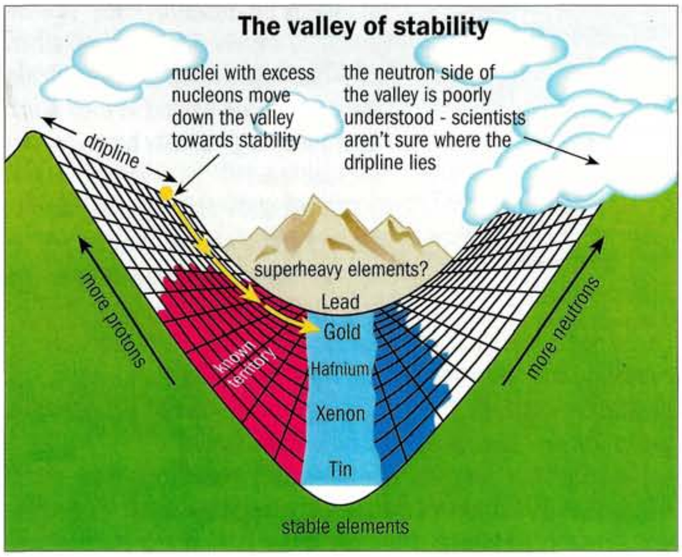


Fig. 1: The "valley of stability" – new nuclear machines such as the Rare Isotope Accelerator will open up studies of nuclear phenomena using beams of short-lived isotopes, which form the high "walls" of the valley.

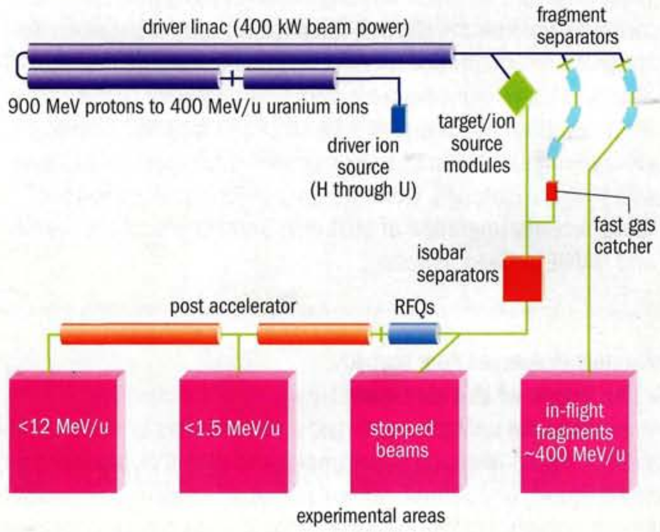


Fig. 2: A schematic layout of the Rare Isotope Accelerator facility showing all of the major components, including the four experimental areas for research at a number of different beam energies.

Though physicists have probed the subatomic world for many decades, it is easy to forget that our understanding of the atomic nucleus is largely limited to studies with stable isotopes. An innovative, exotic-beam facility now under consideration – the Rare Isotope Accelerator (RIA) – could extend the horizons of nuclear physics greatly. RIA will enable broader-based research with high-quality energetic beams of short-lived isotopes.

Of the thousands of known nuclear species, only about 300 are stable, that is they exist along the so-called "valley of stability". The unstable species forming the valley "walls" – those with an overabundance of protons or neutrons – tend to decay quickly, sometimes within milliseconds.

The Organization for Economic Cooperation and Development's Megascience Forum (*CERN Courier* May 1999 p21) has recognized that beams of exotic radioactive isotopes have the potential to open up important, untapped opportunities for fundamental research, because studies of such ephemeral nuclear species by other means has been at best difficult and in most cases impossible.

Responding to these scientific opportunities, the US Nuclear Science Advisory Committee is recommending RIA as the highest priority for major new construction in its 2001 long-range plan for nuclear science. RIA will provide physicists with a powerful tool to complement the long-standing investigations of unstable nuclei at CERN's ISOLDE and other laboratories. It will augment these other facilities not only by creating, but also by accelerating a range of short-lived nuclei that will provide a panoramic view from atop the "walls", overlooking the "valley of stability". Fundamental research in several fields would be addressed at RIA, including:

- **The nature of nucleonic matter** RIA will allow the close examination of the many nuclei that are very far from stability and about which little is known. Such studies will provide fundamental insights into nuclear structure and interactions that are not ▷

Traditional radioactive beam facilities

The ISOL method for producing, separating and studying the decays of radioactive isotopes has been in use since a pioneering experiment in Copenhagen in 1951. ISOL work has been carried out vigorously at the CERN ISOLDE facility for more than 30 years. Innovative work at Louvain-la-Neuve in Belgium made post-accelerated radioactive beams available.

At TRIUMF in Vancouver a powerful new ISOL-type facility – ISAC – was recently commissioned. It now delivers post-accelerated beams for research (*CERN Courier* July 2001 p21). A post-accelerator was also recently commissioned at CERN's ISOLDE as part of the REX-ISOLDE experiment (*CERN Courier* January p4). Planning and R&D for an advanced ISOL-type radioactive beam facility for Europe is currently in progress (see http://www.ganil.fr/eurisol).

The fragmentation method for the in-flight separation of short-lived rare isotopes was pioneered at the Berkeley Bevalac facility in the late 1970s. One advanced facility – based on the heavy-ion fragmentation method – is under construction at RIKEN in Japan and another is being proposed for GSI in Germany. Both of these new fragmentation facilities plan to use storage rings to expand the types of research that can be done with the rare isotopes. Other fragmentation facilities include those recently upgraded at Michigan State University in the US and GANIL in Caen, France.

A cryostat from the injector of Argonne's ATLAS. It contains six, four-gap, quarter-wave resonators. The RIA linacs use superconducting technology over the ion velocity range of 2–85% of the speed of light. The development of superconducting resonators for RIA is in progress at Argonne, Michigan State and Jefferson Lab.

manifest in species near stability.

- **The origin of the elements** Nearly all of the chemical elements in the universe are forged in the interiors of stars, but the chain of events and even the astrophysical sites that produce them are still poorly understood. RIA will permit researchers to investigate the metamorphoses that nuclei undergo in these cosmic cauldrons.
- **The Standard Model** While high-energy accelerators are needed in direct searches for undiscovered particles like the Higgs boson, physicists will use RIA to explore with greater precision the known subatomic particles and the forces that act on them.
- **Nuclear medicine** A third of all patients hospitalized in the US undergo a nuclear medicine procedure. All such procedures require isotopes that are produced in reactors or small accelerators. RIA will bring a new level of technology for the rapid production and exploration of medical isotopes that have specific physical and chemical properties.

Building RIA will require innovations based on current accelerator technology, and researchers at several US institutions are already working to bridge this gap.

Limitations of current technology

There are currently two methods designed for probing unstable isotopes, each of which is limited in its scope. In the first – isotope separation on line (ISOL) – a driver beam of stable ions strikes a heated target. By means of either fission or spallation, the impact produces unstable nuclei at low energy. This "stopped beam" technique has proved useful in recent investigations into the Standard Model at CERN's ISOLDE (*CERN Courier* July/August 2001 p8). This is a slow process, so many isotopes, especially those of refractory and chemically active elements, decay before they can be reaccelerated for study.

The second method of probing unstable isotopes solves some of the problems but creates others. A driver beam of heavy ions strikes a thinner target of light material, which makes the energetic ions fragment like shrapnel from a fast-moving projectile. These high-energy fragments do not require such time-consuming reacceleration but there is greater beam divergence and energy variation than in beams produced by ISOL. The two methods are considered complementary but, even when both are used, researchers are limited in their ability to produce high-quality beams of rare nuclear species.

RIA will allow physicists to have the best of both worlds, providing them with energetic, high-quality beams of essentially any isotope. An innovation based on the new "fast gas-catcher" technology will be necessary to overcome the limitations of the ISOL and in-flight projectile fragmentation methods. This technology was recently developed and put to use for research at Argonne's ATLAS facility.

The technique magnetically separates exotic ions produced in thin targets and brings them to rest in a fast gas-catcher that is filled with pressurized helium. Normally these ions, which are positively charged, would neutralize themselves by capturing electrons from surrounding atoms. However, helium electrons are the most tightly bound of any element and the stopped ions remain positively charged. They are then extracted and reaccelerated so that all of the ions have uniform energy and small divergence.

The whole process – from target to gas cell to post accelerator – occurs in a matter of milliseconds. This new separation technology, in combination with the powerful new driver and efficient post accelerators, will give physicists high-quality beams of exotic isotopes of all elements from lithium to uranium.

Innovations in accelerator and target technology

Along with an increase in flexibility will come an increase in power – RIA will be able to produce beams of exotic nuclei that are far more intense than any that are available now. One of the secrets of producing this intensity will be the acceleration of more than one "charge state" of ions at a time.

Isotopes are typically stripped of many electrons before they are accelerated into a beam, turning them into positively charged ions. Ordinarily, accelerators have worked best with ions of one specific charge, but many nuclei come out of the ion source and strippers

RIA's technical capabilities

RIA brings together a range of technologies to produce intense and high-quality beams of short-lived radionuclides of all of the chemical elements – from the lightest to the heaviest. The short-lived, rare isotopes are produced by a continuous-wave, superconducting 1.4 GV driver linac that will deliver 400 kW beams of any mass from 900 MeV protons to 400 MeV per nucleon uranium. The schematic layout is shown in figure 2.

The main production mechanisms are spallation and fission of heavy targets by light ions, and in-flight fragmentation or fission of heavy-ion beams.

RIA will provide facilities for research with rare isotopes in four energy regimes (stopped beams; ~1 MeV/nucleon reaccelerated beams; ~10 MeV nucleon reaccelerated beams; ~400 MeV/nucleon secondary beams of in-flight fragments). This flexibility will make RIA a valuable addition to existing exotic beam facilities. RIA is also a potential source of both ultracold neutrons and continuous-wave, high-energy neutron beams for a variety of basic and applied research programmes.

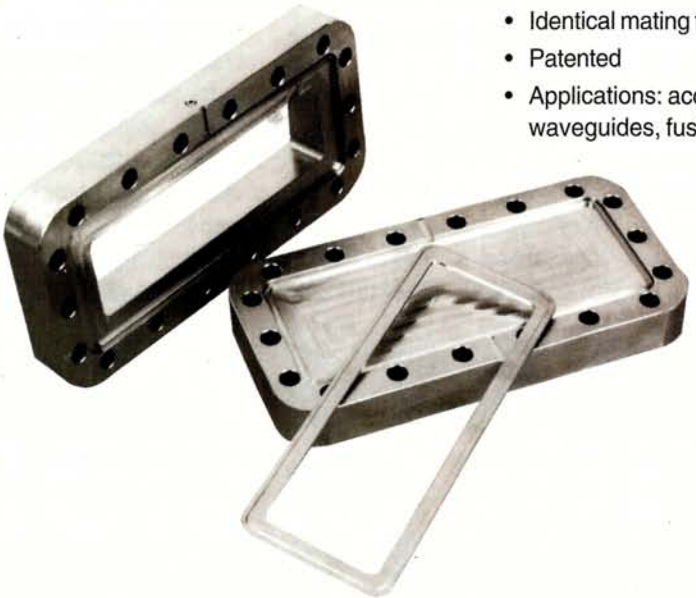
with a greater or smaller number of electrons than desired. Usually a single "charge state" is selected from the mixture – a process that severely limits the available heavy-ion beam intensities.

Argonne scientists have demonstrated that the driver linac can be configured to accelerate several charge states simultaneously. Experiments at ATLAS have confirmed that RIA's beam intensity can be increased eight times by capturing and accelerating multiple charge states after the strippers. Plans have also been worked out to accelerate two charge states directly from the ion source. In combination, this would boost the power of RIA's driver beam by a factor of 16 for the heaviest ions.

Such intense beams would quickly destroy a traditional solid target, so Argonne designers are developing a liquid target that can withstand the beam. Adapting an idea that was originally proposed for removing heat from a fusion reactor, the beam will shine on a stream of liquid lithium, which flows in a closed loop through a heat exchanger to dissipate the high beam power.

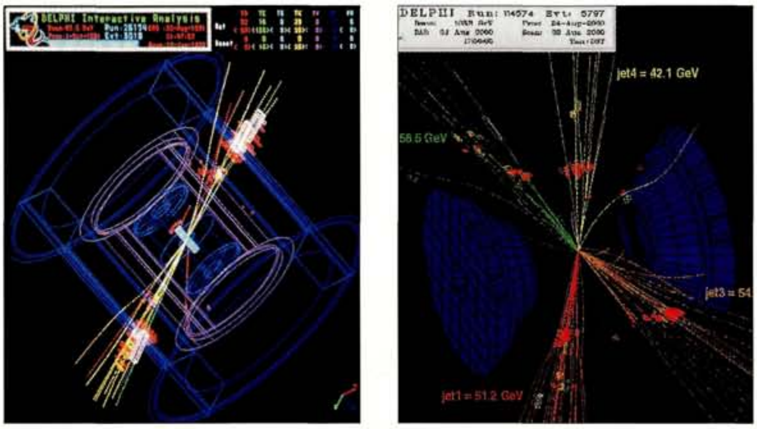
At this time, Argonne and Michigan State University are working together to develop a cost-effective plan for the construction of RIA. A workshop on potential applications of the accelerator was jointly sponsored by Los Alamos and Lawrence Livermore National laboratories in September 2000. Currently, seven US laboratories are participating in RIA research and a national committee is coordinating the ongoing research and development effort. This technical progress will ensure that RIA can achieve the promising scientific goals of the nuclear community.

Chad Boutin, *Argonne National Laboratory.*



Hands-on particles appeal to students

It is not true that particle physics – the underlying mechanisms of the universe – can only be understood after a long and difficult apprenticeship. To reach out and appeal to young students, Erik Johansson, a CERN researcher from Stockholm, prefers to cut through conventional formalism to reveal what happens when elementary particles collide.



Left: a classic Delphi image shows mutually opposite "jets" – closely confined sprays of particles emerging from an electron–positron collision. Right: Delphi's last lap – a tentative Higgs candidate from the final year of operating Delphi.

Elementary particles are the universe's simplest constituents, but their interactions are far from simple. When two elementary particles collide, all sorts of things can happen. Viewed through the eye of a big detector, the outcome is usually a convoluted maze of secondary particles and it is difficult to see at first or even at *n*th glance what is going on. Usually the experiment's computers have to use complex pattern recognition procedures to join up the individual read-out "dots" and reveal the underlying particle tracks. Even then, additional complex analysis is needed.

Occasionally, however, the interactions recorded by the detector are particularly simple, especially for collision scenarios like those at CERN's LEP collider, which from 1989 to 2001 threw high-energy beams of electrons and positrons together.

Electrons and positrons, unlike protons, are truly elementary and contain no constituents (at least as far as we know). They are also particle and antiparticle of each other, and they can mutually annihilate to produce another particle–antiparticle pair, such as two oppositely charged muons. These rare but simple processes provide a direct window into the most basic interactions of nature.

The other tool that can be brought to bear is what CERN researcher Erik Johansson calls "topology". The computers' pattern-recognition programs can reveal regularities in the way the produced particles emerge. These patterns reflect the elementary particle interactions in a direct way.

If an underlying scheme is not clear, information quickly becomes baffling and incomprehensible. An example is the subway system of a large city like London or Paris. Street maps of big cities are fine for finding one's way around on foot. They also usually show where the underground stations are, but this does not make clear how the lines are arranged, so it is not easy to plan an underground journey from such a map.

The key is to use a different map, in which the streets have been thrown away and the station dots are connected by different-coloured lines. Immediately, everything becomes clear – to get from A to B, take the red line and transfer at C onto the blue line. The detailed paths taken by the underground lines are not of vital importance to the traveller, only their general direction and interconnections, so such maps are often schematic. This simplification is a great help to understanding.

So it is with elementary particles. The most versatile elementary particles are the quarks, of which there are six varieties, or "flavours", arranged in three pairs – up and down; strange and charmed; and beauty (or bottom) and top. Quarks are (as far as we know) the ultimate layer in the structure of matter. Substances are made up in turn of molecules, then atoms, then electrons and nuclei, the last being composed of protons and neutrons, and these in turn being built of quarks.

