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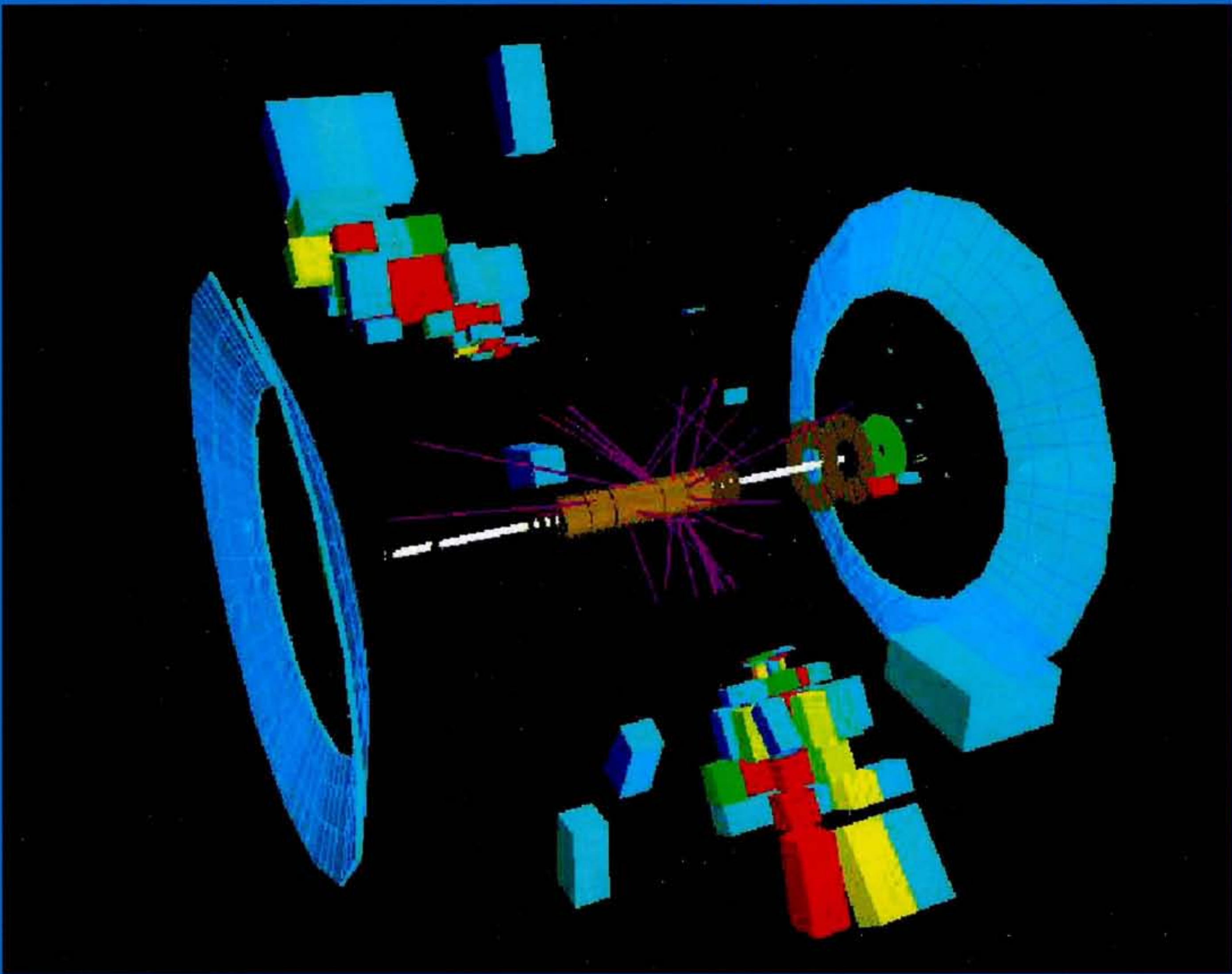

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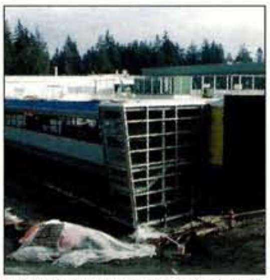
CERN focuses on LHC p5



TRIUMF builds for the future p30

Science meets art p44

Cover: This event display shows jets recorded in the D0 detector at Fermilab's Tevatron. Both the D0 and CDF collaborations have upgraded their detectors to make the most of Tevatron Run II. The collider is now performing well in excess of its Run I best, and is delivering an increased energy of 1.96 TeV. A recent review took a close look at the enticing physics in store. (p13).

NEWS

CERN

CERN Council sets the stage for the LHC

The CERN Council has nominated Robert Aymar, director of the International Thermonuclear Experimental Reactor (ITER), to succeed Luciano Maiani as the laboratory's director-general, to take office on 1 January 2004. Aymar, who will serve a 5 year term, will oversee the start-up of CERN's current major project, the Large Hadron Collider (LHC) in 2007. He was previously with the French Atomic Energy Commission (CEA), and directed the Tore Supra – one of the world's largest tokamaks, based on superconducting toroidal magnets – from its design in 1977 through to its operation in 1988. He is familiar with the challenges presented by the LHC project, as he chaired the External Review Committee that was set up in December 2001 in response to the increased cost to completion of the LHC. Commenting on his appointment, Aymar said: "I am very honoured by this decision, and I thank the Council members for the confidence put in me. CERN is a prestigious institution; I will follow the good examples set by my predecessors, and with the help of the CERN staff, collaborators and supporters, I hope to be able to provide the institution with a future as brilliant and successful as it deserves."

The LHC magnet test hall – one area where Indian scientists work at CERN.

The LHC is now the main focus of activity at CERN, as components for the accelerator arrive at the laboratory from around the world. Council secured the future of the LHC project by unanimously endorsing the new Baseline Plan for 2003–2010, based on a revision of the 1996 financial framework for the LHC, which confirms the target of commissioning the LHC in April 2007. Most of CERN's resources will be committed to the project, leaving only a very limited non-LHC programme. In the plan, overall cost-to-completion budgets (including materials and personnel costs, as well as a contingency) are set for the construction of the LHC and for CERN's share of detector construction.

With the activities surrounding the LHC, CERN's community of scientific users has grown to comprise about half of the world's experimental particle physicists, with nearly a third coming from outside the CERN member states. India has been an active partner for many years, and in the December meeting, Council granted the country observer status. In the past, India has contributed equipment and technical teams to LEP, the PS injector complex and fixed-target experiments. This effort was formalized in a co-operation agreement in 1991, extended in 2001 for a further decade. Then, in the framework of the 1996 protocol signed with the Indian Department of Atomic Energy, India became one of the first non-member states to make significant contributions to the LHC. Indian scientists are also valued members of the ALICE and CMS collaborations, and Indian IT expertise is being put to good use in GRID computing projects.

Recognizing the increasingly global nature of particle physics, and CERN in particular, Council also agreed to create an associate status for non-European states that wish to make more substantial contributions to CERN's activities. The new status would provide a closer partnership, including participation by right in CERN's activities, eligibility of nationals for appointments at CERN, and entitlement of firms in the associate state to bid for CERN contracts. An associate state would contribute to funding at CERN through an annual contribution, but at a lower level than a member state.

KEK

Records tumble at KEKB and Belle

Like all experimental groups around the world, the Belle collaboration at Japan's KEK laboratory is always pushing for higher luminosity, and for the past couple of years the KEKB accelerator team has responded with successive improvements both in hardware and in beam tuning. The latest achievement came in October 2002, when Belle had accumulated an integrated luminosity of 100 fb^{-1} – a tally that no single collider experiment has previously achieved.

A large crowd gathered to celebrate the Belle experiment's first 100 inverse femtobarns. Seated front (left to right): KEK director-general Hirotaka Sugawara and Nobel prize winners Masatoshi Koshiba and Burton Richter.

At the same time, KEKB notched up several milestones itself, with a beam current in the high-energy (electron) ring of 1006 mA, a peak luminosity of $82.56 \times 10^{32}\ cm^{-2}\ s^{-1}$, and integrated luminosities of 149.1 pb^{-1} in an 8 h shift and 433.7 pb^{-1} in a day. These numbers show that KEKB is still steadily progressing towards its design luminosity of $10^{34}\ cm^{-2}\ s^{-1}$.

The teams from KEKB and Belle, together with many others, celebrated these achievements on 28 October, and were toasted by two Nobel prize winners – Professor Masatoshi Koshiba, who shared last year's Nobel Prize for Physics, and Professor Burton Richter, who won the prize in 1976 and was visiting KEK.

TERAHERTZ LIGHT

JLab generates high-power terahertz light

At the Jefferson Laboratory (JLab) in Virginia, US, a multilaboratory team using beams of relativistic electrons has generated broadband terahertz radiation at nearly 20 W average power, several orders of magnitude higher than any other source. The terahertz band – at the far-infrared interface between electronics and photonics – has drawn increasing attention in the past decade, despite the lack of high-average-power sources. The team reported its demonstration of high power in the 14 November edition of *Nature*.

The terahertz work is a spin-off from the superconducting radiofrequency (SRF) electron accelerator central to JLab's mission of probing the quark structure of nuclei (*CERN Courier* May 2002 p19). In a news commentary accompanying the *Nature* report, Mark Sherwin of the Center for Terahertz Science and Technology at the University of California, Santa Barbara, wrote that the high-power demonstration has "opened the door to new investigations and applications in a wide range of disciplines".

Terahertz imaging could reveal interesting features of the many materials with distinct absorptive and dispersive properties in this spectral range, which corresponds revealingly with biomolecular vibrations. The demonstration source would allow full-field, real-time imaging of the distribution of specific proteins or water in tissue, or buried metal layers in semiconductors. High-peak and average-power terahertz sources are also critical for driving new nonlinear phenomena, and for pump-probe studies of dynamical properties of materials.

Left to right: Gwyn Williams, George Neil and Kevin Jordan of JLab's high-power terahertz demonstration experiment.

Non-ionizing terahertz radiation can pass through clothing, paper, cardboard, wood, masonry, plastic and ceramics. It can penetrate fog and clouds. Since the light cannot penetrate metal or water, it cannot be used to inspect seagoing cargo containers or diagnose conditions deep inside the human body. However, eventual applications could include better detection of concealed weapons, hidden explosives and land mines; improved medical imaging and more productive study of cell dynamics and genes; real-time "fingerprinting" of chemical and biological terrorist materials in envelopes, packages or air; better characterization of semiconductors; and widening the frequency bands available for wireless communication.

Whichever applications may ultimately materialize, many will require high-average-power broadband terahertz light. Free-electron lasers (FELs) and fast diodes can produce useful quantities of narrow-band light. Thermal sources and tabletop laser-driven sources can produce broadband terahertz at low average power. The JLab experimenters produced high-average-power broadband emission from subpicosecond electron bunches in the JLab FEL's unique SRF "driver" accelerator – a small, energy-recovering, high-current cousin of the 6 GeV CEBAF, the SRF accelerator that serves JLab's nuclear and particle physics users.

Unlike most linear accelerators (linacs), the JLab FEL's driver linac operates at a very high repetition rate – up to 75 MHz – using SRF cavities and recovering the energy of the spent electron bunches, so that the average current is orders of magnitude higher than in conventional linacs. This energy-recovery linac (ERL) runs with beam current up to 5 mA, compared with only 200 μA in CEBAF. The linac typifies the widening transdisciplinary applicability of smaller accelerators (*CERN Courier* October 2002 p46). In 1999, it provided the first substantial proof of the ERL principle, which is now being incorporated in or envisioned for machines worldwide (*CERN Courier* January/February 2002 p15).

JLab's Gwyn Williams conceived and led the high-power terahertz demonstration experiment, which took place during late 2001 and involved researchers from JLab, Brookhaven National Laboratory and Lawrence Berkeley National Laboratory. They generated the light as synchrotron radiation from very short electron bunches (500 fs) that were accelerated to the relativistic energy of 40 MeV and then transversely accelerated by a magnetic field. Because the electron bunch dimensions are small – in particular, the bunch length is less than the wavelength of observation – the experimenters obtained multiparticle coherent enhancement.

Their demonstration of high-power terahertz radiation (also called T-rays, T-light or T-lux) adds a new dimension to *Science* magazine's 16 August report, in an article called "Revealing the Invisible", that "much research is being directed toward the development of T-ray sources and detectors." Tochigi Nikon Corporation and Teraview (a Cambridge, UK, start-up associated with Toshiba) have begun commercializing low-power terahertz systems. A few hospitals are testing comparatively dim terahertz light for detecting skin cancer. Daniel M Mittleman of Rice University says that for low-power terahertz light, "perhaps the most promising applications lie in the area of quality control of packaged goods." He illustrates by showing how the light can check the raisin count in boxes of raisin bran. Dr Xi-Cheng Zhang, a terahertz expert at Rensselaer Polytechnic Institute, predicts that "the future 'killer application'...will be in biomedicine."

These developments, statements and predictions were made when terahertz average power was still measured in milliwatts, not the tens of watts now demonstrated, or the still higher power that is expected. Nevertheless, the terahertz region still constitutes a gap in the science and technology of light – a region of the electromagnetic spectrum remaining to be better understood, and much better exploited. With commissioning of the 10 kW JLab FEL upgrade under way, Williams and his colleagues are planning an even higher-power terahertz beamline for further attempts to contribute toward those ends.

FREE-ELECTRON LASERS

DESY and SLAC agree to collaborate on X-ray free-electron laser development

Germany's DESY laboratory in Hamburg and SLAC in Stanford, US, have formally agreed to pool resources for the development and promotion of X-ray free-electron lasers. At a ceremony at the Department of Energy in Washington, DC on 1 November 2002, the directors of the two laboratories signed a memorandum of understanding describing the exchange of personnel, equipment, research results and data, as well as know-how. The aim is to accelerate and contribute to the scientific programmes of SLAC's Linac Coherent Light Source (LCLS) project and DESY's TESLA X-Ray Free-Electron Laser (TESLA-XFEL), which, according to current planning, will start operation in 2008 and 2011 respectively. The first step will be the sharing of results from small pilot facilities already under construction in Stanford and Hamburg.

Commenting on the agreement, SLAC director Jonathan Dorfan said: "International collaboration is the most efficient, responsible and cost-effective way of building world-class science facilities. There is already dynamic collaboration between SLAC, DESY and the KEK laboratory in Japan on research and development for a future high-energy physics linear collider. Today's agreement establishes stronger bonds between international centres of excellence."

At the signing ceremony in Washington were (left to right) chair of the DESY directorate Albrecht Wagner, SLAC director Jonathan Dorfan and DESY research director Jochen Schneider.

Albrecht Wagner, chairman of the DESY board of directors, said he is "delighted by this collaboration. Both projects will be enriched and accelerated by the first-class personnel and accumulated expertise at both laboratories."

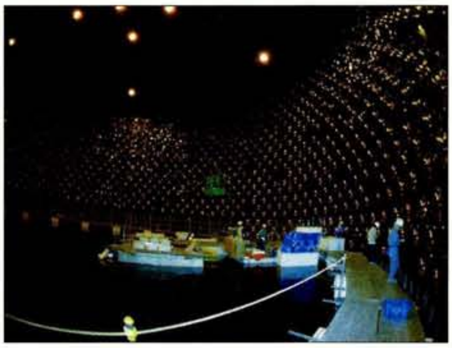
NEUTRINOS

Superkamiokande resumes operation

Just over a year ago, an accident at the Superkamiokande detector in Japan brought neutrino experiments there to a temporary conclusion (*CERN Courier* May 2002 p7). Some 60% of the detector's 11 200 photomultipliers were destroyed. However, the installation of 5200 new photomultipliers is now complete, and data-taking resumed on 8 October 2002.

The instalment of photomultipliers was complete by the end of September, allowing the detector to be refilled with water starting on 3 October. Data-taking resumed as soon as the first row of photomultipliers was immersed, and the refill was complete by mid-December.

To prevent a similar accident from happening again, the new photomultipliers have been encased in rigid bubbles. Their faces are covered with transparent acrylic, while the rest is made of fibre-reinforced plastic.



The Superkamiokande detector – taking data again after an accident destroyed over half of its photomultipliers in November 2001.

JAPAN

J-PARC project is inaugurated

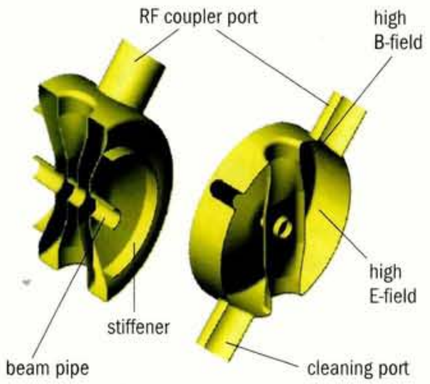
While Japan's KEK laboratory was celebrating the achievements of its B-factory (p5), just 70 km away in Tokai, the official inauguration of the Japan Proton Accelerator Research Complex (J-PARC; formerly called the Japan Hadron Facility) was taking place. This is a joint project between KEK and the Japan Atomic Energy Research Institute.