Quarks are different from all of the other constituents of matter. Molecules can be broken into atoms, atoms into electrons and

A keyhole to the birth of time

Building on Johansson's original idea, CERN's James Gillies and Richard Jacobsson produced an educational CD-ROM physics analysis package for schools. *Particle Physics – a Keyhole to the Birth of Time* contains the same real data and analysis tools as the "Hands-on CERN" Web site and comes complete with a comprehensive and visually attractive tutorial package. The authors' goal is to provide a stand-alone product that teachers can use in class without detailed prior knowledge of particle physics. Bielefeld computer scientist Olaf Lenz designed an easily navigable structure and award-winning American cartoonist Nina Paley created the characters – Malard Decoy and Phyllis Ducque – who act as guides through the content of the CD-ROM. The package is available free of charge to schoolteachers on request to the authors at CERN (e-mail "James.Gillies@cern.ch" or "Richard.Jacobsson @cern.ch").

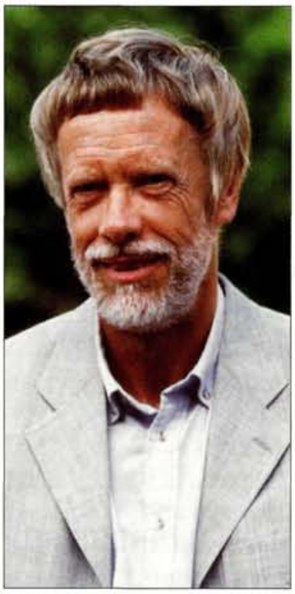
nuclei, and nuclei into protons and neutrons. We know that protons and neutrons are built of quarks, but quarks cannot be isolated. Although we can see that protons or neutrons each contain three quarks, under ordinary conditions, quarks cannot exist on their own as free particles. How, then, can we explore them?

Mapping quark jets

When an electron and a positron annihilate, one possibility is for them to create a quark–antiquark pair (in fact the electron and positron first annihilate into a neutral Z boson, which within 10^{-24} s materializes into the quark–antiquark pair.) However, because quarks and antiquarks cannot exist as free particles, the emergent quark–antiquark pair manifests itself as two narrow sprays ("jets") of subnuclear particles. These jets, the progeny of the produced quarks, fly off back-to-back, each jet confined around the direction of the parent quark. Mapping these jets thus reveals how the parent quarks were produced.

An electron and a positron can also produce other quark and antiquark arrangements, both with and without accompanying gluons (the particles that transmit the forces between quarks). Each quark–gluon arrangement produces a characteristic jet pattern. For example, a quark–antiquark pair that is accompanied by a single gluon will produce three jets of subnuclear particles.

These jet patterns, particularly when emphasized by the use of colour, are the quark–gluon physics equivalent of the subway map.



Erik Johansson – revealing the mystery of particles.

These jet patterns, particularly when emphasized by the use of colour, are the quark–gluon physics equivalent of the subway map.

It is rather like monitoring an underground/subway/metro system by watching how the passengers emerge above ground. A burst of passengers means that a train has recently stopped underground.

Johansson's idea is to select LEP events and prepare them in a way that appeals to 15- to 18-year-old students. He uses electron–positron interactions recorded by the Delphi detector at LEP and presented via a special "Hands-on CERN" Web site at "http://hands-on-cern.physto.se". The Web site also contains introductory material and explanations, together with supplementary material about subjects such as particles and their interactions, particle accelerators and Nobel Prizes. The interactions have been "cleaned up" to delete information that is only of interest to physics researchers and optimized for Internet access.

From these displays, students can quickly see how nature works at the most fundamental level. The displays show basic information, such as collision energy, the various particles produced and their energy and momentum. Analysing these collisions does not require any knowledge of quantum chromodynamics or any other exotic concept. Simple billiard-ball kinematics, with maybe a pinch of relativity, is all that is needed.

In this way, students all over the world can access frontier research data, but nothing can substitute for a visit to a major accelerator laboratory. Only in this way can students fully appreciate what large and complex instruments are needed to probe the smallest constituents of matter. Special programmes of lectures and study are regularly arranged for Swedish students by the Swedish Research Council secretariat at CERN along with Swedish CERN researchers. During a short stay at CERN, students get first-hand experience of how science works. "That day I thought I found the Higgs boson," remarked one recent visitor.

Following a suggestion from Johannson, an extra dimension was recently added to a visit during which students from the UK joined their Swedish counterparts at CERN – at a time in their careers that is useful for future networking. These special programmes aim to rectify the lack of exposure to modern physics in many of the school curricula. ☐

Entangled states allow radical change

The phenomenon of "quantum entanglement" shows vividly how different quantum mechanics is from the everyday macroworld. As well as being intellectually remarkable in its own right, entanglement could also lead to applications in quantum cryptography and computing, as specialist **Giancarlo Ghirardi** of Trieste explains.

A landmark experiment in 1982 by a team led by Alain Aspect (left) of Paris demonstrated that entangled states of distant particles can occur. He is seen here with the 1997 Nobel physics laureate Claude Cohen-Tannoudji.

Quantum pioneer Erwin Schrödinger identified the phenomenon of entanglement (the translation of the German *Verschränkung*, meaning folding, as of arms) as "the characteristic trait of quantum mechanics, the one that enforces its entire departure from classical line of thought".

Interpreting probability

Consider an individual quantum system in a pure state $|\Psi>$ and an observable Ω. Given the most complete specification that the theory allows, what is the probability of a measurement of the observable giving one of the allowed possible outcomes (eigenvalues) ω_k? The answer is the square of the modulus of the scalar product of $|\Psi>$ and the corresponding eigenvector $|\omega_k>$: $P(\Omega = \omega_k|\Psi) = |<\omega_k|\Psi>|^2$.

This implies that $P(\Omega = \omega_k|\Psi)$ cannot be interpreted as the probability that the system, prior to the measurement, actually possesses the "property" $\Omega = \omega_k$ but represents instead the probability of getting the particular result after the measurement has been performed.

Only in the case in which $|\Psi>$ is itself an eigenstate of Ω does the probability take the value 1, and then, following Einstein, Podolsky and Rosen, one can legitimately claim that the system "possesses objectively" – i.e. independently of the measurement being performed or not – the property.

Thus quantum mechanics warns us against attaching too many properties to an individual system. Due to the (non-commutative) nature of the set of observables, if a property corresponding to one of them can be legitimately claimed to be possessed, the same does not hold true for almost all other properties.

The situation changes radically for composite systems and their constituents. This is when entanglement emerges. For simplicity, consider a system S made up of two constituents, S_1 and S_2. Here two different types of states can occur – the factorized and the entangled ones.

The factorized states are simply the product of a state of one constituent multiplied by one of the other: $|\Psi> = |\Psi^{(1)}> \otimes |\Psi^{(2)}>$. Then, according to the previous discussion, there is an observable of system S_1 such that $|\Psi^{(1)}>$ is an eigenstate of the corresponding operator $\Omega^{(1)}$ belonging, say, to the eigenvalue ω_k and an observable of system S_2 such that $|\Psi^{(2)}>$ is an eigenstate of the corresponding operator $\Gamma^{(2)}$ belonging, say, to the eigenvalue γ_j. The state can be written as $|\Psi> = |\omega_k^{(1)}> \otimes |\gamma_j^{(2)}>$, which shows that the subsystems possess the objective properties $\Omega^{(1)} = \omega_k$ and $\Gamma^{(2)} = \gamma_j$.

However, this is not the most general state for the composite system because linear superpositions of factorized states can very well occur, such as the linear combination of two factorized states corresponding to different eigenstates of the considered observables, typically $|\Psi> = \alpha|\omega_i^{(1)}> \otimes |\gamma_k^{(2)}> + \beta|\omega_j^{(1)}> \otimes |\gamma_l^{(2)}>$.

An elementary example

Such a state has no definite property connected to the cited observables; instead there are only probabilities ($|\alpha|^2$ and $|\beta|^2$) of outcomes corresponding to the eigenvectors. In the most general case, it could be that no property could be considered as being attributable to the constituents: the composite system represents a complete entity that, as such, has some property but the constituents of which have no properties at all.

The simplest example is the entangled state of two photons (analogous to the singlet state of two spin 1/2 particles). Suppose there are two photons moving in opposite directions, far away from each other and in the spin state that is the superposition of two states. In the first, both photons are linearly polarized along the vertical direction; in the second, both along the horizontal direction (orthogonal to the axis of propagation):

$$|\Psi> = 1/\sqrt{2}[|1V>\otimes|2V>+|1H>\otimes|2H>] \equiv 1/\sqrt{2}[|1\mathbf{n}>\otimes|2\mathbf{n}>+|1\mathbf{n}\perp>\otimes|2\mathbf{n}\perp>]. \quad (1)$$

This equation disregards spatial degrees of freedom but the photons are assumed to be mutually remote.

The two expressions for the state reflect its rotational invariance. The second simply states that one can choose an arbitrary direction, **n**, in the plane orthogonal to the direction of propagation and express the state as the linear combination of a state in which the two photons are linearly polarized along such a direction and one in which they are linearly polarized in the orthogonal direction.

Erwin Schrödinger (1887–1961) identified the phenomenon of entanglement as a characteristic trait of quantum mechanics.

Equation (1) shows that if one of the two photons is subjected to a test of linear polarization along the arbitrarily chosen direction, **n**, there is a 50% probability that it passes the test and a 50% probability that it is absorbed. Since these are the only possible outcomes, and because **n** is an arbitrary direction, this shows that the individual photons do not possess any polarization property whatsoever (a more general treatment shows that the same is true for arbitrary – circular or elliptical – polarization).

In spite of this, and even though the two photons are very far apart and non-interacting, if we subject one of them (photon 1) to a linear polarization test along, for example, the direction **n**, we will get one of the two possible outcomes. Let us suppose that it passes the test; immediately after the first measurement the state becomes $|1\mathbf{n}>\otimes|2\mathbf{n}>$, which is a factorized state and, moreover, an eigenstate of the polarization along **n** of both photons. Thus, photon 2, which prior to the measurement on its partner had no definite polarization, immediately becomes "polarized along the direction **n**".

The outcomes of polarization measurements along the same direction are always perfectly random but perfectly correlated: either both photons pass the test or both fail to pass it, the two instances occurring at random with equal probabilities.

The locality issue

If we accept quantum theory as a complete theory, we are compelled to recognize that prior to any measurement each individual constituent of the composite system has no objective property, while a measurement on one of the constituents implies the instantaneous emergence of a precise property for its remote and non-interacting partner.

This fact, which nobody had contemplated before Einstein and Schrödinger, seems to imply non-local effects and leads naturally to the question of whether one could at least think that, in a way that may even be out of our control, the constituents already possess precise polarization properties before any measurement takes place.

This implies the incompleteness of the quantum description and suggests the idea of "hidden variables" – variables that are not included in the formal description of the standard theory – the knowledge of which would determine the outcome of any prospective measurement. Quantum probabilities are then due to our ignorance about the precise values of the hidden variables in each case.

However, John Bell's famous inequality proved convincingly that there is no such local hidden variable theory (neither deterministic nor random) that can reproduce all predictions of quantum mechanics. Stimulated by this new insight, various experiments (notably that carried out by Alain Aspect's team at Orsay in 1982 – see box p22) have demonstrated quantum entanglement and its associated non-local phenomena. This phenomenon has a vital bearing on our understanding of quantum measurements.

This quantum non-locality does not conflict with relativity because it cannot be used to send signals faster than light. As stressed by Abner Shimony, quantum non-locality and relativity "peacefully coexist".

A technological breakthrough?

Entanglement even suggests possible revolutionary technological applications. Some of them have been demonstrated already. Others, even more exciting, appear feasible in the near future. Among them are quantum cryptography, quantum teleportation and quantum computation.

Quantum entanglement permits a perfectly secure communication system. Suppose two characters, Alice and Bob, want to communicate secretly in a fully secure way and that there is a source of photons in the entangled state (1), which sends a pair of photons every second to Alice and Bob's remote locations.

They agree to subject the photons reaching them to plane polarization tests either along the vertical or at an angle of 45° to the vertical. They choose at random which one of the two tests they perform for each individual photon and keep a record of the measurements. According to whether the photon passes or fails the test, they write down the number 1 or 0 respectively.

Since any photon has an equal and genuinely random probability of passing or failing the test, each of these two characters will have at the end a perfectly random binary sequence. In all of the cases where Alice and Bob have performed the same measurement (i.e. both have chosen a vertical or both a 45° polarization test) they have obtained the same result and, therefore, they have written the same digit on their list.

At this point Alice and Bob publish their sequence of measurements and delete from the list all of the digits corresponding to cases where the measurements differ. In this way they remain with two identical and perfectly random binary strings.

> "Entanglement even suggests possible revolutionary technological applications. Among them...quantum cryptography, teleportation and computation."

If two people share two such ▷

Entanglement revealed

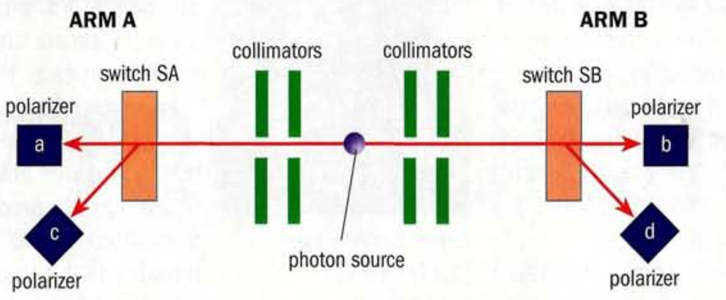


Fig. 1: The 1982 experiment by a team led by Alain Aspect showed that quantum entanglement happens for mutually remote quantum systems. One photon behaves in a way that depends on the test performed on the other photon, even though there is no time to be influenced by it.

One of the most striking physics experiments of the 20th century was in 1982 when a team led by Alain Aspect of Paris demonstrated that entangled states of distant particles can actually occur.

Suppose we have a source of a pair of photons in the entangled state of equation (1) (p21) propagating towards two distant regions where they are subjected to plane polarization tests. In such a situation one cannot think of a photon as possessing a definite polarization property and it has the same probability of passing or failing any conceivable polarization test.

The apparatus can subject the arriving photons to plane polarization tests, which can be chosen (as decided freely by the experimenter) to occur along direction **a** at one extremity of the experiment and along **b** at the other. Obviously each of them can pass or fail the test. Define E(**a**,**b**) as the difference between the quantum mechanical probabilities that the two outcomes agree (both photons pass or both fail the test) and that they disagree (one photon passes and the other fails the test).

The CERN theorist John Bell considered the possibility that the tests at the two arms can be chosen (again according to the experimenter's decision) to occur along four different directions – two at each arm, let us say **a** or **c** at one arm and **b** or **d** at the other. Bell proved that an appropriate linear combination of the expressions E(**a**,**b**), E(**a**,**d**), E(**c**,**b**) and E(**c**,**d**) cannot exceed the value 2 for all conceivable local hidden variable theories (deterministic or stochastic), while for the considered state of the two photons and for appropriate choices of the polarization directions, quantum mechanics predicts a value of $2\sqrt{2}$ for such a quantity. Prior to 1982, various tests confirmed these predictions.

However, some physicists pointed out that such experiments could not be considered as conclusive proof of quantum entanglement and quantum non-locality because the choice of the directions of the polarization tests at the two arms of the experiment was performed long before the photons reached them, and thus one could not exclude (in principle) that the choice at one arm might influence the unfolding of the process at the other arm.

No matter how peculiar this idea is, there is no doubt that it points to a possible loophole in the non-locality argument. Alain Aspect and his collaborators overcame this objection by an ingenious experimental set-up (figure 1). SA and SB are two switches that, according to their settings, let the photon propagate either undeflected or deviated.

According to the path followed by the photon, it is then subjected to a polarization test along one of the two possible directions. For example, if it is undeflected at the left arm, it undergoes a linear polarization test along **a**; if it is deflected at the left arm, it undergoes a linear polarization test along **c** (and similarly for the right arm).

An extremely useful feature of Aspect's experiment is that the choice of the settings of the two switches occurs randomly and "at the very last moment", such that both the choices and the detection events in one arm of the experiment cannot influence those at the other. No signal, even travelling at the speed of light, would have enough time to pass from one arm of the experiment to the other.

The experiment confirmed quantum predictions, implying that one cannot even think that one photon "knows" in advance how it will respond to any test – the outcomes are genuinely random.

Nevertheless, it still behaves in a way that depends on the test performed on the other photon, in spite of the fact that it cannot be physically influenced by the fact that the measurement is performed or by the outcome that is obtained. This experiment proves that entangled, far-away systems exist and that non-local effects are embodied in quantum theory.

identical random sequences of numbers, they can use them for secret communication. The resulting "message" cannot be decrypted by anybody who does not have the random string key.

However, one last problem remains: how can Alice and Bob be sure that nobody has managed to get hold of their random string? A general theorem of quantum mechanics that is a consequence of Bell's analysis says that any attempt by an eavesdropper to get such information or to influence the outcomes induces a certain probability that Alice and Bob's results differ even when their measurements were identical.

The strategy is then clear: they publish a certain number of the outcomes that they have obtained in their measurements, throw them away and keep the remainder. The above theorem implies that if after declaring, for example, 100 digits they find that all of them agree, the probability that someone has attempted to influence their experiments is of the order of 10^{-13}.

Even though Alice and Bob cannot avoid attempts to intercept their communication, they can discover with almost total certainty whether somebody has made such an attempt (in which case they discard their key sequence and repeat their operation on a more secure channel).

Teleportation is a process by which Alice, who has in her laboratory, for example, a photon in a (possibly unknown to her) quantum state and shares with Bob a common source of entangled photons, performs a measurement on the composite system of her photon and the one of the entangled pair. She informs Bob (on a classical information channel) of the result. According to the result, Bob does either nothing or performs simple operations on his photon (such as passing it through elementary optical devices), at the end of which his photon is left precisely in the same state as Alice's original photon. Such teleportation has been already implemented in several laboratories.

> "Another new field is quantum computation...its revolutionary implications derive from an ingenious use of entanglement to devise quantum algorithms."

Another revolutionary new field is quantum computation. Once again, most of its revolutionary implications derive from an ingenious use of entanglement to devise quantum algorithms (the best known being Shor's algorithm for the factorization of the product of two prime numbers), which turn out to be much more powerful than any known classical computing algorithm. The potential improvements allowed by such procedures go far beyond what, up to now, anybody has dreamed could be attainable using a computer.

Further reading

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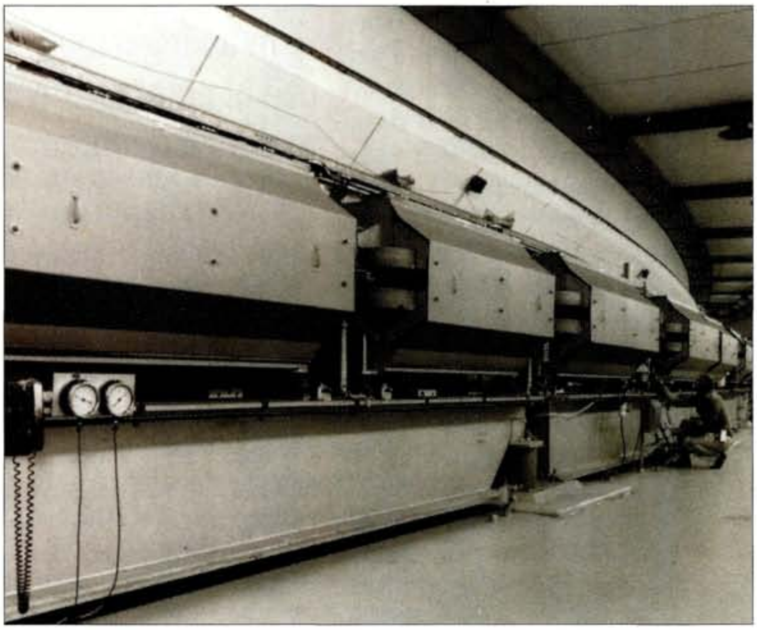
Accelerator tradition is

When the Brookhaven National Laboratory was established in 1947 at Long Island's Camp Upton, it inherited barracks, recreational facilities and a stockade for prisoners of war. Today the barracks remain, converted into offices, but the stockade has given way to world-class research facilities that cover topics from particle physics to the environment.



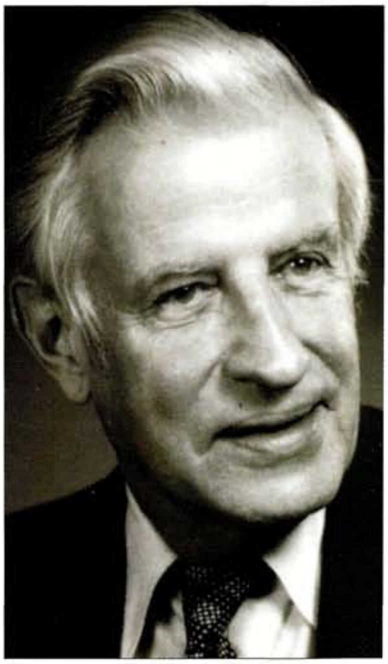
Brookhaven, funded today by the US Department of Energy, was born of the dreams of scientists returning from Los Alamos after the Second World War. They were looking for facilities to continue their research into the mysteries of the atom and they were unable to find them at their home universities. Soon, championed by Columbia physicists Isidor Rabi and Norman Ramsay, the idea of universities coming together to build a common research institute began to take shape. In 1947, nine north-eastern US universities clubbed together to form Associated Universities, Inc. with the goal of establishing a laboratory, and the model for many of today's major laboratories, including CERN, was set.

Man-made cosmic rays

Not long after, plans for the Cosmotron – Brookhaven's first particle accelerator – were laid. Taking its name from the cosmic rays that constantly shower down on Earth, the Cosmotron was the first accelerator to break the giga-electronvolt barrier, reaching energies as high as 3.3 GeV before it was switched off in 1966. The fact that it was also the first accelerator in the world to provide an extracted beam led to the Cosmotron being dubbed the world's biggest slingshot by *Popular Science* magazine.

Scientifically, the Cosmotron lived up to its name, allowing all kinds of particle formerly seen only in cosmic rays to be studied in the laboratory. It was also the machine behind Brookhaven's first Nobel prize. Two guest scientists working at the laboratory in 1956 – T D Lee and C N Yang – interpreted Cosmotron data as arising from parity violation in weak interactions, earning themselves a trip to Stockholm just one year later.

It is perhaps to accelerator physics that the Cosmotron left its greatest legacy, however. From the start, the Cosmotron's builders recognized the limitations of synchrotrons as they were used at the time. In such machines, increasing particle energy was invariably accompanied by increasing orbit instability in the horizontal plane. To build a more powerful machine would require more powerful – and vastly heavier – magnets, imposing a practical upper limit on the energy achievable. The solution, developed by Ernest Courant, Stanley Livingston and Hartland Snyder in the 1950s, was to alternate the horizontal orientation of the bending magnets so that the field gradients in the horizontal plane also alternated. This principle became known as strong focusing and it opened the door to much higher energies.



By this time, Europe's new laboratory, CERN, was getting off the ground. It was founded on the Brookhaven collegiate model with member states taking the place of Brookhaven's universities. Links between the two laboratories were close and news of the strong focusing idea reached the European laboratory in time for it to recast its new proton synchrotron (PS) as a strong focusing machine. The CERN PS duly became the first operational, strong-focusing proton synchrotron in the world with a design energy of 25 GeV instead of the 10 GeV that would otherwise have been pos-

thriving at Brookhaven

Top left: the Alternating Gradient Synchrotron is at the heart of Brookhaven's particle physics programme. Top right: the National Synchrotron Light Source attracts some 2500 scientists each year. Bottom left: John Blewett – Brookhaven accelerator pioneer. Bottom right: Rags to RICHes – the celebrated songwriter Irving Berlin was Camp Upton's most famous resident in the pre-Brookhaven era. (Courtesy Brookhaven National Laboratory.)

sible. Brookhaven's Alternating Gradient Synchrotron (AGS) came on stream soon after and these two machines remain at the heart of the two laboratories' accelerator complexes to this day.

The AGS has provided a rich harvest of physics for Brookhaven, earning the Nobel prize three times. Leon Lederman, Melvin Schwartz and Jack Steinberger had to wait until 1988 to receive the prize for their 1962 discovery of the muon neutrino. James Cronin and Val Fitch had a shorter wait, receiving the call to Stockholm in 1980 for their 1963 observation of CP-violation. Sam Ting picked up the prize for his 1974 discovery of the J/psi particle, along with Burton Richter of California's SLAC laboratory, just two years later.

Physics in collision

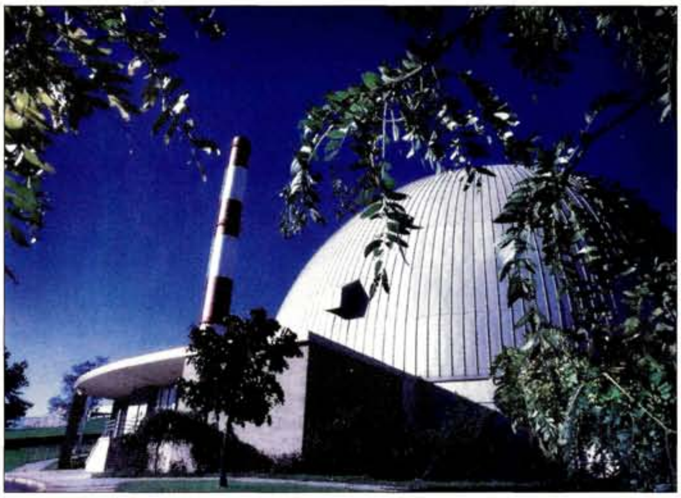
Flush with the success of the AGS, Brookhaven set its sights high and in 1970 accelerator physicist John Blewett revived an earlier idea of building a machine to store and collide proton beams. Named project ISABELLE, Blewett's plan was to build a pair of intersecting storage rings using the AGS as the injector. R&D for the new machine soon got under way and a ground-breaking ceremony was held in 1978. Soon after, however, a mixture of technical problems and changing political winds led to ISABELLE being dropped in favour of an even more ambitious project elsewhere – the Superconducting Super Collider – the downfall of which was later to send shockwaves around the world's particle physics community.

Brookhaven persevered and was soon back with a new proposal to build a relativistic heavy-ion collider (RHIC) on the ISABELLE site. RHIC's main aim would be to seek out and explore the exotic states of matter produced when heavy ions collide at huge energy densities. Using the AGS as the injector, RHIC would also serve as a proton–proton collider with the ability to collide polarized protons, helping to unravel the long-running mystery of nucleon spin (*CERN Courier* November 2001 p25). This part of the programme led to the establishment of a joint research initiative between Brookhaven and the Japanese Institute of Physical and Chemical Research (RIKEN) in 1995. The RIKEN-Brookhaven Research Center is now involved in the full RHIC programme and is also building a high-performance supercomputer for lattice QCD. Set to start up in March 2003, the new machine will reach 10 teraflops for the modest price tag of $5 million (about 50 cents per megaflop).

Accelerator-based programme

RHIC was switched on in 2000 following a decade of development and construction. The timing interlocked perfectly with a fixed-target, heavy-ion programme at CERN (*CERN Courier* April 2000 p13) and provided a new focus for this line of research. RHIC's first polarized protons were injected in December last year. With the AGS fixed-target research programme running concurrently with RHIC for the first time in 2001, Brookhaven's accelerator-based programme is in rude health. The major thrust of the AGS programme is a long-running rare kaon decay experiment that published results recently on statistics of one event seen in 6 trillion kaon decays (p4).

Particle physics at another AGS experiment was also recently in the spotlight with a new measurement of the muon's magnetism, which appeared at first to be at odds with the Standard Model. A closer look at the theory, however, showed that it was the Standard ▷



Left: the Brookhaven energy house proves that conventional technology can go a long way when wisely deployed. Right: the high-flux beam reactor. (Courtesy Brookhaven National Laboratory.)

Model that was at odds with the Brookhaven measurement (*CERN Courier* January/February p7). Science proceeds as an ongoing debate between experiment and theory. However, in modern-day particle physics it is rare that experiment leads the discussion.

National light source

Synchrotron radiation at Brookhaven could not come with a better pedigree. The phenomenon was predicted in the 1940s by, among others, the influential Brookhaven accelerator physicist John Blewett, who was then working for the General Electric Company. It was not until 1978, however, that synchrotron light research first made an appearance at the laboratory. Then, when the Department of Energy recognized the need for a national, second-generation light source, Brookhaven was chosen as the site. The National Synchrotron Light Source (NSLS) produced its first light in 1982 from a vacuum ultraviolet ring. An X-ray ring came on stream a few years later, and between them these two synchrotrons provide X-ray, ultraviolet, visible and infrared light to around 100 beamlines.

For the future, a proposed Center for Functional Nanomaterials will complement the NSLS. This will provide researchers with tools to make and study functional nanoscale materials. Functional materials are those that exhibit a predetermined chemical or physical response to external stimuli. The centre aims to achieve a basic understanding of how these materials respond when in nanoscale form. Nanomaterials offer different chemical and physical properties from bulk materials and have the potential to form the basis of new technologies.

Accelerating to the future

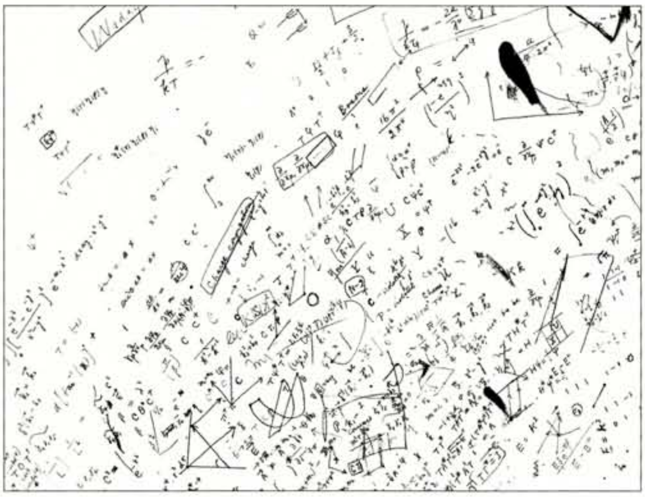
Today, Brookhaven is a laboratory relying heavily on its accelerator facilities for particle and nuclear physics as well as synchrotron radiation research. Keeping an eye on the future of these fields, the laboratory maintains an accelerator test facility (ATF) with a mission to explore new ideas on how to accelerate particles to higher energies and produce X-ray beams of greater brightness than ever. The ATF puts a range of accelerator and laser components at the disposal of a user community investigating the possibilities of novel acceleration techniques that will be necessary in the long term as experimental demands outstrip the possibilities of current-day technology.

The other main string to the fledgling Brookhaven laboratory's bow was reactor-based physics. The laboratory's first reactor – the Brookhaven Graphite Research Reactor (BGRR) – was developed at the same time as the Cosmotron. When it came on stream in 1950, it was the first peacetime reactor to be built in the US after the Second World War. Its dual mission was to produce neutrons for experiments and to refine reactor technology. The BGRR pursued a more applied line of research than its sister facility, the Cosmotron, leading, among other things, to the development of multigrade motor oils through the study of wear in engine components.

Reactor technology moved on and by the late 1950s, Brookhaven embarked on the construction of a new reactor capable of delivering much higher neutron fluxes than the BGRR. The High-Flux Beam Reactor (HFBR) produced its first self-sustaining reaction in 1965. Three years later the BGRR was shut down. HFBR research covered topics as diverse as basic nuclear physics and the development of radioactive isotopes for use in medicine.

The HFBR's illustrious scientific career was marred by an unfortunate end in 1997 when a tritium leak was discovered at Brookhaven, leading to the most delicate period of the laboratory's history. The tritium came from a leak in the HFBR's spent-fuel pool and had remained undetected for many years. Careful sampling showed that the leak was confined and posed no danger to Brookhaven employees or the public. Brookhaven, however, found itself in the spotlight, both locally and globally, and implemented a strongly proactive community and media relations programme. Its image recovered, but too late for the HFBR, which has been permanently shuttered since 1999. The closure of a smaller reactor dedicated to medical research in 2000 marked the end of reactors at Brookhaven.

To physicists, Brookhaven is best known for its accelerator and reactor-based research, but as a multidisciplinary laboratory it also supports major programmes in life sciences and energy research. It was at Brookhaven that Lewis Dahl first identified the link between salt and high blood pressure in 1952. Also in the 1950s, Brookhaven



The art of science – these sketches and notes were made by T D Lee in the summer of 1956 during discussions with C N Yang about parity conservation in weak interactions. (Courtesy Brookhaven National Laboratory.)

scientists Walter Tucker and Powell Richards developed technetium-99m, the world's most commonly used medical tracer. In the 1960s, George Cotzias began a programme of research at Brookhaven that led to the use of dopamine in the treatment of Parkinson's disease.

In energy research, one of the laboratory's highlights was triggered by the 1973 OPEC oil embargo when the US government turned to the laboratory for energy conservation solutions. This led to the Brookhaven energy house – a design concept aimed at reducing energy consumption in a family home simply by using conventional technology wisely. Built in 1980, the house uses solar energy and thermal storage to achieve dramatic energy savings. Its design has been widely imitated.