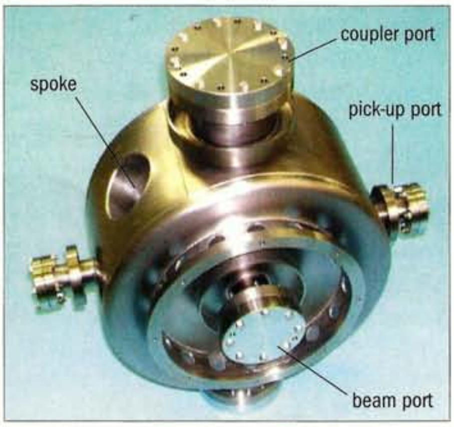
An inaugural lecture on the scope of science in the 21st century was given by former University of Tokyo president Akito Arima, who was also Japanese Minister of Education, Science, Sports and Culture. J-PARC project director Shoji Nagamiya described the status of the project. Funding for J-PARC was secured in 2001, and construction began in June 2002.

Akito Arima (left) and Shoji Nagamiya speaking at the inauguration of J-PARC last October.

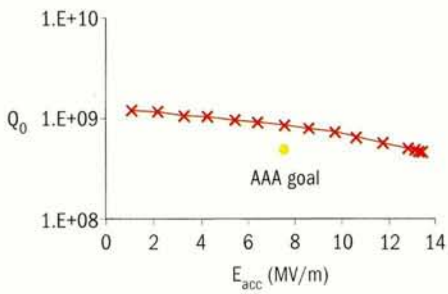
SUPERCONDUCTING RF

LANL develops bespoke cavities for low-energy applications





The Los Alamos spoke cavity in section (left) and assembled. The cavity's diameter is 40 cm.



The cavity's quality factor as a function of accelerating gradient at 4 K shows that the cavity exceeds design expectations.

Superconducting (SC) RF cavities are becoming common in accelerators for high-energy and nuclear physics, and the technologies needed to obtain high fields and high-quality factors in elliptical cavities for electron acceleration have come close to maturity, for example in the TESLA project. However, because mechanical weakness causes some difficulty in adopting elliptical cavities for lower-velocity particles, there is a demand for developing different types of SC cavities, in particular to reduce the costs of future low-energy facilities, such as spallation neutron sources, rare isotope accelerators, and accelerator-driven waste transmutation systems.

One of the promising candidates is the spoke cavity, invented in the late 1980s by Jean Delayen and Ken Shepard at the Argonne National Laboratory. With this, it is easier to extend the acceleration length of half-wave coaxial resonators by adding more spokes in one cavity. A benefit is that for the same frequency a spoke cavity is about half the size of an elliptical one; conversely, a spoke cavity would operate at half the frequency of an elliptical cavity of similar size. This increases the active length by a factor of two, and allows an operating temperature of 4.5 K, with resulting savings in the installation and operating cost of the cryoplant.

In 2002, the Los Alamos National Laboratory (LANL) began developing spoke cavities as part of its Advanced Accelerator Applications (AAA) programme to develop technology for an accelerator-driven waste transmutation system. The LANL team has designed a 350 MHz two-gap spoke cavity, with β (fraction of light velocity) = 0.175, and procured two cavities from the Italian firm Zanon SpA. The diameter of the cavity is 40 cm, the beam aperture is 5 cm and the accelerating length is 10 cm. The two cavities have reached 12.9 MV/m and 13.5 MV/m respectively at 4 K, exceeding the present AAA design goal of 7.5 MV/m by up to 80%. This will help achieve the very high reliability required for the waste transmutation application. Although there are still issues to be discussed, such as drive couplers, multipacting and higher-order modes, this result has encouraged the LANL team to strive for further development of multispoke cavities, which may also prove to be a cheaper and better option for medium velocity ($\beta \sim 0.6$) particles.

An international workshop on the advanced design of spoke cavities was held at Los Alamos on 7–8 October 2002 (see http://laacg1.lanl.gov/spokewk/). For further information about the spoke cavity work at LANL, see http://laacg1.lanl.gov/scrflab/.

NETWORKS

Canadians set record for long-distance data transfer

A Canadian team has succeeded in transferring 1 TByte of data over a newly established "lightpath" extending 12 000 km from TRIUMF in Vancouver to CERN in Geneva in under 4 h – a new record rate of 700 Mbps on average. Peak rates of 1 Gbps were seen during the tests, which took place in conjunction with the iGRID 2002 conference held in Amsterdam in late September. The previous record for a transatlantic transfer was 400 Mbps.

The achievement is particularly notable because the data were transferred from "disk to disk", making it a realistic representation of a practical data transfer. The data started on disk at TRIUMF and ended up on disk at CERN, where in principle they could be used for physics analysis. The data transferred were the result of Monte Carlo simulations of the ATLAS experiment, being constructed at CERN to take data at the Large Hadron Collider.

The transfer used a new technology for network data transfer, called a lightpath. Lightpaths establish a direct optical link between two remote computers, essentially positioning them in a "local-area network" that is anything but local. This avoids the need for more complicated arbitration (or routing) of the network traffic. The link used here to connect TRIUMF and CERN is the longest-known single-hop network.

GRID COMPUTING

Karlsruhe Grid computing centre is inaugurated

Les Robertson, leader of the LHC computing Grid project, takes the stand at the inauguration of GridKa. To the left is FZK executive board member Reinhard Maschuw.

The inauguration colloquium for the Grid Computing Centre Karlsruhe (GridKa) was held on 30 October at the Forschungszentrum Karlsruhe (FZK). FZK hosts the German Tier 1 centre for the Large Hadron Collider (LHC) experiments (ALICE, ATLAS, CMS and LHCb), as well as four other particle physics experiments (BaBar at the Stanford Linear Accelerator Laboratory, CDF and D0 at Fermilab, and COMPASS at CERN).

To cope with the computational requirements of the LHC experiments, a worldwide virtual computing centre is being developed – a global computational grid of tens of thousands of computers and storage devices. About one-third of the capacity will be at CERN, with the other two-thirds in regional computing centres spread across Europe, America and Asia. At the end of 2001, the German HEP community proposed FZK as the host of the German regional centre for LHC computing, and as the analysis centre for BaBar, CDF, D0 and COMPASS. FZK, a German national laboratory of similar size to CERN, accepted the challenge and established GridKa.

After just nine months a milestone has been reached – more than 300 processors and about 40 TByte of disk space are available for physicists from 41 research groups of 19 German institutes. The application software of the eight experiments, as well as grid middleware, has been installed. BaBar was the pilot user and is still the main customer. CDF and D0 have started to use GridKa for the analysis of Tevatron data. During the summer of 2002, ATLAS and ALICE used the centre for their worldwide distributed data challenges. The University of Karlsruhe CMS group uses the centre for analysis jobs.

On 29-30 October, the first GridKa users' meeting was held. On the first day, more than 50 participants attended tutorials about grid computing, the Globus toolkit, software of the European DataGrid project, and the ALICE grid environment AliEn. The second day continued with presentations on GridKa and the status and plans of the experiments. An important contribution was a talk by CERN's Ingo Augustin, who discussed the "European Data Grid: First Steps towards Global Computing".

The highlight of the users' meeting was the inauguration colloquium for GridKa, with almost 200 representatives from science, industry and politics. After an introduction by Reinhard Maschuw of FZK, there were talks about grid computing by Hermann Schunck of the German Federal Ministry of Education and Research, Marcel Kunze of FZK, Tony Hey representing the UK e-Science Initiative, Siegfried Bethke of the Max Planck Institute in Munich, Michael Resch of the University of Stuttgart, Philippe Bricard of IBM France, and CERN's Les Robertson. The central theme of all of the talks was the conviction that grid computing will be an important part of the computing infrastructure of the 21st century. The particle physics community will drive the first large-scale deployment of a worldwide grid, which will have a significant impact on future scientific and industrial applications.

For information about GridKa, see http://grid.fzk.de/grid/. For the LHC Grid Computing Project, see http://cern.ch/LCG/.

TECHNOLOGY TRANSFER

UK boosts technology transfer support

On the PPARC stand at the Britain at CERN exhibition are (left to right), Mike Doran, head of TT networks and strategy at CERN, Nathan Hill of Qi3, Lucy Miles, PPARC industry programme manager, John Attard of Qi3 and CERN's education and technology transfer division leader, Juan Antonio Rubio.

During the past year, the UK's Particle Physics and Astronomy Research Council (PPARC) has begun an innovative approach to strengthening technology transfer with CERN. In September 2001, the UK Office of Science and Technology awarded PPARC £200 000 (€300 000) to appoint a UK Technology Transfer Coordinator for CERN. This role has been contracted to a Cambridge and Oxford-based firm, Qi3, whose task is to foster closer links between CERN and industry. The goal is to bring greater exploitation of science by encouraging wider and more rapid transfer of new ideas, products and processes to UK business.

CERN and PPARC share an interest in technology transfer. Particle physics research naturally pushes existing technologies beyond customary limits and can lead to novel technologies, so CERN's member states have encouraged the laboratory to introduce an active technology transfer policy to demonstrate clear benefits from the research. Technology transfer is now an integral part of CERN's mission, and is implemented via the Technology Transfer Service set up in 2000.

One of the main objectives of PPARC's technology transfer work is to increase the return on its investment in CERN, which currently stands at about £90 million per year. Money to support the new initiative has been awarded from the UK's Public Sector Research Establishment (PSRE) fund. This has been possible because PPARC argued that as the UK has no national particle physics accelerator facility, CERN is effectively the UK's PSRE in the area of high-energy physics.

The Qi3 team of Nathan Hill, John Attard and David Rafe are now working to help UK businesses benefit from the diverse range of technologies developed by scientists at CERN and the associated laboratories in UK universities. Business partnerships, technology licences and spin-out companies will all form routes to commercialization for technologies developed at CERN. The team has already started looking at several opportunities, including novel semiconductor packaging materials, high-speed imaging cameras, accelerator components and cost improvements in the printed circuit board manufacturing process.

For information about this UK initiative, contact Qi3 (nathan.hill@qi3.co.uk or john.attard@qi3.co.uk). For information about CERN's Technology Transfer Service, see http://www.cern.ch/ttdb.

Edited by Archana Sharma

Can Schrödinger's cat learn advanced quantum tricks?

Scientists from the University of Oxford, UK, and the University of California, Santa Barbara, US, have designed a "Schrödinger's cat" that would be the largest quantum mechanical object ever seen. The team, led by Roger Penrose and Dik Bouwmeester, has proposed an experiment that uses an interferometer to split a light beam, with mirrors to reflect the two halves so that they recombine, their waves either adding together or cancelling. In the proposed experiment, the two-fold path of each photon leads to a pair of mirrored cavities in which the photon is reflected back and forth. In one of these cavities, one mirror is just 10 μm wide and mounted on a cantilever such that it moves if a photon strikes it. This mirror is the cat. If the photon behaved classically it would just follow one of the paths, but because it is a superposition it follows both, simultaneously making the mirror move and leaving it undisturbed.

If this experiment proves feasible, it would extend the validity of quantum mechanics by nine orders of magnitude – to an object the size of a blood cell. Previously, the largest objects that have shown quantum behaviour have been of the scale of the 70-atom buckyballs that were persuaded by Anton Zeilinger of the University of Vienna and his colleagues to behave in a quantum manner.

Further reading

C Seife 2002 *Science* **298** 342.

Erwin Schrödinger – is his cat about to come out of the box? (Pauli archive, CERN.)

Edited by Emma Sanders

Gravitational lens sheds light on dark energy

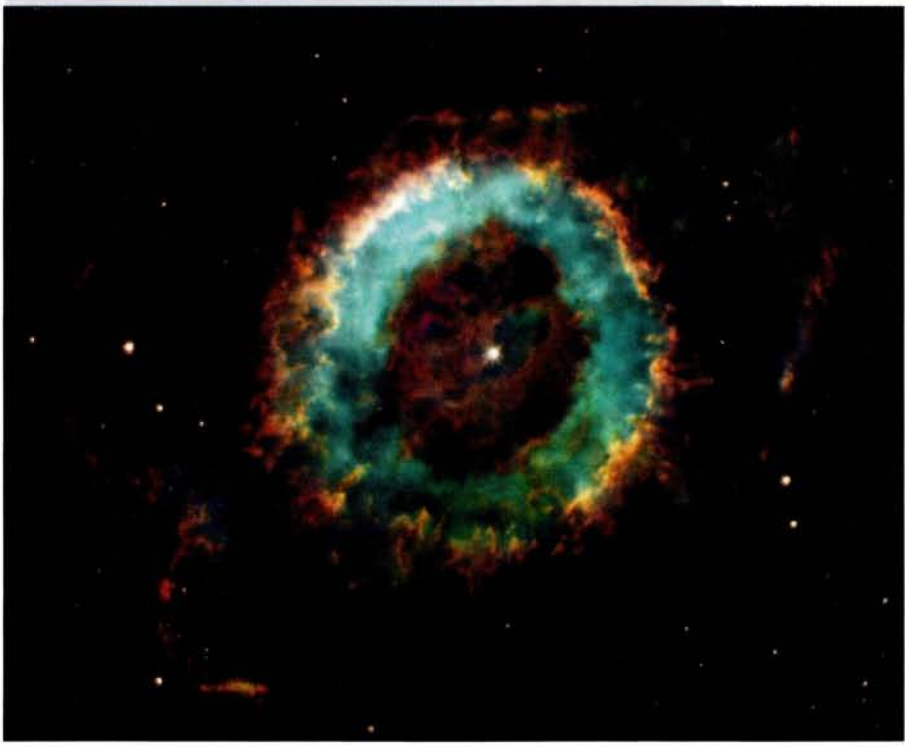
Observations of radio emission from distant quasars have given new weight to the theory of dark energy – a kind of vacuum energy density that changes the acceleration of the universe.

Quasars are incredibly bright – they emit more light than 100 galaxies from a volume no larger than our solar system. In the recent study, radio astronomers searched for quasars that had been gravitationally lensed (Einstein's theory of general relativity shows that the gravitational pull from massive objects is able to deflect rays of light as a lens does).

The astronomers compared the number of gravitationally lensed quasars with the number predicted from observations of intervening galaxies capable of lensing. From this they deduced that around two-thirds of the universe's energy appears to be in the form of dark energy – without the influence of dark energy, only about half the number of lensing events actually observed would be seen.

This is independent evidence in support of dark energy, and confirms previous analysis based on observations of supernovae and of the cosmic microwave background (*CERN Courier* June 2001 p11). The study was carried out using the MERLIN radio interferometer based at Jodrell Bank, UK, the Very Large Array and the Very Long Baseline Array, US.

Picture of the month



The planetary nebula known as "Little Ghost" is the relic of a star with a similar mass to that of our own Sun. After passing through the red giant stage, the star expelled its outer layers into space to leave a faintly glowing nebula and the core of the dying star in the centre. This image was taken using the Hubble Space Telescope. (ESA/NASA.)

Cosmic accelerator reveals hot spots

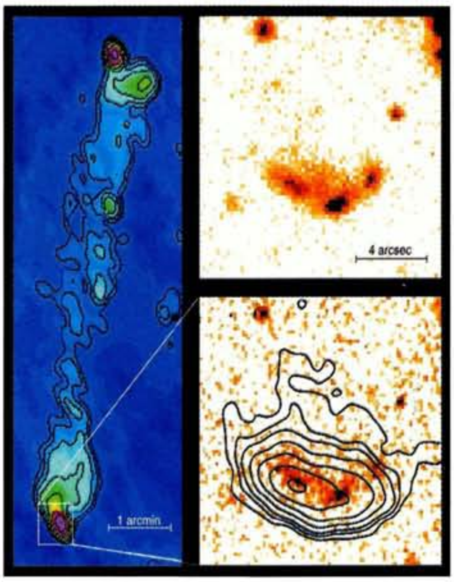


Image showing particle jets at radio (left) and optical wavelengths. (ESO, NRAO.)

Radio galaxies are characterized by enormous jets, up to millions of light-years across, shooting out charged particles at up to almost the speed of light. Bright spots of emission are seen at the end of the jets where the particles plough into the surrounding intergalactic medium, depositing around 10^{44} erg/s in energy.

The exact details of where the particles reach such speeds and how they are accelerated are not clear. The Very Large Telescope in Chile was used to observe radio galaxy 3C445 at optical and near-infrared wavelengths. These observations may help to shed some light on the problem.

The jets of 3C445 extend outwards over 1.5 million light-years either side of the central galaxy. The new observations have been combined with previous observations at radio wavelengths, and show the progression of different areas of acceleration along the jet. The turbulent knots of emission highlight the areas where particles are accelerated, reaching energies that particle physicists can only dream of.

Reference

M A Prieto *et al.* 2002 *Science* **298** 193–195.

Looking forward to physics at Tevatron Run II

It's taken a while, but the world's highest-energy accelerator is back. Fermilab's Tevatron proton–antiproton collider is once again exploring the high-energy frontier, with newly upgraded detectors and a physics programme that will address some of the biggest questions in particle physics.

Spokespersons of the Fermilab collaborations (left to right): Gerald Blazey and John Womersley of DO, and Alfred Goshaw and Nigel Lockyer of CDF.