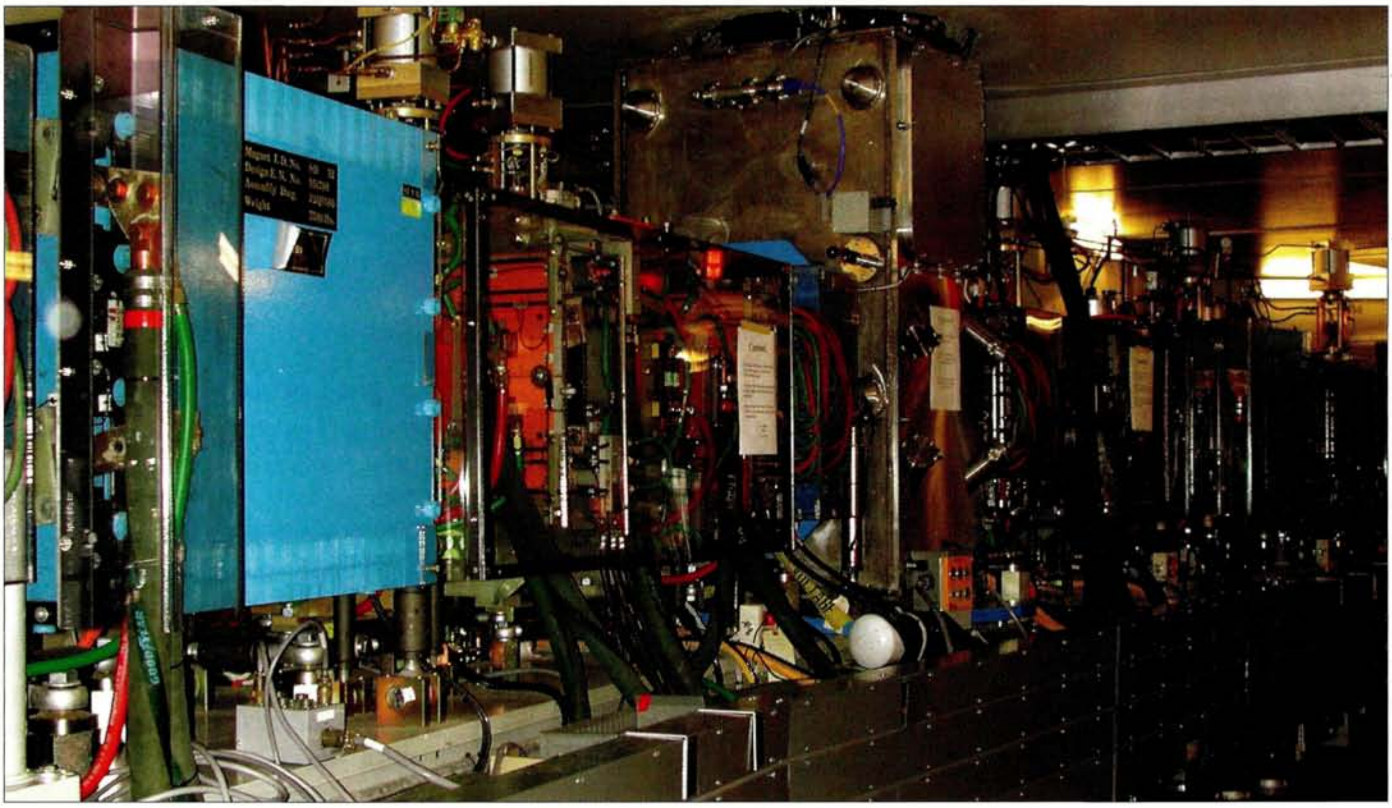
Today, Brookhaven is managed by science associates. It hosts a thriving research community at its flagship facility, RHIC. In particle physics, the laboratory is also the focal point for US participation in the ATLAS experiment at CERN. Brookhaven's proud tradition in accelerator physics continues at the ATF, and the NSLS supports a thriving user community of some 2500 researchers. Brookhaven has also become a focus for the local community. Its mere presence on Long Island put more than $24 million into the local economy in 2001. More importantly for the laboratory and for the image of science locally, Brookhaven has become a centre of culture. A visit to its Web site at the time of writing revealed not only news about the molecular structure of cancer-related proteins unravelled at the NSLS, but also about an extravaganza of gospel music in an auditorium more used to the somewhat more sober proceedings of scientific colloquia.

Further reading

Brookhaven National Laboratory Web site: http://www.bnl.gov/.

Superbends expand the scope of Berkeley's ALS

The first-ever retrofit of superconducting bend magnets into the storage ring of an operating synchrotron radiation source extends the spectrum of Lawrence Berkeley National Laboratory's Advanced Light Source into the hard-X-ray region without compromising soft X-ray availability or performance.

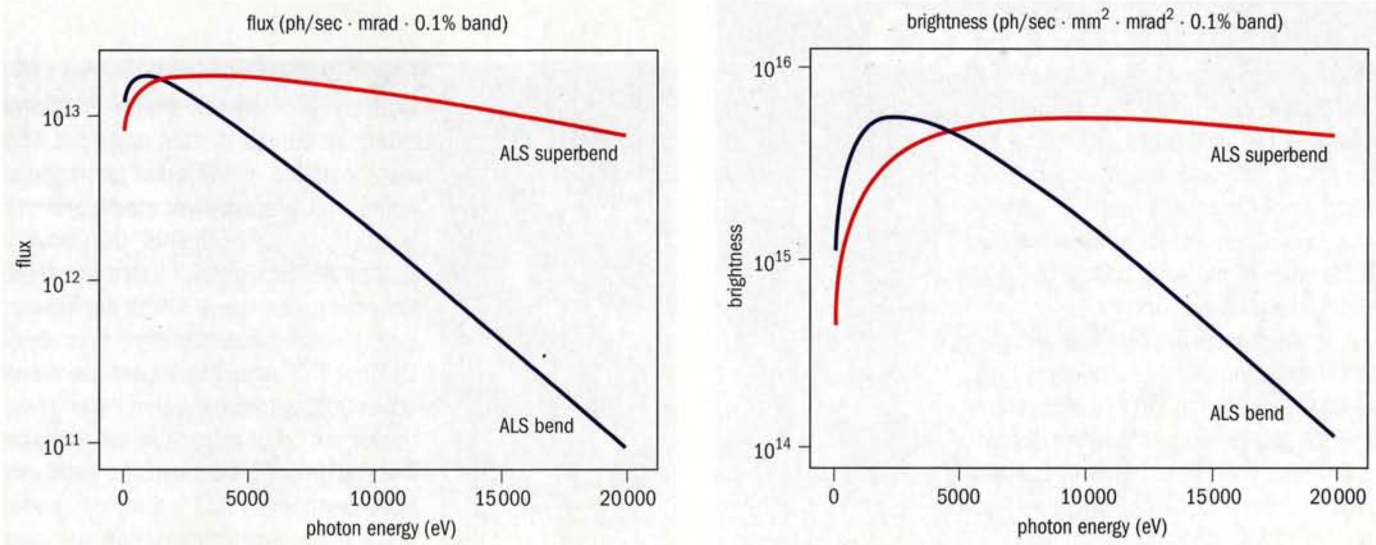


A superbend (silver, centre) in place in the Advanced Light Source storage ring.

At first it was a perfect match. The physical constraints of its site at the Lawrence Berkeley National Laboratory on a hillside above the University of California's Berkeley campus, the research interests of its initial proponents and the fiscal realities of the times all pointed to the same conclusion in the early 1980s: the Advanced Light Source (ALS) should be a third-generation, but low-energy, synchrotron radiation source designed for highest brightness in the soft-X-ray and vacuum-ultraviolet spectral regions.

While the ALS has turned out to be a world leader in providing beams of soft X-rays – indeed, furnishing these beams remains its core mission – there has nonetheless been a steadily growing demand from synchrotron radiation users for harder X-rays with higher photon energies. The clamour has been strongest from protein crystallographers whose seemingly insatiable appetite for solving structures of biological macromolecules could not be satisfied by the number of crystallography beamlines available worldwide.

The question was how to provide these X-rays in a cost-effective way without disrupting the thriving research programmes of existing ALS users. Superconducting bend magnets (superbends) provided the answer for the ALS and a proposal was adopted



The flux and brightness of the ALS superbends (red) show a dramatic increase at higher photon energies relative to those of the normal bend magnets (blue).

(a proposal that was originally made in 1993 by Alan Jackson of Berkeley and Werner Joho of Switzerland's Paul Scherrer Institute) to replace some of the normal combined-function (gradient) magnets in the curved arcs of the storage ring with superconducting dipoles that could generate higher magnetic fields and, thus, synchrotron light with a higher critical energy.

A team headed by David Robin, the leader of the ALS Accelerator Physics Group, took on the pioneering task of retrofitting superconducting bend magnets into the magnet lattice of an operating synchrotron light source. In particular, three 5 Tesla superbends were to replace the 1.3 Tesla centre gradient magnets in Sectors 4, 8, and 12 of the 12-fold symmetric ALS triple-bend achromat storage-ring lattice. The long project culminated early last October when, after a six-week shutdown to install and commission the superbends, the ALS reopened for users with a new set of capabilities.

The superbends have extended the spectral range of the ALS to 40 keV for hard-X-ray experiments. They do not degrade the high brightness of the ALS in the soft-X-ray region, for which the ALS was originally designed, nor do they degrade other performance specifications, such as beam stability, lifetime and reliability. They do not require that any straight sections normally occupied by high-brightness undulators be sacrificed to obtain high photon energies by filling them with high-field, multipole wigglers. Superbend magnets are already serving the first of a new set of protein crystallography beamlines. Ultimately, 12 new beamlines for crystallography and other applications, such as microtomography and diamond-anvil-cell high-pressure experiments, will be constructed.

Superbend history

The ALS was originally based on an electron storage ring with a 198 m circumference and a maximum beam energy of 1.9 GeV to provide peak performance in the vacuum-ultraviolet and soft-X-ray spectral regions. One way for the ALS to respond to the demand that arose in later years for higher photon energies would have been to use some of its scarce straight sections for high-field, multipole wigglers. Later, in 1997 the ALS did install one such wiggler – a device that provides the hard X-rays for an extremely productive protein crystallography beamline (Beamline 5.0.2) operated by the Berkeley Center for Structural Biology.

However, the drawback of the wiggler route was immediately obvious: many wigglers would limit the number of high-brightness undulators that give the ALS its state-of-the-art, soft-X-ray performance and that justified its construction in the first place. Moreover, a wiggler cannot readily service more than one beamline capable of the demanding multiwavelength anomalous diffraction experiments that many crystallographers want to perform, whereas a bend magnet can. In the end, the ALS adopted the superbend alternative proposed by Jackson and Joho – a choice that brought along some imposing challenges.

Superconductivity is no stranger to synchrotron light sources, where superconducting bend magnets have been used in small (mini) synchrotrons dedicated to X-ray lithography. In addition superconducting insertion devices in straight sections are, if not common, a venerable technology. Unlike wigglers and undulators in straight sections, however, superbends would be an integral part of the storage-ring lattice in a large multi-user facility and could not simply be turned off in case of failure or malfunction. So, the stakes were very high – the pay-off would be an expanded spectrum of photons to offer users; the risks included the possibility of ruining a perfectly good light source or, at the very least, causing unacceptable downtime.

In 1993, newly hired accelerator physicist Robin was set to work on preliminary modelling studies to see how superbends could fit into the storage ring's magnetic lattice and to determine whether the lattice symmetry would be broken as a result. He concluded that three superbends with fields of 5 Tesla, deflecting the electron beam through 10° each, could be successfully incorporated into the storage ring. Later, beginning in 1995, Clyde Taylor of Berkeley's Accelerator and Fusion Research Division (AFRD) led a laboratory-directed R&D project to design and build a superbend prototype.

By 1998 the collaboration (which included the ALS Accelerator Physics Group, the AFRD Superconducting Magnet Program and Wang NMR Inc) had produced a robust magnet that reached the design current and field without quenching. The basic design has ▷

remained unchanged through the production phase. It includes a C-shaped iron yoke with two oval poles protruding into the gap. A mile-long length of superconducting wire made of niobium-titanium alloy in a copper matrix winds more than 2000 times round each pole. The operating temperature is about 4 K.

With the strong support of ALS advisory committees and Berkeley laboratory director Charles Shank, Brian Kincaid – at that time the ALS director – made the decision to proceed with the superbend upgrade, and his successor, Daniel Chemla, made the commitment to follow through. The superbend project team, now including members of Berkeley's engineering division, held a kick-off meeting in September 1998 with Robin as project leader, Jim Krupnick as project manager and Ross Schlueter as lead engineer. Christoph Steier then joined the team a year later as lead physicist.


A superbend magnet in its cryostat awaiting characterization measurements.

Subsequently, the success of wiggler Beamline 5.0.2, combined with some pioneering work on normal bend-magnet beamlines by Howard Padmore and members of his ALS Experimental Systems Group, led to the formation of user groups from the University of California, the Howard Hughes Medical Institute and elsewhere that were willing to help finance superbend beamlines, further adding to the momentum of the project.

Superbend team work pays off

For the next three years, the superbend team worked towards making the ALS storage ring the best understood such ring in the world. In every dimension of the project, from beam dynamics to the cryosystem, from the physical layout inside the ring to the timing of the shutdowns, there was very little margin for error. To study the beam dynamics, the accelerator physicists adapted an analytical technique used in astronomy called frequency mapping (*CERN Courier* January 2001 p15). This provided a way to "experiment" with the superbends' effect on beam dynamics both theoretically and experimentally before the superbends were installed.

Another technical challenge was to design a reliable, efficient and economical cryosystem capable of maintaining a 1.5 ton cold mass at 4 K with a heat leakage of less than 1 watt. Wang NMR was contracted to construct the superbend systems (three plus one spare). Wang designed a self-sustaining cryogenic system based on a commercial cryocooler, leads made of high-temperature superconductors and a back-up cryogenic reservoir.

Following some preparatory work during previous shutdowns, the installation of the superbends began in August 2001. The initial installation plan was very tight. In one 11-day period, the superbend team removed three normal gradient magnets and a portion of the electron-beam injection line in straight section 1 just upstream of Sector 12; installed the superbends; modified cryogenic systems; and completed extensive control system upgrades. They also installed many other storage-ring items and prepared for start-up with a beam.

After the installation phase, the goal was to commission the ALS with superbends and return the beam to users by 4 October. This schedule allowed the month of September to commission the ring (with the exception of a four-day break for the installation of the front ends for two superbend beamlines) and a three-day period for beamline realignment. However, commissioning proceeded much faster than had been expected and it was less than two weeks after the start of the installation when the machine was ramped up to full strength, and the effects of the superbends on the performance of the storage ring were fully evaluated.

Because so much was at stake, the storage ring had been studied and modelled down to the level of individual bolts and screws to ensure a smooth, problem-free installation into the very confined space within the storage ring. This attention to detail also paid off in the rapid commissioning. To take one example, the superbends were very well aligned, as demonstrated by a stored beam with little orbit distortion and small corrector-magnet strengths.

At the end of the first day, a current of 100 mA and an energy of 1.9 GeV were attained. At the end of the first weekend, the injection rate and beam stability were near normal. By the end of the first week, the full 400 mA beam current was ramped to 1.9 GeV and studies of a new, low-emittance lattice with a non-zero dispersion in the straight sections (designed to retain the high brightness that the storage ring had without superbends) were begun. By the end of the second week, test spectra taken in some beamlines showed no change in quality due to the presence of superbends.

Since reopening for business in October, the ALS has not experienced any significant glitches that might be associated with such a major change. Overall the ALS has made good on its promises to users of installing and commissioning the superbends without disrupting or delaying their research programmes and operating them with no adverse effects on performance in the bread-and-butter soft-X-ray spectral region, as demonstrated by the values of the storage-ring parameters (p31).

Superbend beamlines are already taking data and more are under construction or planned. Three superbend protein-crystallography beamlines are now taking data, and researchers at the first of these to come on line have already solved 15 structures. Three more crystallography beamlines are on the way. Non-crystallography beamlines currently in the works include one for tomography and one for high-pressure research with diamond-anvil cells, two areas for which superbends are even more advantageous than they are for protein

Effects of superbends on ALS performance

Storage-ring parameter (1.9 GeV)	Before superbends	After superbends
lifetime (hours to decay from 400–200 mA)	8	8
fill time (min)	13	15
energy spread %	0.08	0.1
horizontal emittance (nm·rad)	5.5	6.6
horizontal beam size (μm)*		
x.0	250	310
x.1	50	57
x.2, 3	100	100
x.4	60	65
vertical emittance (nm·rad)	0.2	0.15
vertical beam size (μm)*		
x.0	30	23
x.1	65	54
x.2, 3	20	17
x.4	60	52
orbit stability (at x.0)		
fast (> 0.1 Hz) (μm rms)	2.6 (horiz) 1.3(vert)	unchanged unchanged
long-term [μm peak-to-peak]	±5	unchanged

* x.y refers to sector x and port y. There are 12 sectors in the ALS storage ring. In each sector, port 0 is the insertion-device port and ports 1, 3 and 4 are bend-magnet ports. The straight sections of sectors 1 and 3 are occupied by accelerator hardware and are not available for insertion devices. Superbend beamlines are at ports 2 and 3. Port 4 is only available for infrared beamlines.

crystallography, because they more fully exploit the higher photon energies that superbends can generate. Many other areas, including microfocus diffraction and spectroscopy, would also benefit enormously through the use of the superbend sources.

In summary, a new era at Berkeley's ALS is under way.

Further reading

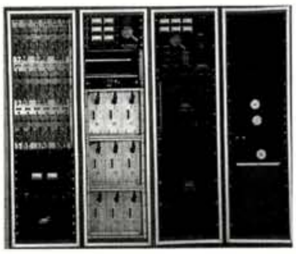
S Marks *et al.* 2001 "ALS Superbend magnet performance" *Proceedings of the 17th International Conference on Magnet Technology* (Geneva).

D Robin *et al.* 2001 "Superbend Project at the Advanced Light Source" *Proceedings of the 2001 Particle Accelerator Conference* (Chicago, Illinois).

D Robin, C Steier, J Laskar and L Nadolski 2000 "Global dynamics of the ALS revealed through experimental frequency map analysis" *Phys. Rev. Lett.* **85** 558.

J Zbasnik *et al.* September 2000 ALS Superbend magnet system" *Proceedings of the 2000 Applied Superconductivity Conference* (Norfolk, Virginia).

David S Robin, **Arthur L Robinson** *and* **Lori S Tamura**, *Advanced Light Source Lawrence Berkeley National Laboratory.*



PEOPLE

APPOINTMENTS & AWARDS

Spiro takes over leadership of DAPNIA

Michel Spiro became head of the French Atomic Energy Commission's (CEA) Department of Astrophysics, Particle Physics, Nuclear Physics and Associated Instrumentation (DAPNIA) on 1 January. He took over from Joël Feltesse, who was recently appointed chair of CERN's scientific policy committee.

Spiro's long and illustrious career covers all aspects of DAPNIA's mandate. Following early work on bubble chambers, he went on to play an important role in CERN's UA1 experiment en route to the discovery of W and Z bosons in 1983. He has also worked on solar neutrino physics with the Gallex experiment at Italy's Gran Sasso laboratory and has more recently been a major figure in the hunt for dark matter in the form of massive compact halo objects.

Spiro further extended his interests to nuclear physics in 1996 when he became director of the CEA project INCA, which is designed to study the incineration of actinides using accelerators. He is currently the chairman of CERN's LEP experiments committee and is the co-author of numerous popular works on physics.

Michel Spiro – head of DAPNIA.

Jenni gets memorial medal

ATLAS collaboration spokesman Peter Jenni received the Memorial medal of Prague's Charles University for his "significant contribution to the collaboration between the Charles University in Prague and the European Laboratory for Particle Physics – CERN" on 20 September 2001.

Jenni has been a strong advocate of Czech participation in the LHC and the wider CERN programme since his first visit to Prague in 1991. He received the medal from university rector Ivan Wilhelm, who is also member of the ATLAS collaboration, in the historical Karolinum building.

The laudatio was read by Jaromir Plasek, vice-dean of the Faculty of Mathematics and Physics, in the presence of physicists collaborating with CERN from the Academy of Sciences of the Czech Republic and the Czech Technical University in Prague.

Peter Jenni (left) receives the Charles University Memorial Medal from the university's rector, Ivan Wilhelm.

Outreach prize invites nominations

Each year the High-Energy Particle Physics Board of the European Physical Society awards a prize for outreach, which is intended to recognize outstanding outreach achievement related to high-energy physics and/or particle astrophysics.

The prize can be attributed to a scientist or a non-scientist and consists of a diploma specifying the work of the recipients and an award of SwFr 2000. This year's prize will be awarded at the 12th General EPS Conference (Trends in Physics) on 26–30 August in Budapest. Nominations should be sent to Jorma Tuominiemi (e-mail Jorma.Tuominiemi@cern.ch) before 15 March.

CERN press spokesman Neil Calder left CERN suitably equipped to become communications director at SLAC, in Stanford.

MEETINGS

The 10th International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY02) will take place at Hamburg's DESY laboratory on 17–23 June 2002. Topics will include SUSY and Higgs collider physics; flavour problems and CP violation; astrophysics and cosmology; SUSY models and grand unification; string theory and M-theory; extra dimensions and branes. Details are available from DESY's Web site (www.desy.de/susy02/).

The seventh edition of the LNF Spring School, Bruno Touschek, will be held in Frascati National Laboratories, Italy, on 20–25 May 2002. The school is designed for graduate students and young postdoctoral researchers, including those from the ESOP (Electron Scattering Off confined Partons; www.nat.vu.nl/~bacchett/esop/) and EURODAPHNE (www.lnf.infn.it/theory/tmr/) networks.

Last year lectures covered CP-violation, cosmic rays, transversity in the nucleon and exclusive processes in QCD. Further information and a complete list of past programmes, can be obtained from the school Web site (http://wwwsis.lnf.infn.it/lnfss02) or by contacting the school (giulia.pancheri@lnf.infn.it).

The Fourth Workshop on RICH Detectors at the NESTOR institute will be held on 5–10 June 2002 in Pylos, Greece. Full information is available at the Nestor Web site (http://www.nestor.org.gr/rich2002).

ANNIVERSARIES

DESY celebrates 10 years of Zeuthen lab

Celebrating at DESY Zeuthen were (left to right) Ulrich Gensch, head of DESY Zeuthen; Johanna Wanka, German federal state of Brandenburg's Minister for Science, Research and Culture; Albrecht Wagner, head of the DESY directorate; and senior statesman of German physics, Volker Soergel, who headed the DESY directorate from 1981 to 1993. (Ilka Flegel, Textlabor, Jena.)

Germany's DESY laboratory celebrated the 10th anniversary of its Zeuthen site on 30 January. Formerly the East German Academy of Science's Institute for High-Energy Physics, the Zeuthen laboratory, south-east of Berlin, was incorporated into DESY in 1992, playing a significant role in the reunification of German science.

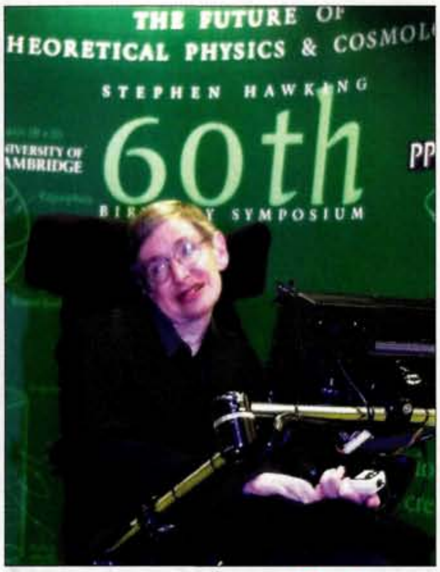
The anniversary celebrations included a colloquium to celebrate both the history and the achievements of DESY Zeuthen and also the commissioning of the laboratory's new Photo Injector Test Facility. This facility will be used to test and optimize electron sources for the TESLA linear collider and X-ray lasers. For details visit http://www-zeuthen.desy.de/.

Beamline editor Rene Donaldson, pictured here in Old Town, San Diego, by her husband Tony, is retiring after a 35-year career in documenting the field of particle physics. Rene started out at the Lawrence Lab in Berkeley. She then moved to Fermilab and then later returned to Berkeley, where she joined the Superconducting Super Collider Central Design Group. For the past 12 years she has been at the Stanford Linear Accelerator Center. At various times she has fulfilled the role of writer, editor, publisher, conference coordinator, technical publications manager – and whatever else she needed to be in order to describe and record the purposes, achievements and plans of the field.

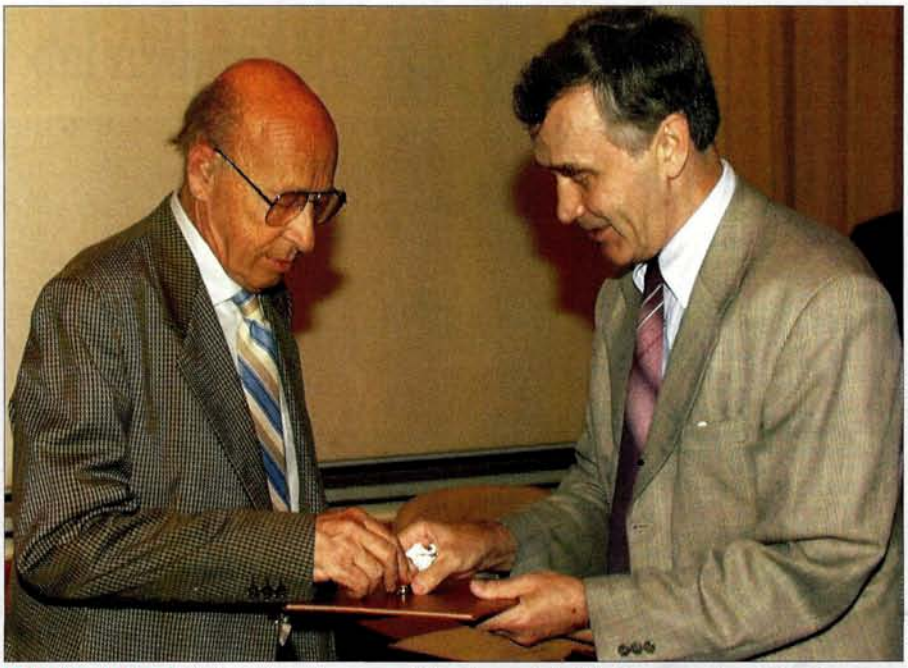
Willibald Jentschke, founding father of Hamburg's DESY laboratory and CERN director-general from 1971 to 1975, celebrated his 90th birthday at DESY on 6 December 2001. Born in Vienna, he emigrated to the US in 1947, where he led the cyclotron group at the University of Illinois in Urbana. He returned to Europe in 1956 to head the physics institute of Hamburg University, with the goal of establishing a modern accelerator centre that would make high-energy physics in Germany internationally competitive. His efforts led to the foundation of DESY in 1959 with its 7.5 GeV electron synchrotron – the first German high-energy accelerator. As head of the DESY directorate from 1959 to 1970, Jentschke decisively shaped the future of the Hamburg lab, endorsing the risky electron–positron storage ring scheme for the DORIS accelerator and promoting the use of synchrotron radiation for research purposes. Jentschke's time as CERN director-general saw the construction of the SPS and the discovery of neutral currents. In 1976 he returned to Hamburg University, from which he retired in 1980.

SLAC marks decade of World Wide Web

America's first World Wide Web server was switched on by the Stanford Linear Accelerator Center (SLAC) in 1991. To mark the 10th anniversary of the occasion, SLAC hosted the Once and Future Web symposium on 3–4 December 2001, details of which can be found on the Web site (www-project.slac.stanford.edu/webanniv/).



Cambridge University marked **Stephen Hawking**'s 60th birthday with a scientific workshop on 7–10 January, followed by a symposium, entitled The Future of Theoretical Physics and Cosmology, celebrating his contributions to the field. After being diagnosed as suffering from motor neurone disease at the age of 21, Hawking defied the odds to forge a spectacular career in science, as well as in the popularization of science. Working with Roger Penrose, he showed that Einstein's General Relativity implies that space and time have a beginning in the Big Bang and an end in black holes. Later he went on to show that black holes are not as black as they seem but in fact emit all kinds of fundamental particles – Hawking radiation. More recently he has proposed that the universe is a unique quantum state. His first popular book, *A Brief History of Time*, rapidly became a publishing legend, heralding a golden age for popular science writing. However, it also gained a reputation for being a hard read. In his latest book, *The Universe in a Nutshell*, Hawking aims to put that right, taking the same material and covering it in a more accessible form. The BBC filmed the entire symposium for a future programme and webcast Hawking's talk. Details of the symposium, including a link to Hawking's talk, are available at the Cambridge Department of Applied Mathematics and Theoretical Physics' Web site (www.damtp.cam.ac.uk/user/hawking60/).



Valentine Telegdi (left), shown here receiving the medal of foreign member of the Russian Academy of Sciences in June 2000 from Academician **Alexander Skrinsky**, celebrated his 80th birthday on 11 January. Hungarian by origin, he has held professorships at the University of Chicago, ETH Zurich and Caltech. In his long-standing association with CERN, he has participated in many experiments. He chaired the laboratory's scientific policy committee from 1981 to 1983. In 1991 he shared the prestigious Wolf prize with Maurice Goldhaber.

Jefferson Lab suffers two retirements

Jefferson Lab associate director, Ronald M Sundelin, retired in January. He led the contingent of superconducting radiofrequency (SRF) experts who migrated to Newport News from Cornell University in the mid-1980s, when the laboratory adopted SRF technology for building the CEBAF accelerator. More recently he directed the laboratory's Office of Technical Performance. In retirement he plans to take up astrophysics.

One month earlier, principal scientist Charles K Sinclair, who is known especially for advancing the science and technology of producing, measuring and employing high-energy polarized electron beams, took his retirement from Jefferson Lab. He has served as deputy head and later acting head of the laboratory's Accelerator Division.

Most recently Sinclair has been involved in Cornell University's development of an energy recovery linac to demonstrate the technical feasibility of a much larger machine of this kind for the production of high-brilliance, very short-pulse X-rays.

Ronald M Sundelin – former Jefferson Lab associate director.

OBITUARIES

George Dixon Rochester 1908–2001

After a long and full life, George Rochester, teacher, researcher and university administrator par excellence, died on Boxing Day.

As a researcher he will always be known as the co-discoverer with Clifford Butler of the so-called V-particles. The discovery of a first strange event in 1946 was followed by the observation of a second in the summer of the following year. An exhaustive analysis of the two events was published at the end of 1947. This was a breakthrough in particle physics that led to great developments, particularly with the new accelerators.

As Ian Butterworth described in his excellent obituary of Clifford Butler (*CERN Courier* September 1999 p40), the two particles observed to decay were the first to be seen of a new class of K-mesons and hyperons. Pais in 1952, followed by Gell-Mann and Nishijima, provided the theory and the world of "strangeness" was launched. Although GDR, as he was affectionately known, never mentioned the matter – and would have been very cross with me for what follows – it is remarkable, to say the least, that the Nobel Prize was not awarded for this seminal discovery. All of the ingredients were there: reputations put firmly on the line, superb technical and interpretative skill and a very big piece in the fundamental particle jigsaw put in place. Remarkable, indeed.

Rochester was born on 4 February 1908 at Wallsend near Newcastle upon Tyne, England. His father was a blacksmith and some of his skills rubbed off on his son, whose experimental skills in later life were of a high order.

A scholarship took him to the then Armstrong College of Durham University (now the University of Newcastle) where a keen researcher, W E Curtis – a noted spectroscopist – provided great stimulus. After his PhD, a year at Stockholm University as an Earl Grey Fellow and two years at Berkeley as a Commonwealth Fellow – still working in spectroscopy – he moved, in 1937, to an assistant lectureship in physics at Manchester University. There he came under the spell of the impressive Patrick Blackett and soon transferred to cosmic-ray physics. Cloud chamber expertise led to a number of interesting results, culminating in the V-particle work.

After Blackett's move to Imperial College and a spell as acting director at Manchester, Rochester moved to Durham in 1955, where he led the physics department to great things. Most notably his wisdom, friendliness and single-mindedness of purpose gave rise, eventually, to the present leading research schools in elementary particle theory, astrophysics and astronomy.

Rochester became Durham's first pro-vice-chancellor and his contributions to university administration were legion.

In the early years of his long retirement he took an interest in the history of astronomy in Durham and provided advice – but only when asked for.

Physics has lost a distinguished practitioner and his colleagues and students a firm friend. His wife, Ida, his constant companion for more than 60 years, died just six days later.