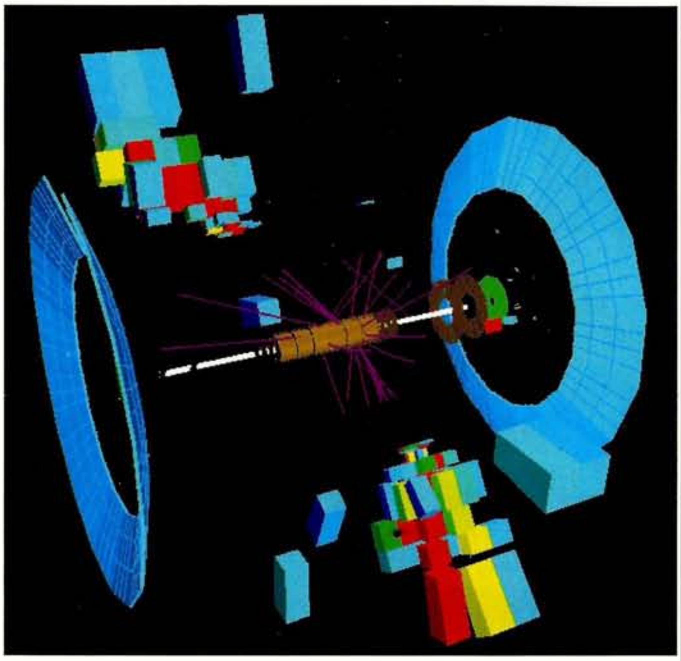
Four CERN scientists took part in the DOE's Tevatron review. Left to right: Francesco Ruggiero, Massimo Placidi, Flemming Pedersen and Karlheinz Schindl.

Tevatron Run II is under way at Fermilab, with upgraded detectors addressing some of the most important questions in particle physics. What is the structure and what are the symmetries of space–time? Why is the weak force weak? What is cosmic dark matter? Why is matter–antimatter symmetry not exact? Until CERN's Large Hadron Collider (LHC) turns on, the Tevatron is the world's only source of top quarks. It is the only place where we can directly search for supersymmetry, for the Higgs boson, and for signatures of additional dimensions of space–time. And it is also the most likely place to directly observe something totally unexpected.

After a somewhat frustrating year, recent progress with the accelerator has been gratifying. Records are regularly being broken for peak and weekly luminosities. The complex is now performing well in excess of its Run I (1992–1995) bests, and is delivering increased energy (1.96 TeV). These improvements have come from well understood modifications, and there is a detailed plan for the next steps. As Steve Holmes, Fermilab's associate director for accelerators, has said: "There is no silver bullet to be found." Rather, we have to make a large number of 10–15% improvements; Holmes notes that $(1.15)^{10} = 4$. The major areas to be tackled are: transfer and acceleration efficiencies; emittance dilution; beam lifetimes in the Tevatron before acceleration; and the role of long-range interactions between the beams. Significant help from other laboratories and from physicists in other parts of Fermilab has also been an important contribution. Fermilab and CERN have set up an exchange programme; Frank Schmidt and Frank Zimmerman from CERN are helping Run II to become a success, and in the future, Fermilab will send machine physicists to CERN to help with LHC commissioning.

The CDF and DO detectors are both working well, emphasizing data-taking efficiency, and are recording physics-quality data. Performance of the tracking, calorimeter and muon detectors is good, and beam-induced backgrounds are under control. CDF is ▷

now running a trigger for B-mesons using displaced tracks from the silicon detector. This is a first at a hadron collider, and has already yielded some very impressive heavy flavour samples. Processing the huge quantities of data from modern experiments is a challenge in itself, as is making it available to the large and widely distributed collaborations. There is a natural synergy between these challenges and current ideas about "Grid" computing (*CERN Courier* December 2002 p46). Both CDF and D0 are already making something like a Grid a reality, using a Fermilab-developed data distribution system called SAM to send their data out to their collaborators. They are also exploring ways for remote physicists to assist in monitoring detector operations.



Jets in the D0 detector are a clear sign that everything is working as it should.

Physics in Run II

The physics goals of Run II involve direct searches for as yet unknown particles and forces, including both those that are predicted or expected (like the Higgs boson and supersymmetry) and those that would come as a surprise. At the same time, we confront the Standard Model through precise measurements of the strong interaction, the quark-mixing matrix, and the electroweak force and properties of the W boson, the Z boson and the top quark. The experiments already have first results in all of these areas. Given the amount of data collected so far in Run II, they are not yet competitive with the results already published from Run I or the experiments at CERN's LEP electron–positron collider, but they show that all the analysis tools are in place and ready.

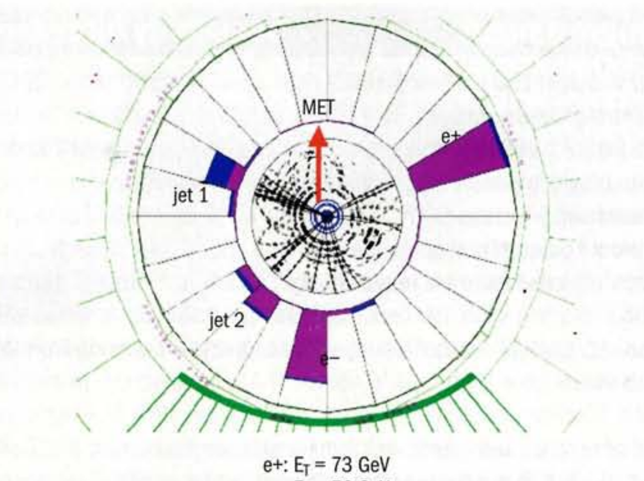
As the world's highest-energy collider, the Tevatron is the most likely place to directly discover a new particle or force. We know the Standard Model is incomplete; theoretically the most popular extension is to make it a part of a larger picture called supersymmetry (which is a basic prediction of superstring models). Here each known particle has a so-far unobserved and more massive partner, to which it is related through a change of spin. If it exists, the lightest supersymmetric particle would be stable, and vast numbers of them would pervade the universe, explaining the astronomers' observations of dark matter. The Tevatron is the only place now available to directly search for supersymmetry. In Run II, the opportunities for discovery include squarks and gluinos, in final states with missing energy (E_T^{miss}) and jets (and lepton(s)); charginos and neutralinos through multilepton final states; gauge-mediated SUSY in E_T^{miss} + photon(s) channels; stop and sbottom; and R-parity violating models. Searches for other new phenomena include leptoquarks, dijet resonances, new heavy W′ and Z′ bosons, massive stable particles, and monopoles.

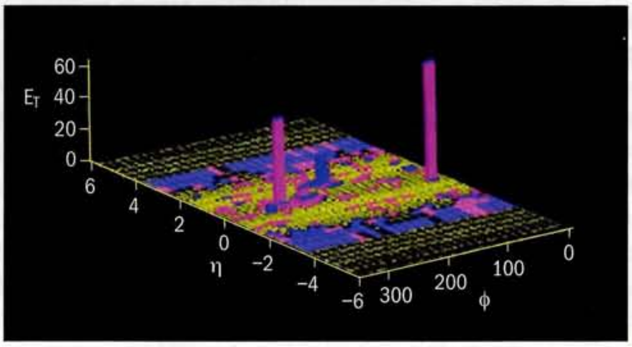
The Tevatron allows us to experimentally test the new and exciting idea that gravity may propagate in more than four dimensions of space–time. If there are extra dimensions that are open to gravity, but not to the other particles and forces of the Standard Model, then we could not perceive them in our everyday lives. However, particle physics experiments at the TeV scale could see signatures such as a quark or gluon jet recoiling against a graviton, or indirect indications like an increase in high-energy electron-pair production. These studies use the Tevatron to literally measure the shape and structure of space–time.

While it is good to be guided by theory, one should also remain open to the unexpected. Therefore both experiments have developed quasi-model-independent (signature-based) searches, which look for significant deviations from the Standard Model. In the Run I dataset, no significant evidence for new physics was found. Perhaps revealing different psychologies, D0 has quantified its agreement with the Standard Model at the 89% confidence level, while CDF has preferred to highlight some potential anomalies as worth pursuing early in Run II.

The experiments have already embarked on a number of searches using Run II data. Work has started on understanding the E_T^{miss} distribution in multijet events as a prelude to squark and gluino searches; trilepton candidates are also being accumulated. At D0, a gauge-mediated SUSY search has set a limit on the cross section for $p\bar{p} \rightarrow E_T^{miss} + \gamma\gamma$. Also at D0, virtual effects of extra dimensions are being sought in e^+e^-, $\mu^+\mu^-$ and $\gamma\gamma$ final states, and limits on the scale of new dimensions at the 0.9 TeV level can already be set. A search for leptoquarks decaying to electron + jet has been carried out. So far, none of the cross sections or mass limits is better than published Run I results, but it serves as a demonstration that the pieces are all in place.

In the Standard Model, the weak force is weak because the W and Z bosons interact with a field (the Higgs field) that permeates the universe. This same field gives masses to all the fundamental fermions. It should be possible to excite this field and observe its quanta – the long sought-after Higgs boson. It is the last piece of the Standard Model, and also the key to understanding any beyond-the-Standard-Model physics like supersymmetry. Finding it is a very high priority. Right now, we are developing the foundations needed for Higgs physics in Run II: good jet resolution; high b-tagging and trigger efficiencies; and a good understanding of all the backgrounds. One area that can be attacked with relatively modest luminosities in 2003 is to search for one or more of the extended suite





On the way to rediscovering top – a top-quark candidate event in the CDF detector.

of Higgs bosons that are predicted in supersymmetric models. Associated production of a SUSY Higgs together with a $b\bar{b}$ pair is enhanced at high $\tan\beta$, and we will be able to improve on present limits with only a few hundred inverse picobarns.

In Run II, we will complement our direct searches for new phenomena with indirect probes. New particles and forces can be seen indirectly through their effects on electroweak observables. The tightest constraints will come from improved determination of the masses of the W boson and the top quark. Both experiments now have preliminary results from their Run II samples of W and Z candidates. They have measured the cross sections at the Tevatron's new centre of mass energy of 1.96 TeV and used the ratio of the W to the Z to indirectly extract the W width. CDF has also taken a first look at the forward–backward asymmetry in e^+e^- production in Run II. Currently, the W mass is known to be $m_W = 80\,451 \pm 33$ MeV; the measurement is dominated by LEP data. Our Run I results fixed the W mass at the 60 MeV level, but it will take a Run II dataset of order 1 fb^{-1} before we can significantly improve the world knowledge of m_W – not a short-term prospect. Given 2 fb^{-1} we will be able to drive the uncertainty down to the 25 MeV level per experiment, with an ultimate capability of 15 MeV per experiment.

The Tevatron collider is the world's only source of top quarks. The top quark was discovered by CDF and D0 in 1995 on the basis of a few tens of events – they are now gearing up to study top quarks in the thousands. The top is the heaviest known quark and, alone among quarks, couples strongly to the Higgs. We need to test its properties and decays with sufficient precision to confirm the Standard Model – is the top really top? Here we can look forward to significant improvements in the short term, because the Run I dataset was so statistically limited. Both D0 and CDF are on the road to "rediscovering" top for the spring 2003 conferences, and both experiments have candidate events. Per inverse femtobarn, we will collect roughly 500 b-tagged top-pair events in the lepton + jets final state. As well as improving the cross-section and mass measurements, we will look for top–antitop spin correlations which can tell us if the top is really the spin-1/2 object it should be, and observe single top production (which allows a model-independent measurement of the Cabibbo–Kobayashi–Maskawa (CKM) quark mixing matrix element $|V_{tb}|$). New techniques are also being developed: D0 has a new, preliminary determination of the top mass from Run I data that uses more information per event, obtains a better discrimination between signal and background than the published 1998 analysis, and improves the statistical error equivalently to a factor 2.4 increase in the number of events. Run II will also test beyond-the-Standard-Model theories that predict unusual top properties, states decaying into top, and anomalously enhanced single top production.

The mixing between the three generations of quarks results in subtle violations of the so-called CP symmetry relating particles and antiparticles. Understanding this symmetry will help to explain why the universe is filled with matter, not antimatter. In the decays of B-mesons, these symmetry violations can be large, and so B-hadrons have become an important laboratory to explore the "unitarity triangle", which relates the elements of the CKM quark-mixing matrix. In Run II, we want to confront the CKM matrix in ways that are complementary to the electron–positron B-factories. CP violation is now established in the B system through the decay $B_d \rightarrow J/\psi K_S$. The measured mixing angle is consistent with the Standard Model, but cannot exclude new physics by itself. The BaBar and BELLE experiments can and will do much more with their data, but the Tevatron can uniquely access the B_s meson, which is not produced at the B-factories, and has therefore been called the "El Dorado" for hadron collider B-physics. By measuring the mixing rate between B_s and $\bar{B}_s$, we can determine the length of one of the sides of the unitarity triangle and complement the B-factories' measurements of its angles. CDF expects to be sensitive to Standard Model mixing with a few hundred inverse picobarns. It will also be interesting to see if there is sizeable CP violation in $B_s \rightarrow J/\psi\,\phi$ (it is expected to be small); while the decay $B_s \rightarrow KK$ at the Tevatron complements $B_d \rightarrow \pi\pi$ that is measured at the B-factories. Together they can pin down the triangle angle γ. There are many other opportunities, such as Λ_b properties and searches for rare decays. CDF already has most impressive results from Run II, building on its Run I experience together with new detector capabilities (silicon vertex trigger and time-of-flight detector). Lepton-triggered signals for $B^{\pm} \rightarrow J/\psi K^{\pm}$, $B^0 \rightarrow J/\psi K^{*0}$ and $B_s \rightarrow J/\psi\,\phi$ are seen, while using the silicon vertex trigger, the purely hadronic modes $B^{\pm} \rightarrow D^0\pi \rightarrow K\pi\pi$ and ▷

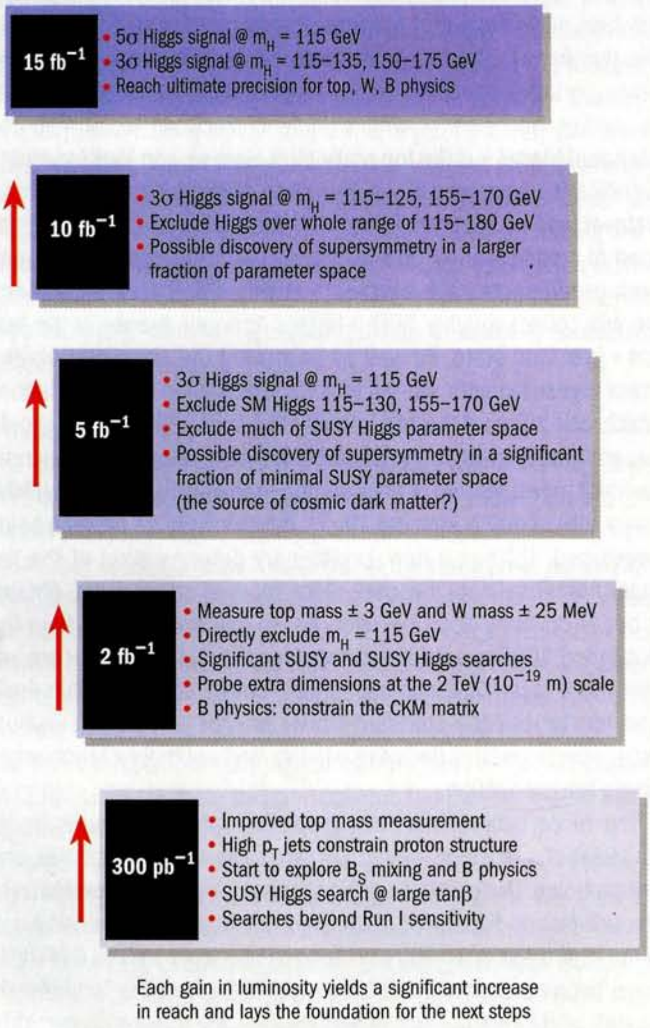


Fig. 1. The physics programme for Tevatron Run II has been classified according to integrated luminosity achieved.

B → hadron hadron are being recorded. We can also look forward to CDF exploiting an enormous sample of charm mesons. In D0, the tools are being put in place for a B-physics programme. The inclusive B lifetime has been measured, and B-mesons are being reconstructed. D0 does not exploit purely hadronic triggers, but benefits from its large muon acceptance, forward tracking coverage, and ability to exploit $J/\psi \rightarrow e^+e^-$.

No one doubts that quantum chromodynamics (QCD) describes the strong interaction between quarks and gluons. Its effects are all around us – it is the origin of the masses of hadrons, and thus of the mass of stars and planets. This doesn't mean it is an easy theory to work with. As well as using hadron colliders to test QCD itself, we find that it is so central to the calculation of both signal and background processes that we need to make sure we can have confidence in our ability to make predictions in this framework. We need to resolve some outstanding puzzles and ensure we understand how to calculate the backgrounds to new physics.

Both CDF and D0 have now measured jet-energy distributions from Run II. CDF are making use of their new forward calorimetry to cover the whole range of pseudorapidity. Jet calibrations are not yet final,

Improvement	Sensitivity increase
luminosity (100 $pb^{-1} \rightarrow 10\ fb^{-1}$)	100
centre of mass energy (1.80 → 1.96 TeV)	1.35
b-pair tagging and other acceptance increases	~2
improved analysis techniques	~2
total effective increase in sensitivity	~500

Table 1. Comparison of top quark sensitivity in Tevatron Run II and Run I.

but already we see events with transverse energies beyond 400 GeV. With the full Run II dataset this will reach as far as 600 GeV, allowing us to pin down the high-energy behaviour of the cross section, and thus the gluon content of the proton (which remains poorly determined at high momentum and a source of uncertainty). Another issue provoking much discussion is the choice of the algorithm used to define jets. D0's Run I data have shown that the two most popular jet definitions (the geometrically based "cone" and the momentum-based recombination "$k_\perp$" algorithms) yield different cross sections for collider data; while qualitatively as expected, quantitatively it is not yet clear whether the differences are understood. We will try to address this question with early Run II data.