Arnold Wolfendale

George Dixon Rochester 1908–2001

Frans Heyn 1944–2001

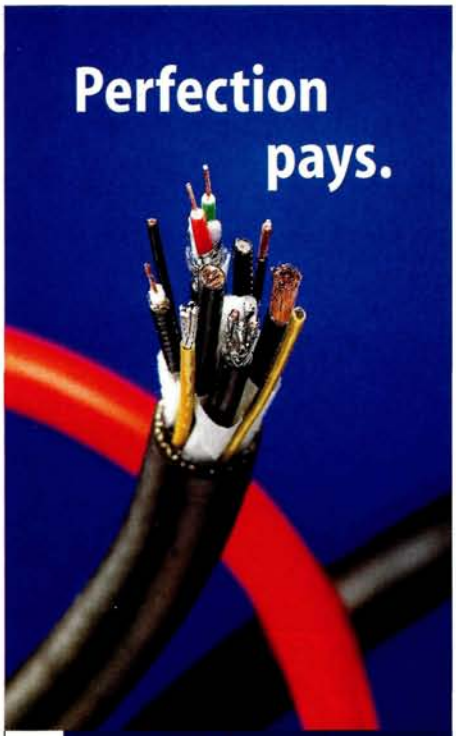
Frans Heyn passed away on 29 December after a long illness. A biochemist by training, he received his PhD in 1975 and went on to become head of the Department of Physical and Biological Sciences at the Netherlands Ministry of Education and Science, with responsibility for research in the fields of physics, mathematics, astronomy, chemistry, biology, earth sciences and medical sciences.

In 1976 he began his long association with CERN as Netherlands delegate to the laboratory's finance committee. He then became delegate to the Council and Committee of Council in 1980. In January 1981 he joined the organization as director of administration – a post that he occupied throughout Herwig Schopper's eight year term of office as director-general.

In 1990 Heyn became the first leader of the new Administrative Support Division – a post that he held until his appointment to the role of adviser in the office of the director-general, Carlo Rubbia, where he remained in the same capacity under the next two director-generals, Chris Llewellyn-Smith and Luciano Maiani. Here he devoted a great deal of time and energy to relations with the European Union and the countries of the former Soviet Union.

He was greatly involved in the ISTC and INTAS before they even officially came into being. Thanks to the ISTC, several CERN experiments – those at the LHC in particular – have benefited from advanced technologies and new sources of finance for equipment manufactured in Russia. Heyn played a vital role in INTAS and, in particular, helped research teams to keep going at a time when the countries of the former Soviet Union were experiencing critical financial problems. Shortly before he died, he agreed to take part in a UNESCO task force responsible for defining a strategy for the revival of scientific co-operation in the Balkans. He was actively involved in this area, literally right up to the last moment.

Frans Heyn 1944–2001.



William Walkinshaw 1916–2001


William Walkinshaw 1916–2001

William ("Bill") Walkinshaw, one of the pioneers of particle accelerator theory in the UK, died on 20 November at the age of 85.

At the beginning of the Second World War he was drafted to the Telecommunications Research Establishment to work on problems related to microwave radar. It was a natural step after the war for him to join D W Fry's particle accelerator group, where he worked on the theory of electron linear accelerators and synchrotrons. Walkinshaw is particularly known for his contribution, working with L B Mullet and R B R Shersby-Harvie, to the design of the very first travelling-wave electron linac. Powered by a wartime magnetron, this machine produced a beam of 0.5 MeV electrons towards the end of 1946. A 4 MeV machine was demonstrated in the following year and studies of these machines for medical use followed.

In 1951 the group moved from Malvern to Harwell and started a study of a possible high-intensity proton linear accelerator of 600 MeV. A severe problem was that of transverse focusing, which was only really resolved by the invention of the strong focusing principle at Brookhaven leading to the use of quadrupoles for focusing. Improvements in the performance of cyclotrons led to the cancellation of the 600 MeV project, but the design of the first sections of this accelerator formed the basis of the injector for CERN's first alternating gradient synchrotron, built by John Adams.

The strong focusing principle gave rise to many ideas for new accelerators worldwide. In the UK, attention centred on the possibility of using "spiral-ridged" magnetic fields to construct high-energy machines with very high intensities. Orbit resonances, however, proved to be a major difficulty - one became known as the "Walkinshaw resonance" - and no feasible design was found. The decision to build the conventional Nimrod machine at the Rutherford Laboratory gave Walkinshaw's group the chance for the first time to make extensive use of digital computers for engineering design calculations.

In the early 1960s, interest at Rutherford switched from accelerator design to the problems of coping with the voluminous data flowing from newly working accelerators. It was natural that Walkinshaw should take charge of this data processing. At first Rutherford lacked sufficient computing power on site and Walkinshaw found himself acting as an impresario orchestrating the use of computers away from home.

In 1967 an IBM system360/75 was delivered to Rutherford. In spite of many teething problems with the new system, after a couple of years the machine was processing users' data around the clock and Rutherford had been established as a most reliable and productive computer centre. In 1970 the laboratory was funded to buy a new supercomputer, a 360/195, with the condition that 50% of processing power be made available to university departments.

Walkinshaw, aware of the wretchedness of having to travel to compute, started a programme to develop Remote Job Entry (RJE) stations - small computers connected to the centre via a phone line. The programme was a great success. Users kept data at the Rutherford Appleton Laboratory but worked from their home department or from CERN, which hosted one of these stations. The RJE project naturally led into full networking, and by the time Walkinshaw retired in 1979 the UK Science Research Council had a network joining its laboratories and most UK universities. Subsequently this network has evolved into the UK academic network, which links all UK academic institutions and runs at speeds of gigabits per second.

J W Burren and J D Lawson

RECRUITMENT

For advertising enquiries, contact *CERN Courier* recruitment/classified, IOP Publishing Ltd, Dirac House, Temple Back, Bristol BS1 6BE, UK.
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ÉCOLE POLYTECHNIQUE
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Faculty Positions in Signal Processing / Information Systems (Joint Appointment with IDIAP)

The Swiss Federal Institute of Technology in Lausanne and the Dalle Molle Institute for Perceptual Artificial Intelligence (IDIAP) in Martigny invite applications for two **"Tenure-Track" Assistant Professor positions** for the Signal Processing Institute of the School of Engineering.

The ideal candidates should demonstrate excellence in research and teaching and have a strong background in one or several of the following areas: signal processing, statistical machine learning, system theory, communication theory, speech processing, image and image sequence processing, multimodal systems, multimedia communications and array processing.

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Applications, including CV with publications list, brief statement of research interests (no more than three pages) and the name, address and e-mail of at least five reference persons, should be sent **no later than 14 June 2002** to:

Prof. Michel Declerc, EPFL
Dean of the School of Engineering
Chairman of the Search Committee
CH-1015 Lausanne, Switzerland

EPFL:
http://ltswww.epfl.ch/
Prof.Murat Kunt
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Please send an application and at least three letters of recommendation to

Prof. Ritchie Patterson, Search Committee Chair, Newman Laboratory, Cornell University, Ithaca, NY 14853.

Applications should include a curriculum vitae, a publication list, and a short summary of teaching and research experience.
Electronic submissions and mail inquiries may be addressed to
search@lns.cornell.edu

Cornell is an equal opportunity/affirmative action employer.

UNIVERSITY of VIRGINIA

RESEARCH ASSOCIATE POSITION EXPERIMENTAL PARTICLE PHYSICS

The Particle Physics group at the University of Virginia (UVa) is seeking to fill a Research Associate position to work on experiments investigating CP violation. We are presently engaged in two Fermilab efforts: HyperCP, which finished data taking in 2000 and is in the analysis stage, and CKM, which which was approved in 2001 and is in the design stage. HyperCP is searching for CP violation in the decays of hyperons and charged kaons as well as performing searches for rare and forbidden processes. One of us (Dukes) is co-spokesperson of the experiment. The goal of CKM is to precisely measure the CKM parameter V(td) and hence test the hypothesis that CKM matrix parameters are the sole source of CP violation. The research associate is expected to take a leadership role on CKM. He or she can also participate in the HyperCP analysis.

The position is immediately available and will be filled as soon as a suitable candidate is found. Applications including curriculum vitae and three letters of reference should be sent to

Prof. Craig Dukes, Department of Physics, University of Virginia,
P.O. Box 400714, Charlottesville, VA 22904-4714, USA

or via e-mail to craigdukes@virginia.edu

The University of Virginia is an equal opportunity/affirmative action employer. Women and minorities are strongly encouraged to apply.

Deutsches Elektronen-Synchrotron
RF-SUPERCONDUCTIVITY

DESY

DESY is one of the large accelerator centers worldwide. The research spectrum reaches from elementary particle physics and solid state physics up to molecular biology and medicine.

In the framework of an international collaboration a Free-Electron-Laser is set up at DESY for wavelengths far below the visible. The project is based on the superconducting TESLA test facility, which supplies the technological foundation for a future linear accelerator for electron-positron collision experiments. Within this framework we are searching for a

Scientist or Qualified Engineer (m/f)

as soon as possible for a permanent position.

You will be in charge of radio frequency (RF) installations for superconducting accelerators and have responsibility for the design, fabrication and operation of RF components for accelerating systems, such as cavities and high power couplers. Furthermore you will take care for and instruct technical personnel. Participation in accelerator shifts is part of this position.
Applicants should have a Physics degree or Diploma-Engineer, preferably in the field of RF technique, experience in the application of software programs (Mafia, HFSS, etc.) for the design of RF components and preferably experience with the design, fabrication and operation of complex RF installations for accelerators. Experience in the instruction and coaching of technical personnel is required.
Please send your letters of application including C.V., list of publications and the names of three referees to our personnel department.

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Deadline: 15.04.2002

Stanford Linear Accelerator Center (SLAC), a high-energy research facility dedicated to performing world-class research and advancing the critical technologies necessary to understand the basic nature of matter, has the following opportunity available:

Experimental Physicist/ Computing Coordinator

You will join the BABAR physics program, which involves large data sets and parallel sophisticated analyses, leading and coordinating our ongoing development activities, including offline/online software, offline/computing hardware and tools and upgrades from PEP luminosity improvements. As a member of the BABAR management team you will participate in making decisions on the future of the collaboration. Under your direction will be a substantial staff of direct/indirect reportees and participants at international computing sites. Best candidates have a Ph.D. in Particle Physics; substantial experience in physics analysis/computing for particle experiments — background in online trigger and data acquisition systems/software, offline reconstruction/simulation/analysis systems and software, leadership of a physics group/subgroup or online computer group management is highly desired; and excellent communication and presentation skills.

SLAC offers competitive compensation and excellent benefits. Send your resume to **SLAC, Employment Dept./Job #22885, 2575 Sand Hill Road, M/S 11, Menlo Park CA 94025; Fax: 650-926-8699; E-mail: employment@SLAC.stanford.edu.** EOE

SLAC
STANFORD LINEAR ACCELERATOR CENTER

OHIO UNIVERSITY

POST-DOCTORAL RESEARCH ASSOCIATE IN EXPERIMENTAL NUCLEAR PHYSICS

The Department of Physics at Ohio University invites applications for a postdoctoral researcher in experimental nuclear physics. The position is renewable for up to two years with the starting date preferably in early 2002. The position will support new and ongoing physics initiatives at Jefferson Lab. Research activities will include significant involvement in detector design and development for the Hall D meson spectroscopy project, as well as studies of electromagnetic production of strangeness using the Hall B CLAS spectrometer. The researcher will be stationed at Jefferson Lab.

Applicants must have a Ph.D. in experimental nuclear or high-energy physics and experience working with hardware and software for accelerator-based experiments. Qualified candidates should send their CV, a description of research interests, details of hardware and design experience, and three letters of reference to:

Prof. Daniel S. Carman, Department of Physics,
Ohio University, Athens, OH 45701,
Phone: (740)-593-2964 email: carman@ohio.edu

Ohio University is an Affirmative Action/Equal Opportunity Employer

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POSITIONS IN ACCELERATOR PHYSICS AT

MICHIGAN STATE
UNIVERSITY

The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University is seeking several highly qualified accelerator physicists or engineers with a strong background in areas related to beam dynamics and superconducting RF technology.

The successful candidates would join the ongoing design effort for an advanced Rare Isotope Accelerator (RIA) facility recommended by the DOE/NSF Nuclear Science Advisory Committee (NSAC) as the highest priority for new construction. Career opportunities exist in several areas, including:

Particle Beam Dynamics: Of particular interest are the areas of beam transport design and linac lattice evaluation.

Radio-Frequency Quadrupole (RFQ): Of particular interest are RFQ designs appropriate for heavy-ion acceleration systems.

RF Systems: Candidates familiar with several facets of RF Systems design are required, e.g., superconducting cavity characterization by utilization of computer codes such as MAFIA and RF system design including appropriate coupling and stabilizing feedback systems appropriate for superconducting cavities.

Depending on the successful applicants' qualifications, appointments will be made at the Research Associate level or at one of three ranks in the NSCL Continuing Appointment System
(see: **http://www.msu.edu/unit/facrecds/policy/nscl01.htm**).

Interested individuals should send a CV and arrange for three letters of reference to be sent directly to

Professor Richard York,
Associate Director for Accelerators,
National Superconducting Cyclotron Laboratory,
Michigan State University,
East Lansing, MI 48824-1321.

For more information, see our website at
http://www.nscl.msu.edu

MSU is an equal opportunity/affirmative action institution.

Rijksuniversiteit Groningen

Full Professor in Theoretical Physics at the Nuclear Physics Accelerator Institute (KVI)

KVI
RIJKSUNIVERSITEIT GRONINGEN

we are looking for:

An enthusiastic and inspiring scientist of international stature who is willing to develop a strong research program, to head a theoretical group, and to interact with his/her colleagues active in the research programs "Nuclear structure and its implications for Astrophysics "Interacting Hadrons" and "Trapped Radioactive Isotopes, Micro-laboratories for Fundamental Physics" (TRIμP).

we offer:

- **The possibility to perform top research in nuclear and hadronic physics at an institute that is recognized by the EU as a "Large Scale Facility"**
- **the position to lead a theoretical group at the KVI**
- **the stimulating atmosphere to interact with experimental groups active in the field of nuclear and hadronic physics,**
- **and a full professor salary (hoogleraar A), with good terms of employment.**

Women are strongly encouraged to apply for this position. More detailed information can be obtained from the Chairman of the selection committee, Prof. Dr. M.N. Harakeh, director KVI, tel: (+31)-50-3633554, email: Harakeh@KVI.NL (see also: http://www.kvi.nl). Also those who would like to draw attention to qualified candidates are asked to contact the chairman of the selection committee.

Please send your application before April 15th 2002, together with three letters of reference to the following address;
Ms. A.M. van der Woude, Personnel Manager, KVI,
Zernikelaan 25, NL 9747 AA Groningen
or email pf@kvi.nl

FACULTY POSITIONS IN ACCELERATOR PHYSICS AT

MICHIGAN STATE
UNIVERSITY

The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) is seeking outstanding candidates to fill a tenure-track position in accelerator physics. Applicants with strong interests in contributing to the ongoing RIA design efforts and similar accelerator-based projects will be given the greatest priority. RIA is the highest priority recommendation for new construction in the new Long Range Plan for Nuclear Science prepared by the DOE/NSF Nuclear Science Advisory Committee (NSAC).

The successful candidate should provide a significant increase in the scope and depth of the accelerator physics program, play a leadership role in developing future facility upgrade options, and contribute to the accelerator physics graduate education program at MSU.

The NSCL is the premier rare isotope facility in the U.S. for the next decade having recently completed a facility upgrade that will increase the intensity of rare isotopes by several orders of magnitude. The NSCL has the tradition of close interaction between groups providing an ideal mix of cutting-edge technical infrastructure and an intellectually stimulating open academic environment.

The accelerator physics group is comprised of 3 tenured faculty and 7 professional scientific staff. Accelerator physics R&D has strong infrastructure support from experienced design and manufacturing groups. A program of R&D in superconducting rf technology has been initiated with requisite facilities in place.

Depending upon the qualifications of the successful applicant, the position can be filled at the assistant, associate, or full professor level. Applicants please send a resume, including a list of publications, and the names and addresses of at least three references directly to

Professor Richard York,
Associate Director for Accelerators,
National Superconducting Cyclotron Laboratory,
Michigan State University,
East Lansing, MI 48824-1321.

For more information, see our website at
http://www.nscl.msu.edu

MSU is an equal opportunity/affirmative action institution.

UNIVERSITY OF
WISCONSIN
MADISON

Postdoctoral Position in Experimental Particle Physics

A University of Wisconsin-Madison research group on the BaBar experiment at SLAC seeks outstanding applicants for one or more positions of postdoctoral Research Associate. Applicants should have a Ph.D. in high energy physics or expect a Ph.D. degree in the near future. In addition, applications are expected to have significant research experience in the area of analysis.