Run I left many unanswered questions about heavy flavour (charm and bottom) production. Resolving these is important, because many new particles result in heavy flavour signatures. The inclusive B-meson production cross section lies significantly above the QCD prediction, though it can be made to fit better using resummation and retuned fragmentation functions (from LEP data). For charmonium, the measured cross section requires a large colour-octet component, but that is not consistent with the observed J/ψ polarization. The CDF secondary vertex trigger in Run II is working beautifully, and the resulting huge charm and bottom samples will allow these puzzles to be explored in much more detail. D0 now has preliminary Run II J/ψ and muon + jet cross sections which are the first steps in measuring the charmonium polarization (and thus production process) and the b-jet cross section.

Another QCD-related puzzle is hard diffraction. In these events, a high-momentum-transfer collision occurs, but one of the incoming beam particles appears to leave the collision intact, instead of being destroyed in the process. This observation is rather surprising and needs to be pinned down better and related quantitatively with similar phenomena observed at HERA. Both CDF and D0 have new instrumentation for diffractive physics in Run II. This will allow us to test some of the basic assumptions that have gone into earlier studies, and will provide a sanity check for ideas of Higgs production through this mechanism at the LHC.

Planning for the future

At the same time as the Fermilab accelerator experts have been working to improve Tevatron operations, they have been trying to incorporate the lessons learned into a solid plan for the future. The planning for the accelerator complex is in two phases. The first focuses on US fiscal year 2003, which ends in September 2003. A full plan and schedule are in place. The US Department of Energy (DOE) recently convened a high-level international review committee, chaired by David Sutter of the DOE, to look at this plan. The committee complimented the laboratory on its recent luminosity progress and its focus on the colliding beam programme, and reported that the goals for luminosity in 2003 are highly likely to be met. By summer 2003, each experiment should have recorded around 200 pb^{-1} of Run II data (almost twice the Run I dataset). The centrepiece will be a greatly increased top quark sample, thanks to the higher beam energy and the much improved b-tagging capabilities of the detectors. A first look at B_s mixing will be possible, together with lifetimes and branching ratio measurements from the B, B_s, Λ_b and charm samples. Jet distributions at the highest energies will constrain proton structure, and searches will follow up on Run I anomalies and extend the Run I reach for many extensions to the Standard Model.

The second phase covers 2004 and beyond. It is now clear that it will take somewhat longer than had been anticipated to accumulate the large datasets ultimately foreseen for Run II: such is the price of realism. As long as the Tevatron remains the world's highest-energy collider, it is a unique facility that must be exploited to its limit; this will remain true until the LHC experiments start producing competitive physics results. We are preparing to run the Tevatron until the end of the decade in order to fully realise its physics potential. The Run II physics programme is a broad and deep one, and will answer crucial questions about the universe. There is no threshold at which this starts (figure 1). There is compelling physics to be done each year and with each doubling of luminosity, starting now with a few hundred inverse picobarns, and to the end of the decade with multi-femtobarn data sets. To explore the 5–15 fb^{-1} domain calls for upgrades to the CDF and D0 detectors. Primarily, these involve new trigger systems to handle more than 10 interactions per crossing at the expected luminosity, and new silicon detectors that make use of LHC R&D to sustain the high radiation doses. These upgrades were successfully reviewed by the DOE in September, and are now moving towards approval, with installation planned for 2005–2006.

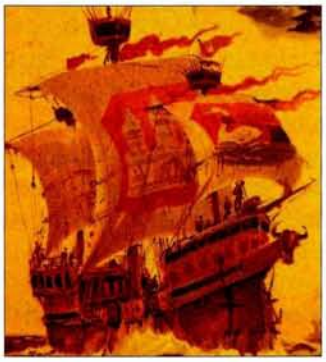
In summary, Run II at the Tevatron provides extraordinary opportunities for the advancement of our knowledge of particle physics. A measure of the increased sensitivity, using top quark production as an example, is shown in Table 1. With a factor 500 increase in sensitivity, the CDF and D0 collaborations are eager to thoroughly explore the energy frontier before passing the baton to the ATLAS and CMS experiments at the LHC.

As Jay Marx from Lawrence Berkeley National Laboratory pointed out at the accelerator review, Run II is a marathon and not a sprint. The combination of high accelerator energy, excellent detectors, enthusiastic collaborations and data samples that are doubling every year guarantees interesting new physics results at each step. Each step answers important questions, and each leads on to the next. This is how we will lay the foundations for a successful LHC physics programme – and hopefully a linear collider to follow.

Gerald Blazey, **Alfred Goshaw**, **Nigel Lockyer** *and* **John Womersley** *(spokespersons of the CDF and D0 experiments).*

Supersymmetry reviewed from the past to the future

Some 400 theorists and experimentalists gathered at DESY in June 2002 for the SUSY02 conference to discuss aspects of supersymmetry and the prospects for unification physics. **Jan Louis** and **Peter Zerwas** report the conference highlights.



Above: Julius Wess (centre) – one of SUSY's founding fathers – registers for the SUSY02 conference taking place in Hamburg, Germany. Left: the poster for SUSY02 featured this painting of the Bunte Kuh, *a 16th century merchant ship from Hamburg that sailed to Amsterdam and London.*

The DESY laboratory in Hamburg, Germany, hosted the 10th International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY02) in June 2002, providing a forum for discussing the present status and future developments of supersymmetry (SUSY). In the week-long meeting – organized by Pran Nath of Northeastern University, US, and Peter Zerwas of DESY – theoretical ideas, analyses of experimental data, the expectations for physics at CERN's Large Hadron Collider (LHC) and the proposed tera-electronvolt range electron–positron linear colliders were on the agenda.

A lively and exciting atmosphere prevailed, with established practitioners exchanging standard and not-so-standard views on the evolution of particle physics with enthusiastic youngsters. The excitement had its roots in the fascinating prospect of addressing fundamental problems of physics in the new generation of accelerators, and in the well-founded hope of hearing about long-awaited breakthroughs that would answer many of the outstanding questions.

Waiting for SUSY

On the experimental side, the conference marked the transition from the experiments completed at CERN's LEP, DESY's HERA, Fermilab's Tevatron and SLAC's SLC colliders, to those at Tevatron Run II and HERA-II and to preparations for physics at future collider facilities.

The experiments at LEP, reviewed by Eilam Gross of Israel's Weizmann Institute, have covered a range of parameter space in the Higgs sector of the minimal supersymmetric extension of the Standard Model, which was summarized by Howard Haber of the University of California, Santa Cruz, US. The experiments seem to have ruled out one of the two parameter ranges singled out previously by theoretical arguments (the so-called small $\tan\beta$ region). However, the large $\tan\beta$ region was not fully covered by LEP and, as Fermilab's Marcela Carena pointed out, it is of great interest for forthcoming Higgs searches at the Tevatron. On the other hand, Wolfgang Hollik of Karlsruhe offered strong support for a light Higgs boson as predicted by supersymmetric theories derived from the theoretical interpretation of precision data at LEP and the SLC.

Ritva Kinnunen of Helsinki, Finland, explained how LHC experiments will be able either to establish or rule out the existence of a light Higgs boson within a few years – in nearly all scenarios as pointed out by Jack Gunion of the University of California, Davis, US. Looking further ahead, CERN's Marco Battaglia discussed how the profile of this fundamental particle could be studied experimentally at a linear collider with very high precision to establish the Higgs mechanism for generating the masses of standard particles.

Robert McPherson of Canada's Victoria University reviewed the search for genuine supersymmetric particles at LEP. In its higher-energy phase, LEP set lower limits on the masses of the scalar partners of leptons close to the beam energy of 100 GeV. Similar limits have been achieved for the fermionic partners of W bosons, while the lightest supersymmetric particle has been constrained to a mass of more than 50 GeV, albeit in a model-dependent way. The masses of squarks and gluinos, on the other hand, have been increased by Tevatron analyses to more than 200 GeV, reported Teruki Kamon ▷

of Texas A&M University, US. This result is complemented by constraints on the stop mass in R-parity violating theories at HERA, discussed by Yves Sirois of the Ecole Polytechnique, France.

The discovery range for SUSY will be extended by the LHC to values of up to 3 TeV, leaving little room in parameter space for supersymmetric particles to hide, as analysed by Brookhaven's Frank Paige. In the future, the properties of such particles could be measured to an accuracy of parts per million in the several hundred giga-electronvolt mass range by machines such as DESY's proposed TESLA collider – presented by Hans-Ulrich Martyn of Aachen – reducing to the percentage level in the multitera-electronvolt range that could be explored by CERN's CLIC. This allows the fundamental parameters in supersymmetric theories to be determined precisely, as Jan Kalinowski of Warsaw, Poland, concluded. Abdel Djouadi of Montpellier, France, Walter Majerotto of Vienna, Austria, and Michael Spira of the Paul Scherrer Institute, Switzerland, described the high-precision theoretical calculations (sometimes to two-loop accuracy) that underpin all of these results and expectations.

More information on supersymmetric scenarios, including the CP-violating sector, examined by Nath, is offered by precision measurements at lower energies. B-decays are affected by supersymmetric particles through virtual-loop effects. Antonio Masiero of Padova, Italy, pointed out that the agreement between present observations and the Standard Model is not at odds with the potential intervention of supersymmetric particles, while Matthias Neubert of Cornell, US, discussed the consequences of rare decays. Errors are still too large to draw definite conclusions in multidimensional SUSY parameter space on flavour physics.

Richard Arnowitt of Texas A&M showed how the discrepancy between the anomalous muon magnetic moment measurement and the predictions of the Standard Model is compatible with wide areas of supersymmetric parameter space. New insight – as presented by Isabella Masina of Saclay, France – might soon be obtained from studying lepton-flavour-violating processes, such as radiative muon decays into electrons. CERN's Concha Gonzales-Garcia and Rabindra Mohapatra of Maryland, US, discussed the recent observation of neutrino oscillations that has prompted new interest in the search for such phenomena in the charged-lepton sector, with novel conversion processes enhanced by virtual SUSY contributions.

Giving mass and energy to the universe

It has long been speculated that the observation of cold dark matter in the universe is related to SUSY. If, as in many scenarios, the lightest supersymmetric particle is stable, it would be a perfect candidate for this new kind of matter. The signals of such particles, accounting for most of the mass of the universe, may be identified in dedicated searches or astrophysics experiments, as described by Keith Olive of Minnesota, US.

Cosmological problems are an excellent test ground for physics at very-high-energy scales. Baryogenesis – crucial for our own existence – can be explained by SUSY mechanisms if stop and Higgs masses are tightly constrained to barely above the present experimental exclusion limits, claimed Carlos Wagner of Argonne National Laboratory and Chicago University, US. A different picture emerges from leptogenesis, presented by Tsutomu Yanagida of Tokyo, Japan,

Tell me where the SUSYs are: Robert McPherson (left) of Victoria University, Canada, and Eilam Gross of the Weizmann Institute, Israel, ask Gordon Kane (centre) of Michigan, US, for theoretical advice.

where decays of heavy Majorana neutrinos with masses close to the grand unification scale are the source for the observed asymmetry of matter and antimatter in the universe.

Cosmological scenarios can cause problems for supersymmetric models. However, as Hans Peter Nilles of Bonn, Germany, explained, in detailed analyses these often appear less severe. Recent data on energy fluctuations in the cosmic microwave background and measurements of the deceleration parameter via the Hubble diagram of Type 1A supernovae suggest a positive cosmological constant. Pierre Binetruy of Orsay, France, emphasized that from a theoretical point of view, these results are more than puzzling, prompting the suggestion from Edward Copeland of Sussex University, UK, that brane-world models may offer alternative scenarios for the cosmology of the early universe.

Connecting to the Planck scale

The most compelling argument in support of the supersymmetric extension of the Standard Model is the unification of the three different gauge couplings – electromagnetic, weak and strong – at the percent level at a scale near 10^{16} GeV. After extrapolation over more than 14 orders of magnitude in energy, the three couplings meet in a tiny area with an accuracy that is much better than expected in many scenarios. This surprisingly successful prediction cannot be matched easily in alternative theories.

Although certain aspects of minimal versions are sometimes problematic, such as too-rapid proton decay, even conventional supersymmetric grand unified theories are still in agreement with data, said Stuart Raby of Ohio State University, US. Graham Ross of Oxford, UK, discussed the possible origin of quark and lepton mass textures in this context. Lawrence Hall of the University of California, Berkeley, US, and John March-Russell of CERN showed how higher dimensions offer additional freedom in building models, and thus are more flexible in removing the stumbling blocks of traditional grand unified theories. While Jon Bagger of Johns Hopkins University, US, discussed questions of SUSY breaking within such models, Edward Witten of Princeton, US, addressed how these models deal with the doublet–triplet splitting of the Higgs field. Riccardo Barbieri of the Scuola Normale Superiore in Pisa, Italy, covered aspects of electroweak symmetry breaking.

Peter Mayr of CERN showed how studying the phenomenological aspects of supersymmetric theories in string theory has been improved by extending the powerful techniques of mirror symmetry to theories with only N=1 SUSY. Furthermore, Jan de Boer of Amsterdam, the Netherlands, showed how string theory can also

The quest for unification

At SUSY02, DESY launched a series of annual lectures with the aim of conveying the fascination of particle physics to a wider audience at the university and in the city of Hamburg, Germany. Edward Witten of the Institute for Advanced Study at Princeton, US, presented the first DESY Heinrich Hertz Lecture on Physics.

DESY director-general, Albrecht Wagner, introduced the series with a description of Hertz's great theoretical and experimental achievements. Born in 1857 in Hamburg, Hertz developed an outstanding talent for physics early in life. After becoming professor of physics at the Karlsruhe Polytechnicum in 1886, he carried out one of the most important experiments of the 19th century – demonstrating the existence of electromagnetic waves. This confirmed Maxwell's theory, in which electricity and magnetism are unified to electromagnetism.

Left: DESY director-general Albrecht Wagner introduced his lecture in front of a portrait of Heinrich Hertz. Right: Edward Witten captivated his audience with his talk "Quest for unification".

It was fitting, therefore, that Witten's lecture covered the quest for unification. He described the steps and arguments leading us from the Standard Model of particle physics to grand unified theories at 10^{16} GeV. An extrapolation of precise experimental data on the three gauge couplings suggests that at this scale, weak and strong electromagnetic interactions merge to form a single unified interaction.

However, the evolution of the couplings of the individual interactions approach a single point accurately only if the Standard Model is extended to a supersymmetric theory. This may also open the door to unifying the genuine particle physics interactions with gravity. This last step may require the expansion of our four-dimensional space–time world to one of higher dimensions as required by superstring theories.

Forthcoming experiments at the LHC and future linear colliders will determine the truth of these ideas. Positive evidence would provide a more comprehensive picture of matter and forces in nature – the "ultimate unification" sought by the most eminent theorists in history.

Witten's presentation is available on video at www.desy.de/susy02/.

be exploited to shed new light on strongly coupled gauge theories, such as quantum chromodynamics, by means of the so-called AdS/CFT correspondence between string and field theory.

If SUSY is realized in nature, high-precision experiments at a linear collider such as TESLA followed by a second phase in a multitera-electronvolt collider such as CLIC, could determine the properties of new particles with very high precision. This is a necessary prerequisite for reconstructing the fundamental supersymmetric theory at the scale where SUSY breaking is localized, emphasized Gordon Kane of Michigan, US. If the SUSY parameters are transmitted at this scale from a hidden world to our visible eigen-world by gravitational interactions, these machines could be used as powerful telescopes to view a domain where particle physics and gravity are linked directly – a vision for the future.

A big step into the new experimental domain of high energy linked with high accuracy – successfully pioneered by LEP and the SLC – was outlined by DESY's director-general, Albrecht Wagner, who presented the well-advanced plans for the TESLA machine, which has an energy target that is close to 1 TeV. If preparations continue as they are now, the particle physics community could be operating this unique tool for SUSY particle diagnostics by 2012.

Living in higher dimensions

The idea of the Standard Model being localized on a four-dimensional brane that is embedded in a higher dimensional space–time can be formulated in string theories. Ignatios Antoniadis of CERN, Mirjam Cvetic of Pennsylvania, US, and Luis Ibanez of Madrid's Institute for Theoretical Physics, Spain, presented models where constructions of this type are carried out explicitly. Phenomenological aspects of extra dimensions on a tera-electronvolt scale are important for experiments at the next generation of particle accelerators. These were discussed by James Wells of the University of California, Davis, and Greg Landsberg of Brown University, US, who focused on the radiation of black holes from high-energy particle collisions.

It is likely that the structure of space–time is modified at ultrashort distances. An interesting aspect of this is the potential non-commutativity of space (and time). This would mean, for example, that measurements of the *x* and *y* co-ordinates of an event would affect each other in a similar way to the position and momentum measurements in standard quantum mechanics, albeit with the interference being characterized by a very-small-scale parameter. Volker Schomerus of Potsdam, Germany, showed that such an idea can be developed within string theory, while Julius Wess of Munich, Germany, developed similar ideas from a field-theoretical point of view.

The possibility that additional strongly coupled gauge groups on a tera-electronvolt energy scale could have a significant impact on the pattern of electroweak symmetry breaking and the Higgs sector was covered by Savas Dimopoulos of Stanford, US, Stefan Pokorski of Warsaw and Lisa Randall of Harvard, US. This possibility is also suggested by reducing elegant theoretical structures in higher dimensions to the standard 3+1 space–time dimensions.

The physics programme discussed at the conference focused on the innermost structures of the microcosm, for matter as well as space–time, but it found them deeply connected with the structure of the universe at large – the final step of ultimate unification.

Jan Louis, *Martin-Luther University, Halle, Germany, and* **Peter Zerwas**, *DESY, Hamburg, Germany.*

Radiation hard silicon detectors lead the way

3D silicon detectors offer exciting new approaches to imaging for particle physics and other fields. **Cinzia DaVia'** explains.

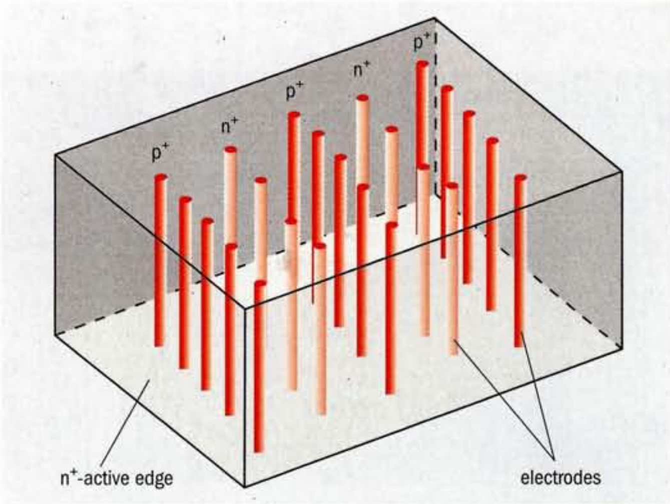


Fig. 1. In 3D detectors, the electrodes and the active edges are fabricated inside the detector bulk using micromachining techniques.

Design parameter	3D	Planar
depletion voltage (V)	<10	70
collection length (μm)	~50	300
charge collection time (ns)	1–2	10–20
edge sensitivity (μm)	<10	~300

Table 1. 3D and planar detector design parameters for a 300 μm thick silicon substrate.

Silicon is the material of choice for the tracking detectors being made for experiments at CERN's Large Hadron Collider (LHC). Silicon offers reliable, fast and cheap detectors. Segmented detectors, processed using microelectronic planar technology, have been used successfully to precisely image the tracks of charged particles in many experiments. The operation of such devices, however, is compromised when they are irradiated with high fluences (above 5×10^{14} particles/cm^2) of neutrons or high-energy hadrons, corresponding to about 5 years of LHC operation at a luminosity of 10^{34} cm^{-2} s^{-1} for detectors closest to the beam. Radiation-induced defects are introduced into the crystal lattice, completely transforming its electrical properties. A dramatic result of these changes is the loss of charge released by a traversing particle, produced for example by a proton–proton interaction in the LHC. This loss of information compromises the reconstruction of important events like the secondary vertices that would be produced by the decay of Higgs bosons into b quarks and antiquarks. Studies by a number of CERN-based research and development collaborations (*CERN Courier* April 1999 p25) carried out in the past 10 years have helped physicists to understand and reduce radiation damage effects in silicon. The fundamental results obtained by these collaborations have contributed much to approximately doubling the useful life of trackers in the LHC's ATLAS, CMS, ALICE and LHCb experiments to almost 10 years of operation.

An order-of-magnitude increase of the luminosity after the initial phase of the LHC experiments is the natural next step to improve the statistics for rare events. This would involve a reduction of the proton–proton bunch crossing to 12.5 ns, and an increase of beam intensity producing a consequent increase of the radiation rate (Gianotti *et al.* 2002). A new form of silicon sensor whose fabrication makes use of micromachining technology as well as the standard processes of planar technology, used for many years both for sensors and their readout chips, can satisfy these severe requirements.

3D solution

3D sensors proposed by Sherwood Parker of the University of Hawaii and colleagues in 1995 (figure 1), initially to solve the problem of charge loss in gallium arsenide detectors, have been fabricated using silicon (Parker *et al.* 1997). Active-edge 3D sensors, proposed in 1997 and also indicated in figure 1, should have efficient charge collection to within a few microns of their physical edges (Kenney *et al.* 2001). In this new configuration, the p^+ and n^+ electrodes penetrate through the silicon bulk, rather than being limited to the silicon wafer surface.

The advantages of 3D design, compared with the traditional planar design, are shown schematically in figure 2. Since the electric field is parallel (rather than orthogonal) to the detector surface, the charge collection distance can be several times shorter, the collection time considerably faster, and the voltage needed to extend the electric field throughout the volume between the electrodes (full depletion) an order of magnitude smaller, for 300 μm thick silicon (table 1).

This technology has many potential applications, for example in extreme radiation environments, luminosity monitors, and medical and biological imaging (Kenney *et al.* 2001, Parker *et al.* 2001). ▷

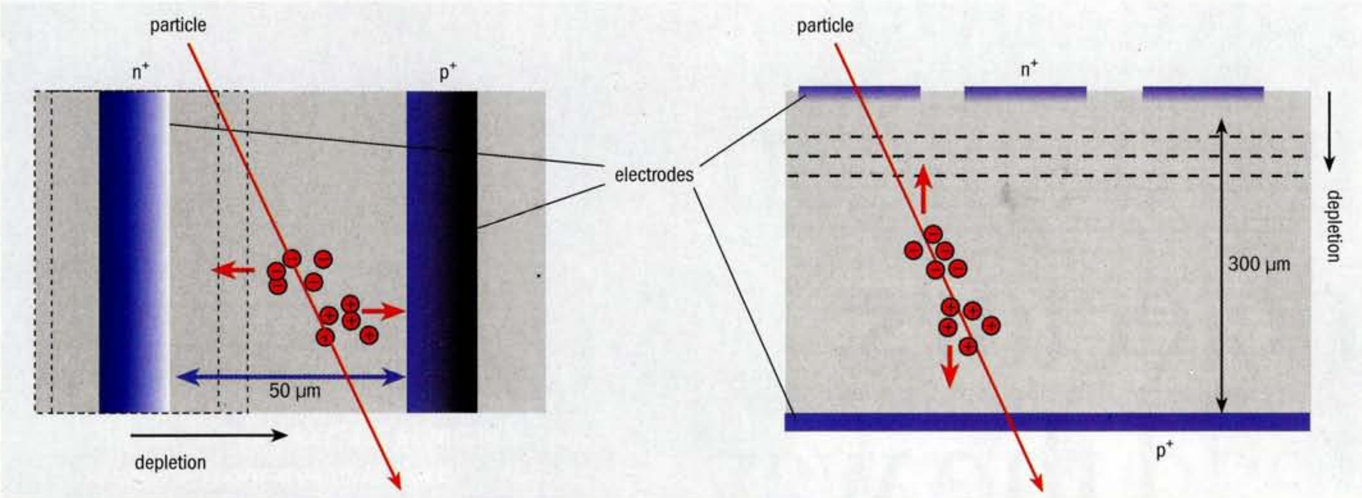


Fig. 2. A 3D detector (left) compared with a standard planar detector (right). The same charge generated by a traversing ionizing particle (approximately 24 000 electrons) is collected by a 3D detector over a much shorter length at higher speed, and with full depletion bias voltage 10 times lower (see table 1).

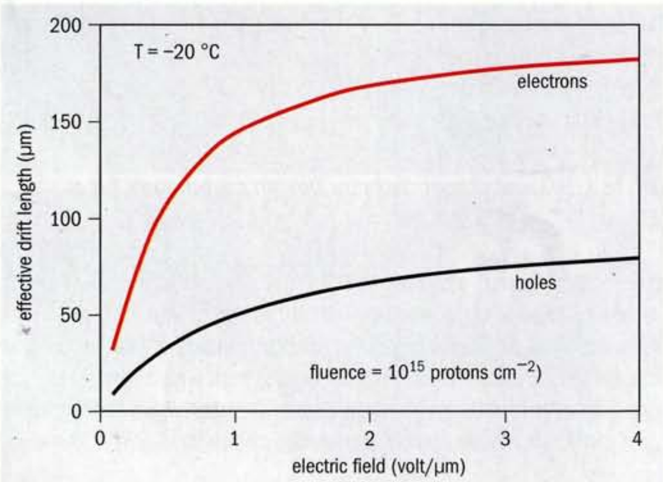


Fig. 3. The effective drift length of electrons and holes in silicon after an irradiation proton fluence of 10^{15} particles/cm^2 operated at −20 °C.

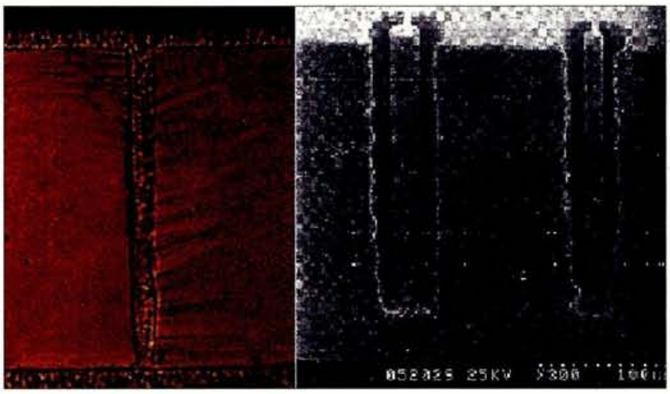


Fig. 4. Right: a 290 μm deep etching of a C-shaped hole, followed by the deposition of 2 μm of polycrystalline silicon. The good quality of the etching and the uniformity of the deposition are revealed by a saw cut through the holes that misses the pillars. Left: a broken wafer showing how the electrode looks after being filled with polysilicon.

Radiation effects in silicon detectors

Insulating layers on the surface of detectors charge up when traversed by charged particles. This can be tolerated. Damage to the bulk by both charged and neutral particles, however, is more difficult to combat. It takes just 25 eV to knock a silicon atom out of its lattice point. This leads to the formation of defects, in some instances involving impurity atoms in the material. Defects can be electrically active, leading to increased space-charge, leakage current and charge trapping. Increased space-charge prevents the electric field from penetrating the material unless high bias voltages are used. Moreover, radiation-induced space-charge can increase after the radiation source is removed, a phenomenon called reverse annealing. It has proven necessary to cool between −10°C and −20°C to reduce the leakage current and reverse annealing. The addition of oxygen into wafers has been found to reduce the space-charge build-up and improve reverse annealing for damage caused by charged particles. The use of multiguard structures, where biased guard rings surround the active detector area, has allowed high-voltage operation at the expense of larger inactive regions at the detector edge. Guard structures are used for achieving long-term stability, to reduce the current in the active area, and to prevent avalanche breakdown when high bias voltage is required. Cooling below 200 K also reduces the radiation-induced space-charge, which aids detector operation – a phenomenon called the Lazarus effect (Palmieri *et al.* 1998).

The electric field inside a silicon detector must be as large as possible. The risk of trapping of the carriers decreases if the electric field is large (figure 3). The effective drift length of a carrier ($L_{drift} = v_{drift} \times \tau_{tr}$) depends on the electric field value via the drift velocity v_{drift}. τ_{tr} is the trapping time of the carriers (the time taken by an electron or a hole to travel towards the collecting electrode before being trapped by a defect). It is clear that electrons will make a greater contribution to the signal, since their drift length is three

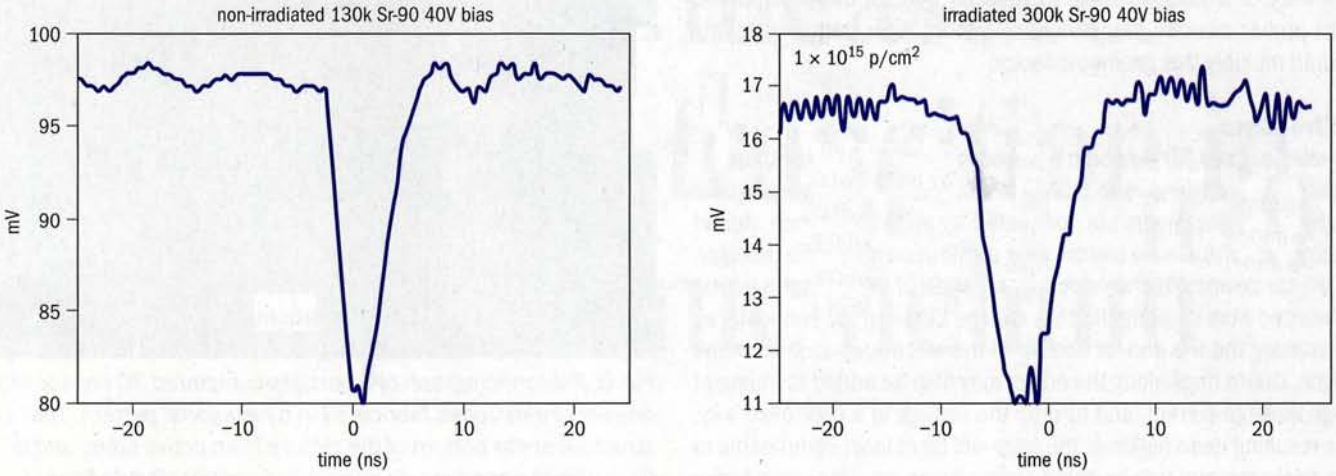


Fig. 5. Oscilloscope traces of ionizing particle signals in two 3D detectors operated at 130 K and 300 K before (left) and after (right) heavy irradiation. The bias voltage is 40 V in both cases, and the rise times are 1.5 ns with a pulse duration of 5 ns, and 3.5 ns with a pulse duration of 10 ns.

times longer than that of holes. Drift lengths decrease linearly with fluence, making devices with a large collection distance inefficient at high radiation levels (DaVia' and Watts 2002).

Prior to irradiation, electrons and holes contribute equally to the signal in the case of a pad detector where both electrodes have the same area. For a detector with a segmented collecting electrode, the larger fraction of the signal is produced by the carrier that travels towards it. This can be derived using a famous theorem due to Simon Ramo and (independently) William Shockley (Ramo 1939; Shockley 1938). Since electrons are harder to trap, it is important that the amplifier is connected to the n^+ electrode, which collects electrons in a segmented detector. This is true for the ATLAS and CMS pixel detectors.

An example of the current state of the art is well illustrated by the pixel layers of the ATLAS vertex detector, which will be placed as close as 4 cm from the interaction point. The signal is collected on the n^+ side of the detector. The n^+ on n design is feasible by "spraying" a thin, moderately doped p layer between the n^+ contacts, to prevent them from being shorted by electrons attracted to trapped positive charge at the interface between the field oxide and the silicon. The active thickness of the detector is reduced from the standard 300 μm to an average of around 230 μm to enhance the penetration of the electric field in the active area. This thickness, together with multiguard structure, allows operation up to around 600 V bias. This is a field of about 3 V/μm. Oxygenation of the wafer prior to detector processing reduces the radiation-induced space-charge, and consequently allows the detector to be fully depleted even after a fluence of 10^{15} particles/cm^2. Under such conditions, about 98% of the signal charge generated in the detector is collected.

This result demonstrates that a combination of oxygenation and electron collection leads to efficient operation at reasonable bias voltages. This is important for power dissipation and thermal runaway, and has been further demonstrated by recent results from a group at Liverpool University, where similar conclusions were reached using a p-type silicon substrate (Casse *et al.* 2002).

3D detectors

Deep reactive ion etching has been developed for micromechanical systems. This allows microholes to be etched in silicon with a thickness-to-diameter ratio as large as 20:1. In the 3D detectors presently processed at Stanford, US, by a collaboration involving scientists from Brunel University in the UK, as well as Hawaii and Stanford, this technique is used to etch holes as deep as several hundred microns, at distances as short as 50 μm from one another. These holes are then filled with polycrystalline silicon doped with either boron or phosphorus, which is then diffused into the surrounding single-crystal silicon to make the detector electrodes (figure 4). The silicon substrate used for this process is p-type, and the crystal orientation is <100>, where 1,0,0 represent the crystal plane co-ordinates. Silicon atoms line up in certain directions in the crystal. <100> corresponds to having a particular crystal plane at the surface, and is preferred for a better surface quality. Once the electrodes are filled, the polycrystalline silicon is removed from the surfaces, and the dopant is diffused. Aluminium can be deposited in a pattern that will depend on how the individual electrodes are to be read out.

3D geometry and active edges would have been an impossible dream only 10 years ago, and now they provide a natural way to construct imagers for charged particles and X-rays

The response of a 3D detector, where all the electrodes have been connected together by an aluminium microstrip, is shown in the oscilloscope traces of figure 5. The fast radiation hard electronics used for this test were designed by the CERN microelectronics group (Anelli *et al.* 2002). The fast response, observed after 10^{15} protons/cm^2 at room temperature and 40V bias voltage, confirms that the combination of short collection distance and high electric field can improve the radiation ▷

tolerance of silicon detectors by possibly a factor of 10 compared with planar devices. Improvement factors from better materials should multiply this geometric factor.

Active edges

An example of a 3D sensor in the process of fabrication is shown in figure 6. The electrodes in this case are distributed in a hexagonal pattern, and the edges are completed by an active trench, doped appropriately to set the electric field distribution inside the detector. In planar devices, the conducting cut edge of the sensor must be prevented from shorting the bias voltage between the two surfaces by spacing the top and/or bottom of the electrodes away from the edges. Guard rings along the edges may also be added to intercept edge leakage current, and to drop the voltage in a controlled way. The resulting dead region at the edge will be at least comparable to the thickness and can be three or four times as large, so a space must be allowed for a series of guard rings.