The successful candidate will be based at SLAC and participate in the measurement of the CP asymmetry in B decays or rare decays in the B system.

Please send a full CV and three letters of recommendation to the following address (preferably by e-mail or by fax):

Prof. Sau Lan Wu
CERN, PPE Division
Bldg. 32, R-A05
CH-1217 Geneva 23
Switzerland

wu@wisconsin.cern.ch

Tel: (4122) 767-7171, Fax: (4122) 782-8395

University of Wisconsin is an Affirmative Action/Equal Opportunity Employer.

The Deutsche Elektronen-Synchrotron DESY in Hamburg and Zeuthen, member of the Hermann von Helmholtz-Gemeinschaft Deutscher Forschungszentren, is a national centre of basic research with 1,400 employees and more than 3,000 scientific guests from Germany and foreign countries per year. The accelerators in operation are dedicated to particle physics and research with synchrotron radiation.

The Theory Group at Zeuthen has an opening of a position for a

Theoretical Physicist in Elementary Particle Phenomenology

The position is limited to three years, with the possibility of later tenure.

The candidate should be highly qualified and take an active role in research in Quantum Chromodynamics at high energies and virtualities, with focus on higher order calculations.

Applicants should have a Ph.D. in physics, several years of experience in theoretical elementary particle physics and an established record of research in quantum field theory, especially QCD at high energies. The candidate shall have experience in elementary particle phenomenology, perturbation theory in higher orders, numerical methods and Monte Carlo simulation. Close cooperation with the experimental groups and excellent communication skills are essential. More information on the position is given by Johannes.Bluemlein@desy.de.

The salary and the social benefits correspond to those in German public services (BAT-O Ib).

Deadline for applications: 31.03.2002
Handicapped applicants will be given preference in case of equal qualification.
DESY encourages especially qualified women to apply.

Please send your application documents, including the list of publication and 3 Letters of Reference, to:

DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY
Personalabteilung, Chiffre 04/2002
Platanenallee 6, D-15738 Zeuthen, Germany
Tel.: +49(0)33762-770 / www-zeuthen.desy.de

PSI PAUL SCHERRER INSTITUT

research for the future

Electronic Engineer

Radio-Frequency group of the Swiss Light Source (SLS)

Work Tasks

- Develop, realize and test high frequency regulation systems for the PSI particle accelerator facilities.
- Contribute to the maintenance and upgrading of the existing Radio-Frequency systems.

Your Profile

Candidates will possess a degree in electrical engineering and have a background in regulation systems with practical experience in micro-controllers, processors and DSPs. You should have the ability to integrate easily within an existing team, and implement your own initiatives in a scientific environment.

For any further information please contact Dr. Patrick Marchand, (Tel. +41 56 310 40 26, e-mail: Patrick.Marchand@psi.ch).

Please send your application to:
PAUL SCHERRER INSTITUT, Human Resources, ref.code 0203-01e,
CH-5232 Villigen PSI, Switzerland

Further job opportunities: www.psi.ch

POSTDOCTORAL FELLOWSHIP ATLAS Group

The Physics Division of the Lawrence Berkeley National Laboratory plays a major role in the silicon strip detector system for the ATLAS Experiment at the Large Hadron Collider at CERN. To support this work, we seek a postdoctoral candidate for a 2-year term position with possibility of renewal.

Initial work will be on the assembly and testing of silicon strip modules at Berkeley Lab. The successful candidate will also have the opportunity to be involved in data analysis from one of the ongoing experiments with Berkeley Lab participation. Required qualifications include a PhD in Experimental High Energy Physics and demonstrated strong potential for outstanding achievement as an independent researcher. Experience with silicon detector systems or other complex electronics/detector systems is preferred.

Candidates should submit an application with CV and 3 letters of recommendation via e-mail to gensciemployment@lbl.gov (no attachments), or mail to Lawrence Berkeley National Laboratory, One Cyclotron Road, MS: 50-4037, Berkeley, CA 94720. Applications should reference job number PHAT/014489/JCERN. For more information visit: http://www.lbl.gov/. Berkeley Lab is an Affirmative Action/Equal Opportunity Employer committed to the development of a diverse workforce.

BERKELEY LAB

Postdoctoral Research Associate in Nuclear Physics

The I.U. nuclear physics group has an active program with experiments to study nucleon structure, nuclear dynamics, and the properties of the weak interaction. The wide range of questions being addressed by 11 faculty members include parity violation in thermal neutron-proton capture at LANSCE, flavor and spin structure of the nucleon at RHIC with the STAR detector, and neutrino oscillations with the miniBooNE experiment at Fermilab. Local facilities include a 200 MeV cyclotron and a 500 q^2/A electron cooled storage ring. While the major programs on these no longer include nuclear physics they do provide excellent facilities for development and testing. The laboratory also provides strong personnel infrastructure to enable strong participation in major off-site projects. Opportunities are available on all major research projects. For further information, please access our Web site at http://www.iucf.indiana.edu/

Initial appointments as research associate will be for one year, with possible renewal for two additional years. A Ph.D. in experimental subatomic physics is required. Applications for postdoctoral positions are accepted on a continuing basis and starting dates can be adjusted to suit the situation of the candidates.

Send resume, bibliography and contact information for three references to

Dr. John M. Cameron, Director
Indiana University Cyclotron Facility
2401 Milo Sampson Lane, Bloomington, IN 47408.

FAX: 812-855-6645
Email:cameron@iucf.indiana.edu

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JUSTUS-LIEBIG-
UNIVERSITÄT
GIESSEN

Fellowships

THE EUROPEAN GRADUATE SCHOOL COPENHAGEN-GIESSEN

COMPLEX SYSTEMS OF HADRONS AND NUCLEI

At Giessen University **Graduate student fellowships** for doctoral projects in experimental and theoretical hadron physics and **Marie Curie Training Site (MCTS) Fellowships** for research visits of postgraduates from EU and associated countries of up to one academic year are available on:

- Structure of hadrons and their interactions
- Properties of mesons and baryons in free space and a nuclear environment
- Flavour dynamics of strange and charmed systems
- Signals of the Quark-Gluon Plasma

related to the physics at GSI, DESY, MAMI, ELSA, JLAB, RHIC and LHC. Graduates with excellent academic records and knowledge in hadron or nuclear physics and Quantum Field Theory and postgraduates interested in a MCTS fellowship are encouraged to send applications to the speaker of the Graduate School, Prof. Dr. U. Mosel, Institut für Theoretische Physik, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany

email:euro-grad@physik.uni-giessen.de

Deadline: March 31, 2002.

including a C.V., a list of your academic achievements, and two letters of recommendation. Information on the Graduate Program, the MCTS Program and the admission rules you will find at http://www.physik.uni-giessen.de/EuroGrad/. The working language is English.

Giessen University is an equal opportunity employer.

UHH
Universität Hamburg

Institute for Experimental Physics
Faculty Position in Experimental Particle Physics
The Institute for Experimental Physics invites applications for a

Professorship (C4-tenure) in Experimental Particle Physics

which will be vacant from 01.04.2003. The candidate is expected to play a leading role in the Institute's group activities with the OPERA-Experiment at the Gran-Sasso Laboratory and to shape the future research program of the Institute. Further research activities of the Institute in the field of high energy physics are experiments at HERA, the TESLA Project and astro-particle physics. The teaching duties (8 SWS) include lectures, tutoring, and the supervision of diploma and doctoral students.

Canditates should have a demonstrated excellence in research in experimental particle physics and experience in teaching and working with students.

The University of Hamburg is an equal opportunity/affirmative action employer and welcomes applications from qualified women. Equally qualified handicapped applicants will be given preference.

Applications containing the customary documents (CV, academic records, teaching experience and the list of publications) should be sent by **30.04.2002** to the President of Hamburg University, Administration – 632.5 –, Moorweidenstrasse 18, D-20148 Hamburg, Germany.

TOR ZUR WELT DER WISSENSCHAFT

SERVICE DE PHYSIQUE THEORIQUE (SPHT), SACLAY,

is opening a senior staff position (professor level) in theoretical physics.

Deadline for applications : March 10th, 2002.

For more information see http://www-spht.cea.fr/

CERN COURIER RECRUITMENT BOOKING DEADLINE

April issue: 8 March
Publication date: 21 March
Contact Debra Wills:
Tel. +44 (0)117 930 1196 **Fax** +44 (0)117 930 1178 **Email** debra.wills@iop.org
cerncourier.com

HARVARD UNIVERSITY

POSTDOCTORAL RESEARCH FELLOW EXPERIMENTAL HIGH ENERGY PHYSICS

The High Energy Physics Laboratory at Harvard University periodically has openings for Postdoctoral Research Fellows. Our research program is funded by the U.S. Department of Energy and includes studies of e+e- collisions with the SLAC Babar detector, of proton-antiproton interactions using the Fermilab CDF detector, and of neutrino interactions in the MINOS experiment at Fermilab/Soudan. We are also participating in the preparations for the ATLAS experiment at CERN's LHC.

The current opening is with the Babar experiment. The successful candidate will be expected to participate in the construction and the deployment of a new trigger system. Experience with state-of-the-art detector systems and software experience with the analysis of a high-energy physics experiment are appreciated. Interested applicants should send their CV, a statement of interest, and arrange to have three (3) letters of reference sent to:

Dr. George W. Brandenburg, Director
High Energy Physics Laboratory,
Harvard University
42 Oxford Street,
Cambridge, MA 02138.

For any questions regarding this opening please contact
Prof. Masahiro Morii morii@physics.harvard.edu.

Harvard is an equal opportunity, affirmative action employer.

MAX-PLANCK-GESELLSCHAFT

Max Planck Institute for Physics invites applications for a

STAFF POSITION IN THEORETICAL PHYSICS

with orientation towards particle physics phenomenology. The appointment may be five-year or permanent, depending on qualifications. Salary and benefits will be determined according to BAT scale (german civil service). The Max Planck Society would like to increase the participation of women in its research activities and encourages women to apply. In cases of equal qualification, preference will be given to the handicapped.

Applications, including curriculum vitae, list of publications, and names of three referees, should be sent before 31 March 2002 to

Leo Stodolsky, Max-Planck-Institut fuer Physik,
Foehringer Ring 6, 80805 Munich, Germany.

http://www.mppmu.mpg.de.

Universität Bielefeld

Fakultät für Physik

Tenured Professorship (C-3) in Theoretical Physics

The Department of Physics invites applications for a professorship in Theoretical Physics in the field of Astro-Particle Physics and Cosmology. The appointment will be made for August 1, 2003.

Candidates should have a strong record of successful research in this field. They should complement the Bielefeld research program and should be willing to cooperate with the existing groups (quantum field theory, particle phenomenology, statistical aspects of particle physics, lattice gauge theory and its numerical simulations). The successful applicant will participate in the general teaching duties of the department, in particular in theoretical physics. Therefore interest and ability in teaching are prerequisites for this position.

Applicants must have a doctorate (or equivalent) in physics and 'Habilitation' or a sufficient record of scientific achievements. Women are especially encouraged to apply.

Applications should be sent by regular mail before May 31, 2002 to

Dekan der Fakultät für Physik, Universität Bielefeld,
Postfach 100131, D-33501 Bielefeld, Germany

e-mail: **dekanat@physik.uni-bielefeld.de**

http://www.physik.uni-bielefeld.de

BESSY

BESSY, the Berliner Elektronenspeicherring-Gesellschaft for Synchrotronstrahlung m.b.H., member of the Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL) operates an electron storage ring as a light-source for the VUV and soft X-Ray range for German and international research groups as a research and service facility. For the development of a free-electron laser BESSY is looking for

Postdoctorals in Physics

Key number FEL 111

to join our scientific team in the design and planning phase of a SASEFEL. Besides theoretical studies on the SASE-process, focal points are the cooperation in the design of superconducting accelerator resonators for a CW linear accelerator, the development of precision components to diagnose ultra-short, intensive electron bunches, the design of bunch compressors, and the development of a photoinjector to produce highly brilliant electron pulses.

A solid background in accelerator physics is expected. Experience at accelerator facilities is an advantage.

The work contracts are based on the Bundes-Angestelltentarifvertrag (BAT/BAT-0) and are limited to the project duration of three years. A further financing of the project will be sought. BESSY is an Equal Opportunity Employer. Among equally qualified applicants, handicapped candidates will be given preference.

Applications with reference to the **above key number** as well as earliest possible date of engagement should be submitted as soon as possible to:

Berliner Elektronenspeicherring-Gesellschaft
für Synchrotronstrahlung m.b.H. (BESSY)
- Personalverwaltung -
Albert-Einstein-Str. 15, 12489 Berlin-Adlershof

ILLINOIS

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

The experimental high energy physics group at the University of Illinois has openings for postdoctoral research associates i) to participate in the CLEO-c experiment at the Cornell Electron Storage Ring, and ii) in the development of real-time embedded software tools for the BTeV experiment.

The main goal of the CLEO-c experiment is to perform precision studies in the charm sector, including D-mixing, decay constants, branching ratios, quarkonia and QCD. The Illinois group designed, built, and is currently operating the trigger system for the CLEO-c experiment, hence experience with high-speed electronics is strongly preferred. The successful candidate will have the opportunity to perform physics analysis on all CLEO datasets, will participate in the operation of the CLEO-c detector (the trigger system in particular), and will have the freedom to contribute to other projects of interest to our group (BTeV, Linear Collider, and neutrino physics).

The main goal of the BTeV experiment is to challenge the Standard Model explanation of CP violation, mixing, and rare decays in the b and c quark system. The Illinois group will develop methodologies and tools for designing and implementing large scale real-time embedded systems, with the Pixel and Muon Triggers of the BTeV experiment as a large-system baseline. Experience with at least three of the following is preferred: high energy triggers, high-speed electronics, FPGA design, DSP software, Linux, C/C++.

Candidates should send cover letter, vita, and arrange three letters of recommendation to be sent to:

Professor Mats Selen, UIUC Dept of Physics,
1110 W. Green St., Urbana, IL 61801.

Applications received by March 31, will be given full consideration. Start date(s) negotiable.

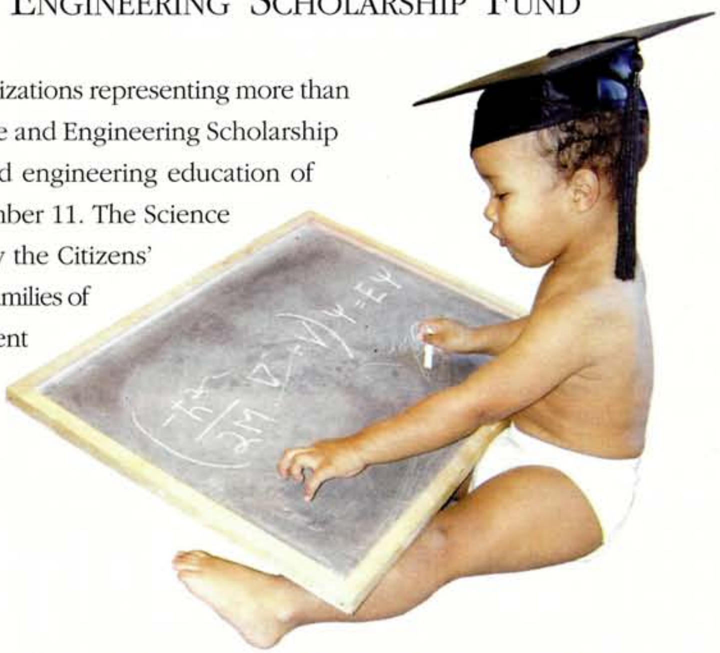
The University of Illinois is an Affirmative Action/Equal Opportunity Employer.

SEPTEMBER 11TH

The Science and Engineering Community Can Make a Difference.

DONATE TODAY TO THE SCIENCE AND ENGINEERING SCHOLARSHIP FUND

In response to the tragedy of September 11, dozens of organizations representing more than a million scientists and engineers have established a Science and Engineering Scholarship Fund. Donations to the Fund will support the science and engineering education of dependents of those who were killed or injured on September 11. The Science and Engineering Scholarship Fund will be administered by the Citizens' Scholarship Foundation of America®. It is part of an overall Families of Freedom Scholarship Fund™ chaired jointly by former President Bill Clinton and former Senate Majority Leader Bob Dole.



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Deutsches Elektronen-Synchrotron
HASYLAB-Research

DESY

DESY is one of the large accelerator centres worldwide. The research spectrum reaches from elementary particle physics and solid state physics up to molecular biology and medicine.