In 3D devices, the voltage at corresponding points on the top and bottom surfaces is equal, so there is no voltage drop across the edges. Etched trenches, filled with suitably doped polycrystalline silicon, can then be used to make the edge into an electrode, with depletion possible to within a few microns of the physical edges. The freedom of such detectors from insensitive edge regions can be of great advantage when several devices are combined to cover large areas, or when the detector needs to be placed very close to the beam.

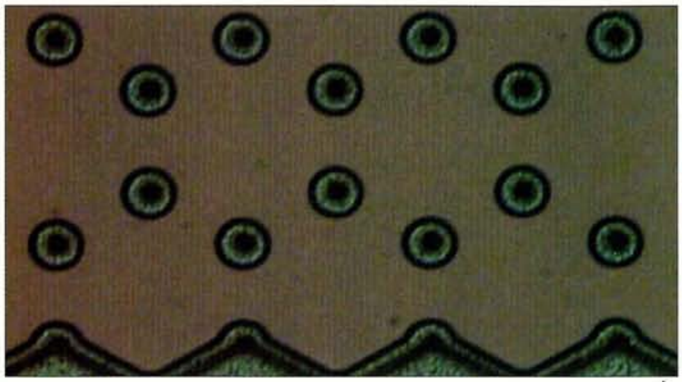


Fig. 6. Photomicrograph of a partially completed 3D sensor with one set of electrodes fabricated in a hexagonal pattern. The structure at the bottom of the picture is an active edge, and is filled with the appropriate dopant to form the electric field inside the sensor.

Silicon detectors are a good example to demonstrate how the particle physics community can benefit from the technology developed by the microelectronics industry. 3D geometry and active edges would have been an impossible dream only 10 years ago, and now they provide a natural way to construct imagers for charged particles and X-rays. The structural molecular biology community will take advantage of 3D detectors to study protein folding, while research is ongoing to apply this technology to X-ray mammography. Other groups are exploring alternative methods for fabricating 3D structures (Pellegrini *et al.* 2002).

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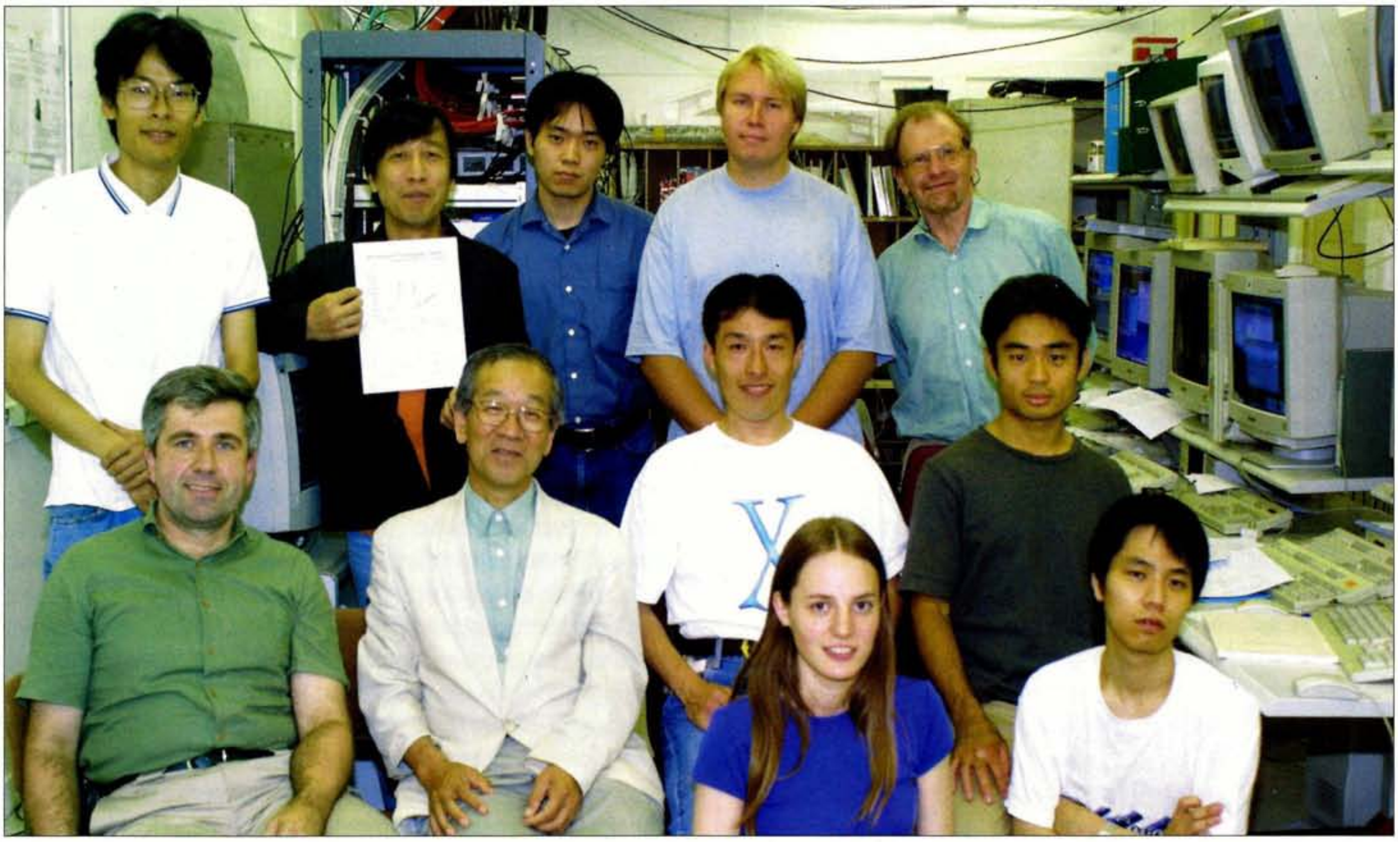
Cinzia DaVia', *Brunel University, UK.*

ASACUSA measures microwave transition in antiprotonic helium

The ASACUSA collaboration has reinforced its status as a paragon of precision physics by following up its impressive six parts in 10^8 measurement of the antiproton's charge and mass with new measurements of its magnetism. **John Eades** reports.



Members of the ASACUSA team proudly display the microwave experiment result.

Recent months have seen the much-awaited synthesis of cold antihydrogen atoms by two groups working at CERN's Antiproton Decelerator (AD; Amoretti *et al.*; Gabrielse *et al.*). The aim of these collaborations is to compare spectral features of hydrogen and antihydrogen as a test of the CPT invariance principle, which states that under certain realistic assumptions about the quantum fields that represent them, matter and antimatter will always behave in the same way. However, it is not just in antihydrogen atoms that CPT symmetry can be tested, as the ASACUSA collaboration is demonstrating.

If CPT violation occurs anywhere in nature, it must be very small, and experimental searches for it have usually been done with kaon beams. These beams are coherent superpositions of particle and antiparticle waves, and since slightly different masses imply slightly different de Broglie wavelengths, a limit of a few parts in 10^{19} can ▷

Inside antiprotonic helium

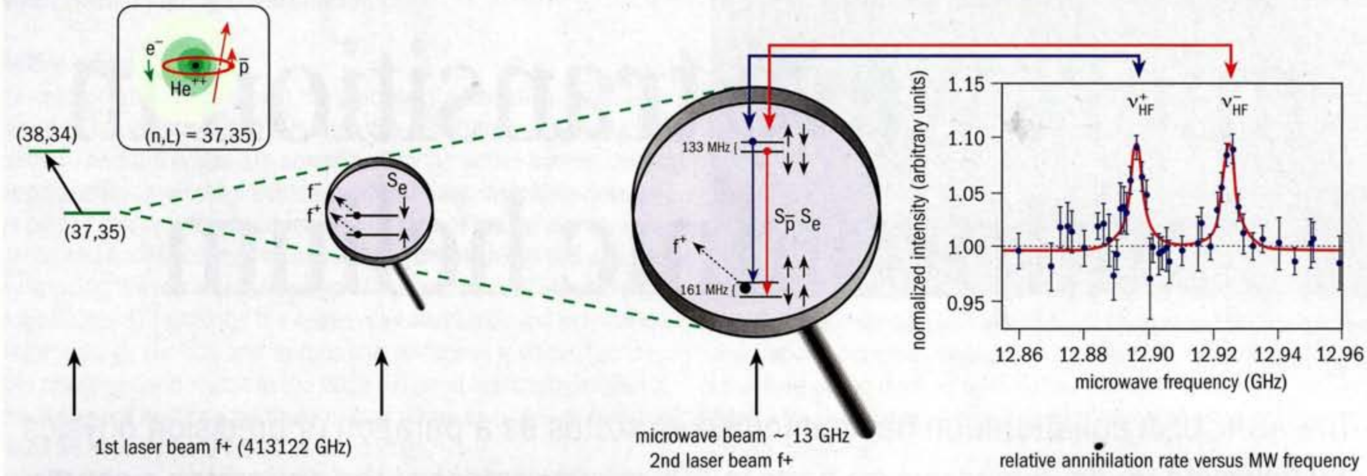


Fig. 1. ASACUSA's triple resonance experiment on the antiprotonic helium atom.

In the antiprotonic helium atom (figure 1, inset), a 1S electron and an antiproton are bound to an alpha-particle nucleus by the Coulomb force. As the 1S electron carries no orbital angular momentum, its magnetic dipole moment $\vec{\mu_e} = g_e^s \vec{S_e} \mu_B$ comes only from its spin, $\vec{S_e}$. The dipole moment due to the antiproton spin $\vec{S_{\bar{p}}} \times h$, is a thousand times smaller, but it carries a large orbital angular momentum $L_{\bar{p}} \approx 35 - 40h$, and this dominates the value of its total magnetic dipole moment $\vec{\mu_{\bar{p}}} = (g_{\bar{p}}^l \vec{L_{\bar{p}}} + g_{\bar{p}}^s \vec{S_{\bar{p}}})\mu_{\bar{N}}$.

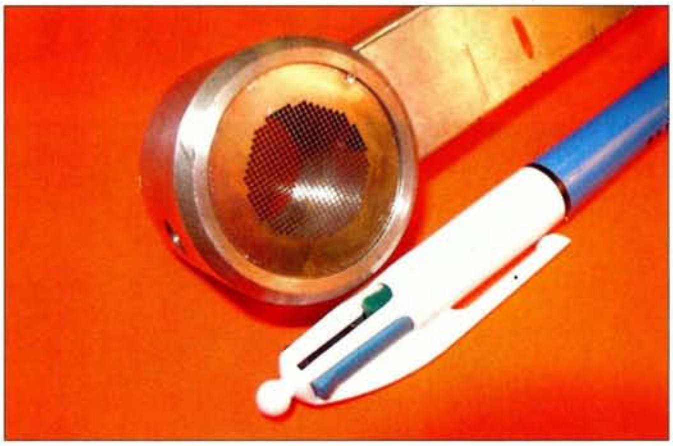
In these expressions the various "g-factors" measure the coupling of a particle's magnetism to its orbital or spin electric currents, $\mu_B \equiv Q_e h/(4\pi m_e c)$ is the Bohr magneton and $\mu_{\bar{N}} \equiv Q_{\bar{p}} h/(4\pi M_{\bar{p}} c)$ is the antinuclear magneton.

As the two leptonic and hadronic magnetic dipoles μ_e and $\mu_{\bar{p}}$ interact at a distance similar to the electron–proton distance in the hydrogen atom, the magnetic properties of antiprotonic helium are qualitatively similar to those of ground state H and $\bar{H}$ atoms. However, the frequency needed to flip the electron spin is expected to be near 13 GHz in antiprotonic helium rather than the 1.42 GHz value for the hydrogen atom's ground state; that required for the antiproton spin-flip should be a few hundred MHz. The helium nucleus, having no spin, plays no role.

These arguments are more quantitatively displayed in figure 1 for the state with principal quantum number $n = 37$ and orbital quantum number $L = 35$. The figure shows the electron spin up and down hyperfine doublet (left centre), and at higher resolution, the further splitting of these into superhyperfine doublets with antiproton spin up and down (right centre). In the experiment, antiprotonic helium atoms were created in cold helium gas contained in a microwave cavity (see picture on opposite page). The frequency of microwaves entering the cavity through a waveguide could then be tuned to search for stimulated electron spin-flip transitions. But why are two laser beams required in addition to the microwave beam? Certain atomic states like (37,35) can be metastable against annihilation, while adjacent ones, for example (38,34), reachable from them by laser stimulation, are not (*CERN Courier* October 2001 p35). A laser pulse at frequency f^+ stimulates transitions between the two, forcing atoms in the two states with electron spin up to annihilate, but not in those in with electron spin down, for which the transition frequency f^- is slightly different. A resonant microwave pulse will then flip some of these untouched "electron-down" atoms to the "up" state, and a second f^+ laser pulse following the microwave pulse can be used to detect this population transfer. The experiment was done by scanning the microwave frequency near the QED-calculated down–up frequency, and looking for resonant peaks in the ratio of annihilation rates forced by the two laser pulses. The resulting frequency spectrum is shown on the right.

be placed on any kaon particle and antiparticle mass difference by a detailed study of the interference effects observed in them. However, kaons are mesons, containing both a matter and an antimatter quark, and CPT violation might not show up in conjugate pairs of this kind. Protons (p) and antiprotons ($\bar{p}$) are made only of quarks and antiquarks respectively; hydrogen (H) and antihydrogen ($\bar{H}$) atoms are made only of quarks and leptons, and of antiquarks and antileptons. In such systems, CPT violation at some small but crucially important level can certainly not be excluded with equal rigour.

Although we have no quantum interferometer for the CPT conjugate H–$\bar{H}$ pair, we do have powerful laser beams, which we can use to probe its members with extremely high precision. Since no other assumption than CPT invariance need be made in interpreting what happens when one of them is removed from a spectrometer and replaced by the other, the H–$\bar{H}$ pair is in many ways the ideal CPT test-bench. However, it is very difficult to produce antihydrogen atoms moving so slowly that they do not drift out of a laser beam before it can stimulate one of their spectroscopic transitions. Solutions to this problem are now evidently in sight, but many difficulties remain before the extreme sensitivity afforded by laser tech-



ASACUSA's microwave cavity. The fine mesh windows admit the pulsed antiproton beam on one side and the two laser beams on the other with 90% efficiency. They are, however, opaque to microwave energy introduced into the cavity through the rectangular waveguide.

niques (and indeed necessary for meaningful tests of CPT invariance) can be reached.

ASACUSA's alternative approach involves the much easier task of replacing an electron in an ordinary atom by an antiproton and measuring the spectroscopic frequencies of the resulting "antiprotonic atom". However, we do not have the CPT conjugate "protonic antiatom" with which to compare it, and must calculate its transition frequencies from quantum electrodynamics, assuming the known proton values for the antiproton (and also that the calculations were done properly). In this way, the ASACUSA collaboration has determined the relative charge and mass of the proton–antiproton pair to six parts in 10^8 (Hori *et al.*) by laser-stimulating optical-frequency transitions in antiprotonic helium (figure 1) – the only variety of antiprotonic atom known to live long enough to permit such quantum gymnastics (*CERN Courier* October 2001 p35).

How might we use this atom to investigate the antiproton's magnetic properties? Unknown large-scale fields are sometimes measured by determining the energy required to turn over a magnetic dipole of known strength placed in them. At the atomic scale, this is the basis of classic experiments on magnetic effects like the ground-state hyperfine splitting in hydrogen. Likewise, by measuring the energy of the photon needed to flip the known magnetic dipole of the electron in the unknown magnetic field of the antiproton, we can measure the latter particle's own dipole field.

ASACUSA has now carried out such an electron spin-flip experiment (Widmann *et al.*), in which two laser beams and a microwave beam were tuned to resonate with the antiprotonic helium atom (see box and figure 1 for an explanation of this "triple resonance" experiment). Microwave resonance peaks occurred at 12.89596 and 12.92467 GHz, corresponding to electron spin-flips in states of the atom with antiproton spin "up" and "down". These values are consistent with calculated values assuming the proton's orbital magnetic dipole moment for the antiproton, and limit any difference between them to less than six parts in 10^5. The measured values also depend on the antiproton's spin magnetic moment, but the corresponding limit for this (1.6%) is not yet as good as the value (0.3%) deduced from the fine structure of X-ray spectra in heavy antiprotonic atoms. A precision measurement of this latter quantity will require major improvements in the laser system. Therefore what will probably come next from ASACUSA are even tighter limits on the orbital moment, charge and mass.

The present result has an unusual feature. According to the equation for $\mu_{\bar{p}}$ (see box), what is being measured is mainly the ratio $g^l_{\bar{p}}/g^l_p$ of the factors defining the orbital current magnetism relationship for the members of the CPT conjugate pair. However, we have no atoms with orbiting protons in our matter world, and g^l_p has always implicitly been taken by definition to be equal to 1. Thus while CPT invariance is respected within the six parts in 10^5 limit given above, we do not know, in the empirical sense, that either g-factor really has the value unity.

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John Eades, *Tokyo.*

TRIUMF: the home of Ca

TRIUMF supports a broad range of research at the world's largest cyclotron, as well as coordinating Canadian contributions to international particle physics.

The acronym for Canada's national laboratory for particle and nuclear physics, TRIUMF, was out of date almost as soon as it was coined. Derived from "TRI-University Meson Facility", it reflected the three universities – British Columbia, Victoria and Simon Fraser – that initially conceived the Vancouver laboratory in 1965. Well before the proposal was approved in 1968, however, the University of Alberta had come on board, and today 11 Canadian universities belong to the TRIUMF club. The remainder of the acronym has also become rather misleading, since TRIUMF is now more than a meson facility. The laboratory's current activities include operating the radioactive beam facility, ISAC, and the coordination of Canada's role in the Large Hadron Collider (LHC) project at CERN.

The TRIUMF cyclotron was built under the guidance of J Reginald Richardson, who studied under Ernest Lawrence at Berkeley. It produced its first beam in 1974. The cyclotron is literally at the heart of the laboratory, with a meson hall to one side and a proton hall to the other. It was the first cyclotron in the world to provide two extracted beams simultaneously at different energies. Today, it provides four beams supplying experiments in particle and nuclear physics, astrophysics, materials science, and a range of medical and industrial applications.

Particle and nuclear physics

In recent years, TRIUMF's on-site particle physics experiments have been centred around two major facilities, TWIST and CHAOS. TWIST (the TRIUMF Weak Interaction Symmetry Test detector) was built by a 30-strong Canadian-Russian-US collaboration. It uses a stack of precision tracking chambers within a superconducting solenoid to measure the energy spectrum and angular distribution of the decay positrons from highly polarized muons, with the aim of determining the so-called Michel parameters to a few parts in 10^{-4}. The purely leptonic decay $\mu \rightarrow e \nu \bar{\nu}$ is one of the best experimental tools for studying the structure of the weak interaction, providing an opportunity to explore physics beyond the V-A structure of the Standard Model. The current data-taking phase should provide intermediate results for the ρ and δ parameters at the 10^{-3} level by the end of 2003.

CHAOS (the Canadian High Acceptance Orbit Spectrometer) has been used by a Canadian-Italian-German-Australian-US collaboration to test the predictions of Chiral Perturbation Theory (ChPT) by determining its low energy constants from a study of pion–nucleon scattering at low energies. One programme has focused on differential cross section and analysing power measurements over a large angular range at energies below the Δ resonance. These measurements have led to much more precise phase shifts and a determination of the Σ term related to the strangeness content of the nucleon. It has confirmed a revision of the pion's strong coupling constant $g_{\pi pp}$ towards lower values (13.05 ± 0.008).

The TRIUMF cyclotron magnet, half-complete, in January 1972.

The ISAC-II building will be ready in February this year.

A second programme has studied observables in pion-induced pion production on the proton to access the pion–pion scattering lengths $a^0_{\pi\pi}$ and $a^2_{\pi\pi}$, which are calculable in ChPT. This programme has also been conducted on a range of nuclei to study a possible renormalization of the pion field in nuclei.

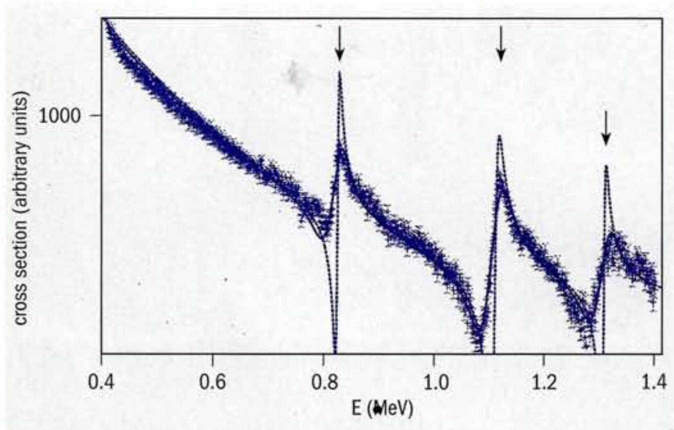
Radioactive beams

In 1995, the Canadian federal government and the province of British Columbia approved funding for a state-of-the-art radioactive beam facility at TRIUMF – the Isotope Separator and Accelerator (ISAC; *CERN Courier* July/August 2001 p21). ISAC is supplied by a 40 μA, 500 MeV proton beam from the cyclotron, which interacts with a target to produce isotopes with lifetimes as short as 10 ms for study. These are either fed directly to experiments in a low-energy area, or accelerated in RFQ and drift-tube linacs to 1.5 MeV/u for use in a high-energy area.

The low-energy beams (up to 60 keV) are used in a broad programme covering fundamental symmetry tests, nuclear structure studies in nuclei far from stability, and condensed matter studies using light polarized ions. Precision measurements of pure-Fermi β-decay lifetimes and branching ratios have been made for ^{74}Rb, and together with that of the Q value, when complete, will improve the

nadian subatomic physics

One of two HECs delivered to CERN for ATLAS.



Excitation function for $p(^{21}Na,p)$ scattering showing ^{22}Mg excited states at 6.33, 6.62 and 6.81 MeV, of special interest for nucleosynthesis in novae.

testing of CVC and the determination of the V_{ud} element of the quark-mixing matrix. Correlation studies in β decay with trapped atoms (the TRINAT programme with ^{38m}K and polarized ^{37}K) are placing constraints on extensions of the Standard Model.

A low-temperature nuclear orientation refrigerator for online NMR and perturbed angular correlation studies, and a large germanium gamma-ray detector array (the former Chalk River 8π spectrometer), are being used in studies of nuclear structure.

A novel facility for β-NMR studies of condensed (especially superconducting) materials has been commissioned. Light polarized ions (currently ^{8}Li) are produced via collinear polarized laser beam excitation, while the spectrometer sits at an adjustable high voltage. The range of the ions can be adjusted so that they stop on the surface of the sample or at a prescribed depth, allowing studies of magnetism on surfaces, in thin layered materials and at interfaces.

On 25 July 2001, the first accelerated beam was delivered to the high-energy area. Early experiments included studies of unstable isotopes that are important in the rapid proton and neutron capture processes of nova and supernova nucleosynthesis. ISAC's nuclear astrophysics programme is carried out at two complementary facilities in the high-energy area – a large-acceptance recoil spectrometer system (DRAGON) and a large-acceptance scattering facility (TUDA).

Early measurements made with DRAGON include a study of the capture of a proton by sodium-21 to yield magnesium-22, a key step on the way to the production of sodium-22 in novae. One of TUDA's first measurements was the elastic scattering of a sodium-21 beam from a proton target, which yielded information that helps to constrain the sodium-21/magnesium-22 reaction at the high temperatures found in novae. Future measurements will explore other key processes in the nucleosynthesis cycles of novae, as well as reaction chains that are important in normally burning stars.

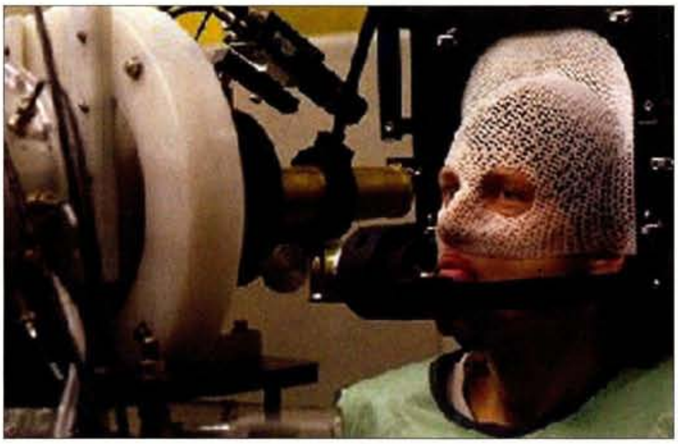
Work on an upgrade to the ISAC facility, ISAC-II, began in spring 2002 and is scheduled for completion by 2005. ISAC-II will incorporate a superconducting linac to extend the facility's reach, providing 6 MeV/nucleon ions up to atomic masses of around 150, and 15 MeV/nucleon light ions.

Muon spin rotation

The condensed matter programme is very active, with 150 users served by three muon beamlines. By stopping highly polarized muons in a sample and studying the relaxation of their spins using muon spin rotation (μSR) techniques, forefront research is carried out in superconductivity, exotic superconductors, magnetism, semiconductor impurity behaviour, and (in chemistry) free radicals, supercritical water, and gas-phase reaction rates.

Particle physics off-site

TRIUMF provides infrastructure support for Canadian physicists involved in experiments at other laboratories, with the help of staff stationed both at TRIUMF and at the member universities. Its major current activity is coordinating Canada's contribution to CERN's LHC proton–proton collider and the ATLAS experiment. The first phase of the LHC work (from 1995 to 2000) provided magnets, power supplies, HV equipment, kickers, RF cavities, diagnostics and electronics towards upgrading the PS Booster and PS machines to meet LHC beam requirements (*CERN Courier* April 1998 p5). Beam dynamics work included design of the LHC cleaning insertions. The second phase, providing components for the LHC itself, will bring the total contribution to C$41 million (€28 million): 52 warm twin ▷



A patient awaits proton therapy for an eye tumour.

quadrupoles for the cleaning insertions (*CERN Courier* December 2002 p30); the injection kicker power supplies; and beam-position-monitor electronics.

The Canadian ATLAS group (and hence TRIUMF) is involved in several construction projects centred around measuring particle energies in the liquid argon Hadronic Endcap Calorimeters (HECs): half of the main 4 m diameter HECs, now delivered to CERN (with the University of Alberta); the forward HECs (with Carleton and Toronto); and the 50 feedthrough ports, each with 1920 signal lines, for the endcap cryostats (with Victoria). TRIUMF is also involved in building the pipeline electronics for the calorimeters and the third-level trigger electronics (with Alberta), in developing physics simulations (for which it is an active member of the GEANT4 consortium), and in participating in the ATLAS data challenge and high-speed data-transfer test between TRIUMF and CERN in preparation for ATLAS data analysis (p9).

The laboratory is also strongly involved in the HERMES experiment at DESY, Germany, and in the rare decay searches E787 (where the first-ever $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events have now been seen) and KOPIO ($K^0 \rightarrow \pi^0 \nu \bar{\nu}$) at the Brookhaven Alternating Gradient Synchrotron. Significant contributions have also been made to BaBar at SLAC, US, and continue at the Sudbury Neutrino Observatory (SNO) in eastern Canada.

Advanced detectors

The University of British Columbia and TRIUMF are constructing an integrated infrastructure facility at TRIUMF to develop innovative detector technology for scientific, medical and industrial applications. The Laboratory for Advanced Detector Development (LADD) is funded by the Canada Foundation for Innovation and the British Columbia Knowledge Development Fund, in conjunction with the University of Montreal and the British Columbia Cancer Institute. These facilities are pooling resources and personnel to form a world-class R&D partnership unique in Canada. LADD's state-of-the-art infrastructure will enable Canadian universities to provide important contributions to experiments in high-energy and nuclear physics, materials and astrophysical sciences, and medical imaging applications.

LADD research will concentrate on the development of new types of imaging detectors and systems for gamma rays and charged particles – key components in fundamental physics experiments and in industrial and medical imaging applications. Initial projects include detector systems for the KOPIO experiment at Brookhaven and positron emission tomography (PET) imaging technologies.

Applications

The application of basic physics has always been high on TRIUMF's agenda, with pioneering work on muon-catalysed fusion and medical applications being carried out at the laboratory. Although the initial promise offered by the muonic atom approach to fusion has not been realized, TRIUMF's medical work has led to important spin-offs. In the 1970s and 1980s, the laboratory investigated the use of pions in cancer therapy. The motivation for this came from a 1961 paper by Peter Fowler and Donald Perkins that pointed out that pions – like other hadrons – deposit most of their energy in a Bragg peak at the end of their trajectories. Moreover, when pions are captured, the capturing nucleus disintegrates, adding a star burst of radiation to the Bragg peak that could increase the effectiveness of the treatment. Clinical trials showed that while the side effects were less severe for patients who received pion therapy rather than more conventional treatment, the survival rate was the same, so the programme was ended. However, cancer treatment at TRIUMF continues, with a proton beam in routine use to treat eye tumours.

TRIUMF research into new radioisotopes for medical applications is exploited directly by the medical isotope firm MDS Nordion, under an agreement whereby TRIUMF receives royalties on sales. The company operates two small cyclotrons on site (one designed in a TRIUMF–Ebco collaboration), and is currently installing a third. The laboratory is also involved in projects with local hospitals, for example operating, and providing a source of radiotracers for, the PET scanners for the UBC Neurodegenerative Disorders Centre, which is renowned for its research into Parkinson's disease.

Non-medical work includes a proton irradiation facility developed with space science applications in mind. The TRIUMF cyclotron's energy range is well matched to that of protons from solar flares, making them ideal for evaluating materials to be used in space.

Future plans

Since 1995, TRIUMF has been funded on the basis of two 5 year plans – an arrangement that has enabled the lab to make commitments to sizeable projects such as ISAC-I, ISAC-II and the CERN LHC collaboration. But what of the future? The wheels of government grind slowly, and it will soon be time to submit a proposal for the years 2005–2010. For the past year, the TRIUMF user community and management have been engaged in a process to determine what should be included. This is not yet complete, but there seems to be broad agreement that the lab's main thrust must be to exploit the newly completed ISAC facilities as fully as possible (perhaps providing additional simultaneous radioactive ion beams), while continuing to supply major engineering support for Canadian physicists' experiments at other labs. Such a programme should provide exciting research possibilities for the future.

Jean-Michel Poutissou *and* **Michael Craddock**, *TRIUMF, and* **James Gillies**, *CERN.*

In a spin at Brookhaven

The mysterious quantity that is spin took centre stage at Brookhaven for the SPIN2002 meeting last September: **Yousef Makdisi** and **Thomas Roser** report.

SPIN2002 participants pose for the traditional group photo on a sunny day at Brookhaven.

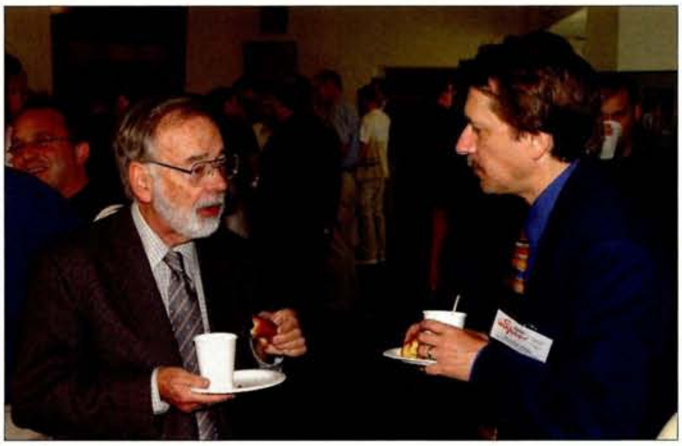
The 15th biennial International Spin Physics Symposium (SPIN2002) was held at Brookhaven National Laboratory on 9–14 September 2002. Some 250 spin enthusiasts attended, including experimenters and theorists in both nuclear and high-energy physics, as well as accelerator physicists and polarized target and polarized source experts. The six-day symposium included 23 plenary talks and 150 parallel talks. SPIN2002 was preceded by a one-day spin physics tutorial for students, postdocs, and anyone else who felt the need for a refresher course.

In the opening talk, "A Beautiful Spin", Xiang-dong Ji of Maryland reviewed the history of spin, starting with the 1925 publication by George Uhlenbeck and Samuel Goudsmit that introduced spin as a fundamental property of most subatomic particles. Ji noted that our 3+1-dimensional space–time is symmetrical under translation and rotation; this symmetry results in two universal observables, mass and spin. Understanding these two fundamental quantities has been a central goal of particle and nuclear physics throughout much of the 20th century. He went on to describe the invaluable role that spin plays in uncovering physics beyond the Standard Model, nucleon structure and nonperturbative quantum chromodynamics (QCD).

Quark structure

Over the last decade, great progress has been made in measuring the quark spin structure functions of the nucleon with the SMC experiment at CERN, HERMES at Hamburg's DESY laboratory, and at the Stanford Linear Accelerator Center (SLAC) in California. Todd Averett of the University of William and Mary and Andrew Miller of TRIUMF summarized this progress. Inclusive deep inelastic scattering (DIS) measurements have established that quarks and antiquarks combined (valence and sea) contribute only a small fraction of the nucleon spin on average. Therefore there must be a significant contribution from gluons and/or orbital angular momentum. It is possible that the valence quark contribution to the nucleon spin is large, but is offset by a negative sea quark polarization.

Semi-inclusive DIS data, where an outgoing hadron is observed, should separate the contributions from valence and sea quarks. New results were presented from HERMES showing little or no sea polarization, but with large errors, so it is difficult to draw a conclusion at this stage. The indication of a positive strange quark polarization is quite interesting. Future parity-violating W-boson production from high-energy polarized proton collisions should directly measure antiquark polarization, separated by flavour. Scaling violations in DIS ▷



Charles Prescott (left) of SLAC and Thomas Roser of Brookhaven, former and current chairs of the International Spin Committee, in discussion over coffee at SPIN2002.

Maryland's Xiang-dong Ji presented George Uhlenbeck and Samuel Goudsmit as the heroes of spin. Uhlenbeck and Goudsmit first proposed the property of spin in 1925.

data at different energies provide a first glimpse of gluon polarization, which appears to be significant. Future results from the experiments COMPASS at CERN, E-160 at SLAC, and PHENIX and STAR at Brookhaven, with complementary kinematic coverage, are eagerly awaited. Richard Milner of MIT-Bates showed recent plans for the next-generation measurements of polarized DIS using a proposed high-luminosity electron–ion collider (EIC).