Particle accelerators produce high intensity radiation for most diverse, innovative applications.
For the research at the Hamburg synchrotron radiation laboratory HASYLAB we seek a

Postdoc (m/f)
for research with Synchrotron Radiation

The Hamburger Synchrotronstrahlungslabor HASYLAB is currently operating 80 different instruments using synchrotron radiation from the storage rings DORIS and PETRA. The undulator beamline BW3 provides VUV- and soft x-ray radiation with high flux and high spectral resolution for experiments on atoms, clusters surface and bulk solids.

We are looking for a candidate (m/f) holding a PhD in experimental physics for the development of experimental methods and the investigation of the electronic structure of clusters, nanocrystals and superlattices with photoemission (UPS, XPS) and absorption techniques (XANES, NEXAFS). Interested applicants, who are not older than 32 years, are invited to send their documents incl. 3 referees to our personnel division.

The position is limited to 2 years with the possibility for prolongation by one additional year.

The salary and the social benefits correspond to those in public services (BAT IIa). DESY is open for flexi-time and other modern models for working hours.

Handicapped persons will be given preference to other equally qualified applicants.

DESY is committed to equal opportunities and therefore welcomes applications of qualified women.

Deutsches Elektronen-Synchrotron DESY
code: 22/2002 • Notkestrasse 85 • 22603 Hamburg • Germany
Telefon +49 40 8998-2527 or -2304 • www-hasylab.desy.de
email: personal.abteilung@desy.de
Deadline for applications: 04.04.2002

CORNELL
UNIVERSITY

SENIOR RESEARCH ASSOCIATE IN
ACCELERATOR PHYSICS

Cornell Lab of Elementary Particle Physics is seeking an accelerator physicist or technologist at the Senior Research Associate level. The successful candidate will work with the Cornell team on continuing upgrades of the CESR e+e- storage ring, carrying out of accelerator physics experiments using the Cornell facilities or other accelerators and development work and planning for the Linear Collider.

This is a continuing appointment requiring a PhD in physics or allied field and at least 10 years of experience in accelerator work. The successful candidate will have standing in the international community and have demonstrated leadership capabilities.

Applications containing a curriculum vitae and three letters of reference should be sent to
Prof. Maury Tigner at search@lns.cornell.edu or to
SRF Search Committee, Floyd Newman Laboratory,
Cornell University, Ithaca, NY 14853

Cornell University is an equal opportunity, affirmative action employer.

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Email deutschland@vatvalve.com

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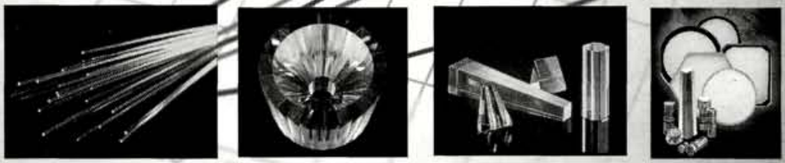

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In Europe – Tel: +44 (208) 309 9021
In Japan – Tel: +81 (45) 474 5786

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SAINT-GOBAIN
CRYSTALS & DETECTORS

BOOKSHELF

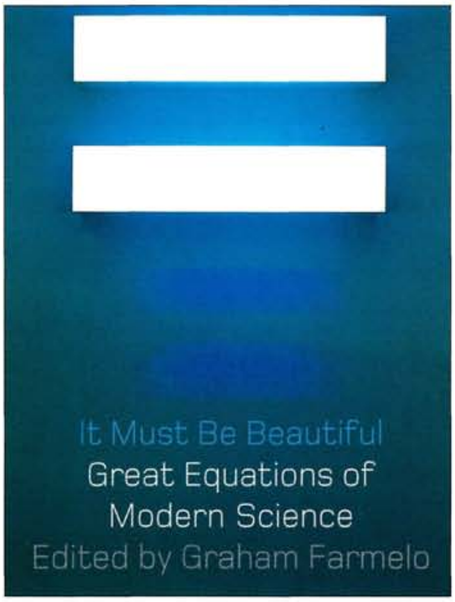
It Must be Beautiful: Great Equations of Modern Science edited by Graham Farmelo, Granta Books, ISBN 1 86207 479 8, £20.

In this lively volume of semipopular essays, 12 leading scientists, historians of science and science writers discuss "beautiful" equations of 20th-century science. Some of the essays are elegant and revealing discourses centring on the equations themselves; others are equally interesting but more historical in nature, sometimes verging on the biographical. Almost all are accessible to a broad audience with a little scientific background.

Roger Penrose and Frank Wilczek thoughtfully discuss the meaning of Einstein's equations of general relativity and Dirac's equation respectively. Steven Weinberg, in his extended afterword, also discusses the Dirac equation, and both Wilczek and Weinberg focus on how the equation has survived despite our significantly altered understanding of its meaning since Dirac's time.

The meaning of the possibly less well known, but certainly beautiful, equations of Yang-Mills theory (as well as such topics as the Higgs mechanism) are also nicely introduced by Christine Sutton. Igor Aleksander provides a rewarding piece on Claude Shannon's great work founding information theory, and John Maynard-Smith discusses some fascinating aspects of the theory of evolution (including his own use of the theory of games in evolution theory, to which this essay provides a good introduction), while Robert May introduces the deceivingly simple logistic equation with its chaotic solutions.

The essays from Graham Farmelo, Peter Galison, Aisling Irwin and Arthur Miller are also stimulating. Since they tended to be less centred on the equations, they leave room for dispute. For example, Arthur Miller makes a remark near the end of "Erotica, aesthetics and Schrodinger's wave equation" (Schrodinger's erotic life is endlessly fascinating to historians) that "the Heisenberg-Schroedinger dispute...was fundamentally one of aesthetic choice" and he points out that physicists use Schrodinger's formalism rather than Heisenberg's matrix mechanics for aesthetic reasons. But Born's great work on the probability interpretation showed that Schrodinger's interpretation of the wavefunction was incorrect, giving, for example, no understanding of the interference terms in a sum of wavefunctions. Furthermore, surely the reason Schrodinger's wavefunction (given the correct interpretation) is so popular is because it is easier to use than matrix mechanics, and because it stimulates visualization in the reader, which ultimately leads to suggestions for applications.



Surprisingly, the contents include an essay on Drake's equation. This is the formula for the number of technological civilizations in our galaxy, depending on such things as the rate of star formation, the likelihood of intelligent life evolving and, least knowable of all, the typical lifespan of a technological civilization. This sums up this collection nicely – you can expect to be entertained and informed in equal measure, often by surprise, and hopefully its success will lead to a second volume.
John March-Russell, CERN.

Great Physicists: the Life and Times of Leading Physicists from Galileo to Hawking by William H Cropper, OUP, ISBN 0 19 513748 5, £24.95.

Physics is the study and formulation by physicists of how nature works. Without physicists, nature would still work but there would be nothing to describe it. Few, even among the physics community, know much about physicists, other than some hype about cult figures like Einstein, Feynman and Hawking.

Only a handful of geniuses, active at a time when their talents can bear fruit, can achieve the milestone discoveries or reveal the new insights that make science history. Here, William Cropper provides biographical snapshots of 30 famous physicists (in 29 chapters – Erwin Schrödinger and Louis de Broglie share a bed), extending through time from Galileo to Hawking, who was born on 8 January 1942, exactly 300 years after Galileo's death. Hawking himself has remarked on this coincidence, and the fact that these dates provide the parameters of this study reflects the book as a whole.

The portraits are drawn from standard biographies, and those who are acquainted with these works will find nothing new. As Cropper explains in his preface, "No claim is made that this is a comprehensive or scholarly study...Read these chapters casually and for entertainment, and learn the lesson that science is a human endeavour."

The first section covers the giant figures of Galileo and Newton, who centuries later still tower over the subject. Subsequent sections deal with thermodynamics (from Carnot to Nernst); 19th-century electromagnetism (Faraday and Maxwell); statistical mechanics (Boltzmann alone); relativity (Einstein supreme); quantum mechanics; nuclear physics (Curie, Rutherford, Meitner, and Fermi); particle physics (Dirac, Feynman and Gell-Mann); and astronomy, astrophysics and cosmology (Hubble, Chandrasekhar and Hawking). Most of the book, therefore, deals with 20th-century figures.

The cast of characters is Cropper's choice and spans the whole spectrum of personality and destiny: tragic figures like Boltzmann, victims of fate like Meitner and Planck, ascetics like Dirac, the flamboyant Feynman, intellectual aristocrats like Gell-Mann and simple geniuses like Rutherford.

The book's subjects include two women (Curie and Meitner) but are mainly confined to Europe and North America. The exceptions are Chandrasekhar, born in India, who spent his research career in Europe and the US; and Rutherford, born in New Zealand, who spent his research career in England and Canada. There are no Russians, which is a pity, considering the wealth of contributions to physics made by scientists in that country and who have been well represented by Nobel awards.

Each biographical snapshot is prefaced by a useful summary, before a fuller account and an appraisal of the science (including some assimilable equations). Each is also labelled by a thumbnail portrait illustration, but otherwise there are no photographs of events (other than a bubble chamber). There is a separate chronology of the main events of the period covered, but there is no systematic indication of exact dates of birth and death, such as in Asimov's work.

However, Cropper has done physics a great service by compiling this book, which compresses between two covers valuable material that would otherwise need a small library.
Gordon Fraser, CERN.

Les neutrinos vont-ils au paradis? [Do Neutrinos Go to Heaven?] by François Vannucci. Published in French by EDPSciences, ISBN 2 86883 559 7, €18.

François Vannucci presented me with his manuscript as his first detective story. I am not surprised that his literary debut takes this form. Vannucci's early career at CERN was followed by a stint at the Stanford linear accelerator. He has been lucky enough to have worked on experiments led by great figures of science in research leading to key discoveries.

That Vannucci is bent wholly on the pursuit of rare game comes as no surprise, and neutrinos with their mysteries were an ideal hunting ground. The nature of the prey lent flavour to the chase. As the secrets of each particle discovered were revealed, they shed new light on the structure of matter at the smallest scale, and on the micro-instants that followed the Big Bang.

Research went on in powerful groups, sometimes numbering several hundred, with ever-more burgeoning budgets. The sociology of this special world had little in common with the atmosphere prevailing in the small university labs of yesteryear. The groups were often led by outstanding physicists whose laurels had often been won as a result of remarkable discoveries – frequently the combined fruit of a great theoretical background and an encyclopaedic knowledge of engineering methods.

But humans being humans, with a genetic baggage built up through scores of millennia of the struggle for life, high-energy physics has included in its ranks the same numbers of men of intelligence, geniuses, madmen, the generous, the envious, the selfish, the disinterested, the brutes, the power-hungry, the poets, the mystics and the cynics as any other group of humanity swept up in any adventure on an equivalent scale. Vannucci introduces us to the way in which the never-ending human comedy is played out at any elementary particle research centre. He brings us into a little world of Parisian physicists headed by a boss with boundless ambition and a fascination for neutrinos. This individual suffers from the shortcomings often found in such people – he is the monster whom no boss would admit to being, yet many ranking physicists will find he has features that smack of their own bosses.

In this book, the research ends in a fiasco that is both material and social. The writer draws a ferocious and desperate fictional portrait of the lives of this team, worn out by failure and disappointed by a leader who had nonetheless fascinated them. Some are still neurotically attached to their boss despite the blind alley that he has led them into. He hangs himself, and we anxiously follow the narrator's efforts to escape the spell that he has cast.

I hope Vannucci's new-found narrative gift will persuade him to inform the public of other secrets from the world of the physicist.
Georges Charpak

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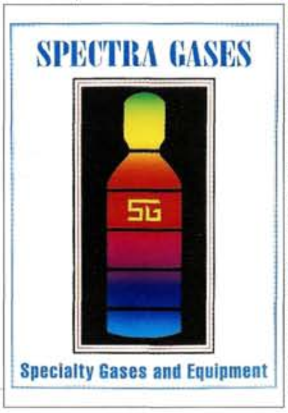

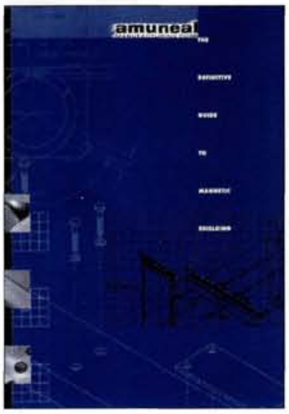

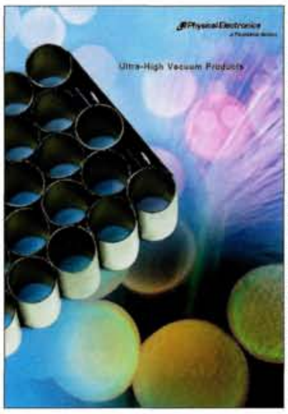

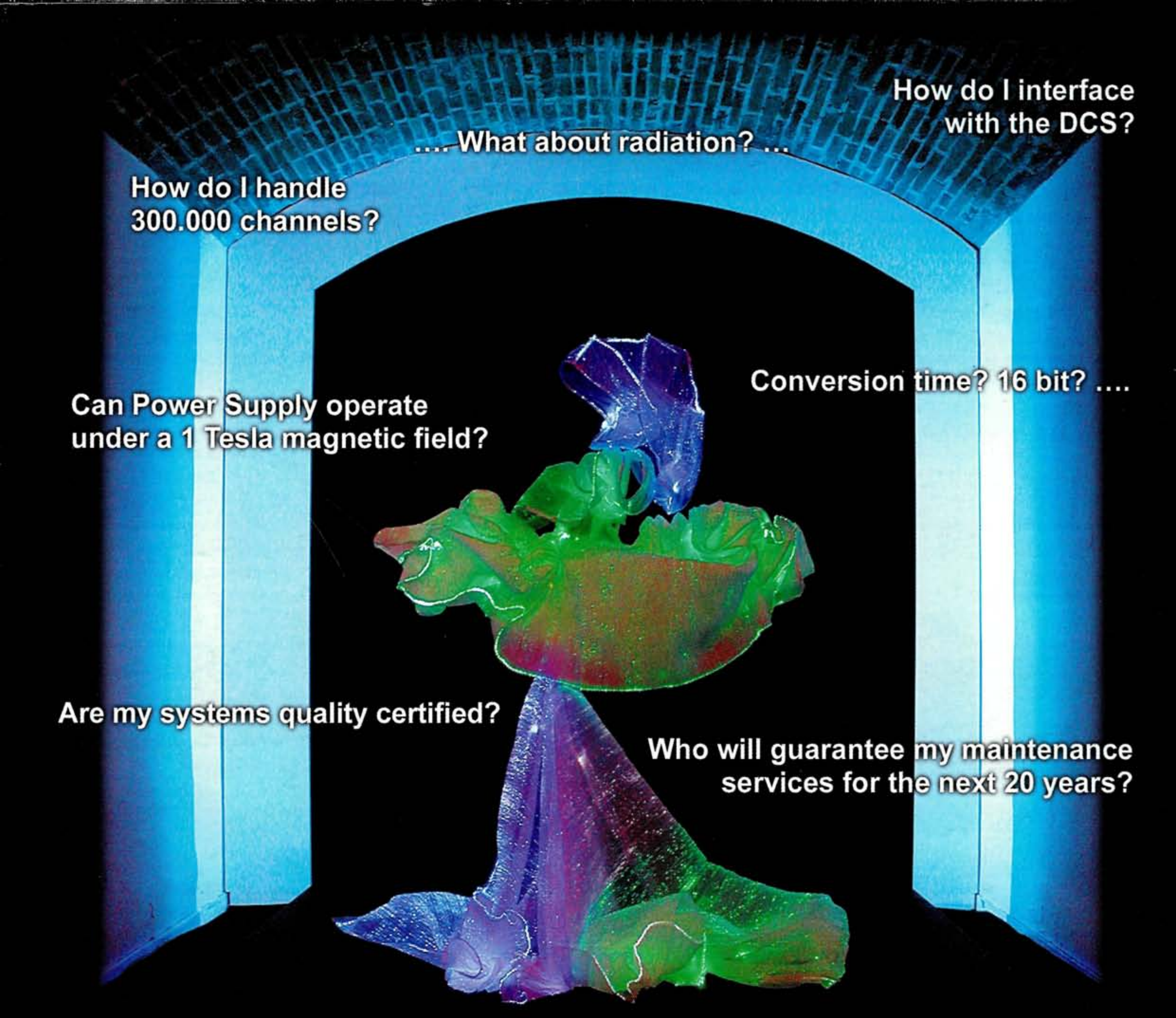
How do I interface
with the DCS?
.... What about radiation? ...
How do I handle
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Conversion time? 16 bit? ....
Can Power Supply operate
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Are my systems quality certified?
Who will guarantee my maintenance
services for the next 20 years?