On the theory front, Marco Stratmann of Regensburg reviewed the theoretical framework for describing longitudinal spin asymmetries in perturbative QCD, and the progress made in the corresponding higher-order calculations. He then ventured into the domain of high-energy polarized proton collisions and outlined the framework for global QCD analyses. Kostas Orginos of the RIKEN-Brookhaven Research Center (RBRC) reviewed the progress, results and future prospects for learning about nucleon spin structure from lattice QCD. Philip Ratcliffe of the University of Insubria expanded on the latest attempts to explain the large observed single-spin transverse asymmetries in inclusive hyperon and pion production, as well as lepton-induced production. Recent theoretical advances calculate such asymmetries perturbatively in terms of intrinsic transverse-momentum degrees of freedom in hadrons, and of higher-twist effects. He highlighted the re-emerging domain of transversity and how to access it in polarized hadron production processes such as Drell–Yan, as well as semi-inclusive processes in polarized lepton–nucleon collisions. Inevitably, he pleaded for additional experimental data. Marc Vanderhaeghen of Mainz reviewed the relatively new and exciting field of DIS exclusive processes and generalized parton distributions, which could provide information on the orbital angular momentum of partons in the nucleon.

Klaus Helbing of Erlangen reviewed the status of the experimental verification of the Gerasimov–Drell–Hearn (GDH) sum rule, which relates a weighted integral of the spin-dependent photon–nucleon absorption cross-section to the anomalous magnetic moment of the nucleon, and is widely believed to stand on very solid ground in QCD. Proton results from the Mainz Microtron and ELSA machine at Bonn have now verified this sum rule at the 5% level. Further experimental information in the resonance region and at high energies from laboratories such as Jefferson Laboratory (JLab) in Virginia will be important. This is especially true for the neutron. The rich spectrum of low-energy electron and photon-induced experiments from HIGS at Duke University, LEGS at Brookhaven, GRAAL in Grenoble and LEPS at Harima, Japan (listed in increasing energy from 0.6 to 2400 MeV) were covered by Andrew Sandorfi of Brookhaven. He detailed work on the GDH sum rule and lambda production with an effort to understand the 1405 MeV resonance. He looked to the future EIC and back-scattered photons to extend the reach to 6500 MeV.

Brookhaven's Haixin Huang reported on the first operation of the Relativistic Heavy Ion Collider (RHIC) as a polarized proton collider. Polarized proton beams in RHIC were recently accelerated to 100 GeV without significant loss of polarization; this confirmed that the two Siberian snakes installed in each ring indeed work as predicted at Novosibirsk by Yaroslav Derbenev and Anatoly Kondratenko about 25 years ago. The world's first polarized proton collisions in a collider were observed at RHIC at a centre-of-mass energy of 200 GeV and a luminosity of about $1.5 \times 10^{30}\,cm^{-2}s^{-1}$. However, due to a significant polarization loss in the Alternating Gradient Synchrotron (AGS), which serves as the injector for RHIC, the maximum beam polarization was only about 25%. This can be partly ascribed to a weak temporary replacement for the AGS's failed 30 MW motor-generator. The proton beam polarization was measured by the proton–carbon Coulomb nuclear interference reaction, a topic that was also covered by Boris Kopeliovich of the Max Planck Institute in Heidelberg in his theoretical review of proton–proton elastic scattering. Brookhaven's Les Bland reported on the hadron spin physics experiments during RHIC's first short three-week polarized data run. These included the observation of large asymmetries in neutral pion production by the STAR experiment, and in neutron production by the PHENIX experiment at large Feynman-x (the ratio of observed longitudinal momentum to the maximum allowed) in polarized proton–proton collisions at 200 GeV in the centre of mass.

Representing the next generation of spin physicists, Michigan graduate student Vassili Morozov presented some other impressive polarized beam efforts. During the venerable Indiana University Cyclotron Facility (IUCF) cooler ring's final year, Morozov and his colleagues spin-flipped both vector and tensor polarized deuterons for the first time. They also spin-flipped polarized protons with a measured spin-flip efficiency of 99.93 ± 0.02% (*CERN Courier* April p6). There were many reports of the impressive progress on polarized sources and polarized solid and gas targets. Their ever-increasing intensities and polarizations are essential to the field of spin physics, and were highlighted in a review by Erhard Steffens of Erlangen, and in workshop summaries by Vladimir Derunchuck of IUCF) and Manouchehr Farkhondeh of MIT-Bates.

Beyond the Standard Model

Turning to probes of physics beyond the Standard Model, Ernst Sichtermann of Yale presented the recent highly precise measurement of the muon anomalous magnetic moment (g-2) using the high-intensity polarized positive muon storage ring that is fed by the AGS. The latest result is about a two-sigma deviation from the Standard Model (*CERN Courier* September p8). Considerable theory work is in progress, and negative muon data are being analysed by the experiment. New experiments are planned to measure the neutron electric dipole moment using polarized neutrons at Los Alamos.

Krishna Kumar of Massachusetts reviewed parity violation in polarized electron scattering. Two major experiments – SAMPLE at Bates and HAPPEX at JLab – are using parity violation to study the strangeness content of the proton. The new high-precision E158 experiment's measurement of parity violation in Moller scattering at SLAC will test the Standard Model predictions for the electron's weak charge.

The last day of SPIN2002 focused mostly on the future. Gudrid Moortgat-Pick of DESY discussed polarized electron–positron linear colliders and supersymmetry. Gordon Cates of Virginia described some impressive advances using spin physics in the field of medicine. Jacques Soffer of Marseilles ended the symposium with confidence that we are poised to witness significant progress in our understanding of spin and QCD in the near future. He also echoed the sentiment of the opening presentation: that the universe without spin would collapse. This happy note set the stage for the 16th International Spin Physics Symposium, SPIN2004, which will take place at the International Centre for Theoretical Physics in Trieste, Italy, in early autumn 2004. The many dedicated spin physicists attending SPIN2002 can now look forward to more exciting results, and a deeper understanding of the mysterious quantity that is spin.

Further reading

Copies of transparencies are available at http://www.c-ad.bnl.gov/spin2002/.

Proceedings to be published by the American Institute of Physics.

Yousef Makdisi *and* **Thomas Roser**, *Brookhaven National Laboratory.*

CERN summer experience benefits US students

Northeastern University's programme of research experience for US undergraduates at CERN is five years old. **Suzanne Harvey** takes a look at its impact.

Boston's Northeastern University launched its Research Experience for Undergraduates (REU) programme at CERN in 1998. Joining summer students from the laboratory's member states, the participants use their experience to help them to establish what direction their careers will take. Christine Nattrass, a double major in biochemistry and physics at Colorado State University, says that her experience in the programme has influenced her future. "Now I'm more certain I want to study physics rather than biophysics or biochemistry," she says, "and I think I'd like some kind of particle physics. The research experience confirmed my suspicions that physicists are more fun to work with than biochemists."

2002 REU participants (clockwise from top left): Andrew Essin, Peter Richmond, Jeff Atwell, Karen Andeen, David Le Sage, Janice Hester, Dave Maffei, Shawn Kwang, Christine Nattrass, Sophia Domokos and Kathy Cooksey.

Christine admits, however, that only time will tell just how deeply the whole programme has influenced her. Other students say that the experience at CERN helped determine what course their future studies will take; some have decided that they are more interested in theory than in experiment, while others say that the work they did over the summer has reaffirmed their love of the field.

Assessing the impact

Just as the students have to determine how their experiences in the programme have affected them, so the long-term impact of the programme itself must be assessed. Just how important are educational and research programmes of this sort, and what should their future be? It is often difficult to make these decisions when the programmes are still new, but now that the REU programme has reached maturity, we can begin to get a clearer sense of its value.

CERN has had a summer programme for undergraduate students for more than 40 years (*CERN Courier* July/August p8), but US students have only been able to participate since the REU programme was formed. Historically, only CERN member states have had the opportunity to send their students to experience what it's actually like to work in a physics research group at the laboratory. In 1997, however, Stephen Reucroft, an experimental physicist at Northeastern University, sent a proposal to the US National Science Foundation (NSF) for funding to send US students to the summer student programme at CERN. Independently, Homer Neal of the University of Michigan made a similar proposal, and the NSF suggested that the two join forces. The result was the programme that exists today. CERN agreed to take 10 US undergraduates from the REU programme, starting in 1998.

After three years of running a joint programme, Reucroft and Neal split the programme in two and started sending 10 students each. The CERN summer student programme places half, and Northeastern University and the University of Michigan place the remainder. Additional funding has been provided by the Ford Motor Company, which now supports five students.

Participants in the REU programme are chosen from colleges all over the US, from small institutions as well as the larger, better-known universities. A committee of physicists chooses students with a strong academic record, an interest in physics, demonstrable creativity and a desire to take advantage of CERN's culturally diverse environment. The social and cultural life of the programme is as important as the research and educational elements.

REU organizers brief successful candidates about what they ▷

Undergraduate Dave Maffei worked on the electromagnetic calorimeter for the CMS experiment.

can expect, and encourage them to network before they leave for Switzerland. There is a four-day orientation meeting for students in the US, and a programme administrator accompanies them to CERN and gives them a tour of the laboratory's facilities. After they have settled in, the REU administration keeps in touch with the students throughout the summer. One of the programme's coordinators, Artemis Egloff, says: "We try to keep a good balance between helping them and smothering them with too much attention. They like to be independent and we encourage them."

While at CERN, the US summer students work with an assigned research group, supervised by a physicist who works with them and assigns them various tasks, allowing them to see what work as a particle physicist is like. Students perform research, take measurements, write computer programs, papers and reports, learn to use specialized software, build and test equipment, and inevitably do manual work. In short, they are expected to cover the entire range of activities that makes up experimental particle physics.

Students are expected to learn new skills on the fly – things that they don't learn in the classroom. Their work is often disorganized and their days frequently unstructured, but as Reucroft points out, this is what research is often like. Students are often surprised at how much mundane manual labour is involved in science, such as connecting cables, and moving and stacking lead bricks.

Although hands-on work forms a large part of the activities at CERN, the students also attend lectures in experimental and theoretical physics, and in accelerator and detector techniques. Andrew Essin, a student at Reed College, Oregon, explains: "There were lectures on experimental high-energy physics, which allowed me to get a view of more than just mathematical formalism and phenomenology, to see the nitty-gritty of creating and detecting particles, accumulating and processing vast quantities of data and all that good stuff that I might miss if I simply concentrated on theoretical studies." The CERN lectures focus on the detailed techniques of particle physics in both experiment and theory. Since the students are a mixture of potential experimentalists and theorists, the lecture material benefits all of them. In ordinary classroom lectures, most of what is taught about physics is historical information, neatly packaged.

The lectures often cover material that is too new to be taught to US physics undergraduates. As a consequence, some of the students find the lectures difficult. One, however, said that even the material he did not understand will be valuable to him eventually – either he will process it once it has had time to settle, or else the fact that he has already been exposed to it will make him feel more comfortable next time he comes across it.

International culture

The international atmosphere at CERN makes it an ideal place for US students to learn how scientists from different countries bring different approaches to physics. Students and advisors not only work together, but also get to know each other socially. Many returning students have remarked on the spirit of tolerance that reigns in CERN's multicultural setting, with people choosing to pass over potentially awkward social situations rather than giving them too much weight or taking offence at unintended slights. Inevitably, this attitude is carried over into the work environment. The students learn how people in other countries are educated, and discover the strengths and weaknesses in the US system, as well as in others. It is one of the aims of the REU programme that as the students develop, they will keep in mind what they have learned, and perhaps bring good ideas back to the US system.

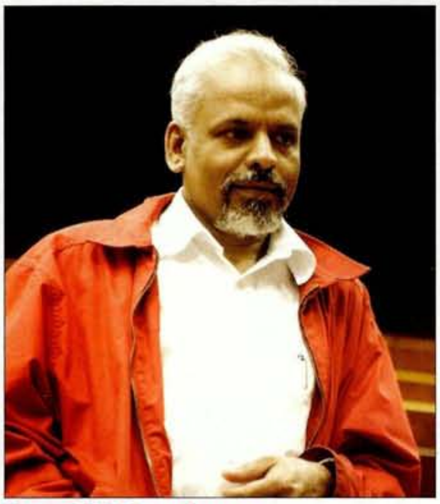
The vast majority of undergraduates participating in the REU programme have gone on to pursue PhDs in the sciences, including various aspects of physics, biophysics and aeronautical engineering. One became a Rhodes Scholar, and another went into business, although she changed her mind after a year and went back to physics because her experience at CERN was so good. One spent time developing computer simulations at a financial institution and is pursuing a Masters degree in architecture at MIT. He hopes to enter into a physics PhD programme after he has completed his Masters.

One of the main challenges of the REU programme is placing students with advisors. Even the best-intentioned researchers can find themselves unexpectedly busy by the time the summer arrives, and it is not uncommon for students to find themselves working largely independently. However, Reucroft says that experience has shown that if an advisor can motivate a student and give them a start, they frequently end up working happily and productively on their own.

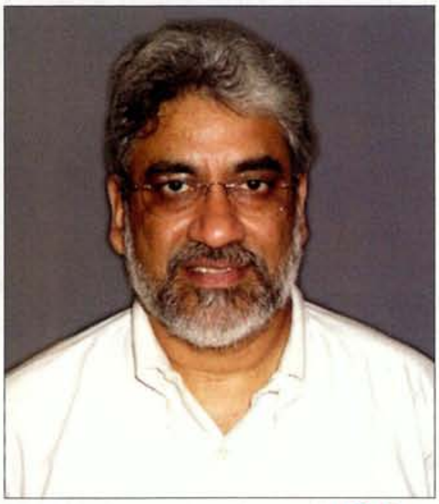
Like the CERN summer student programme, the REU programme has a great potential impact. It helps students decide whether or not to pursue an advanced degree in physics. By ensuring that they are well informed about the nature of research before they embark on their career, it helps students find out whether experimental or theoretical physics – or even no physics at all – is right for them. It also attracts young people to science, exposing them to the demands and rewards of working at the leading edge of experimental physics, showing them how experiment and theory work together, and how particle physics impacts other branches of science. Perhaps most importantly, students also learn skills that are helpful in whatever career they choose to pursue, such as programming, problem solving and working with people from different backgrounds. All of the students who have participated in this programme say that they would recommend it to their friends. And it is safe to say that the majority will go on to be good ambassadors for science and for international collaboration, wherever their future careers take them.

Suzanne Harvey, *Massachusetts General Hospital.*

PEOPLE



Katepalli R Sreenivasan, born in India and now a citizen of the US, has been appointed director of the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy. A world-renowned experimental physicist whose major fields of interest are fluid dynamics and turbulence, he is currently a professor of physics and mechanical engineering at the University of Maryland, US, where he also directs the Institute for Physical Science and Technology. He is scheduled to begin his tenure at the ICTP in March. (Photo: ICTP Photo Archives, Massimo Silvano.)

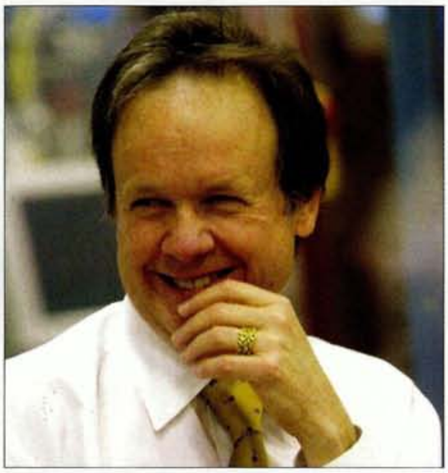


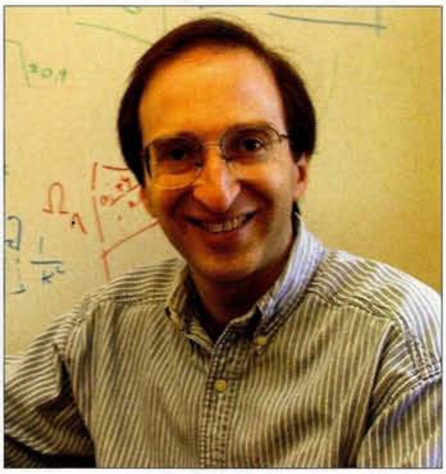
Condensed matter experimentalist **Shobo Bhattacharya** has been appointed director of the Tata Institute of Fundamental Research (TIFR) in Mumbai, India. Bhattacharya received his undergraduate education at Presidency College, Calcutta, and at Delhi University, and his PhD at Northwestern University, US. He has worked at the University of Rhode Island, MIT Francis Bitter magnet lab, Argonne National Laboratory, the University of Chicago and the Exxon Corporate Research Lab. He comes to TIFR from NEC Research Institute, where he was a Fellow in the science division.

Murray Gell-Mann (left) was among the well-wishers at a symposium organized by Beijing's Tsinghua University last year to celebrate the 80th birthday of Nobel prize winner **Chen Ning Yang**. Yang, born on 22 September 1922 in China's Anhui Province, shared the 1957 Nobel Prize for Physics with Tsung Dao Lee for their theoretical work on parity violation. Tsinghua University awarded Yang an honorary professorship in 1998. Yang said he hoped to see both China and the world make great progress in science and technology before he reaches 90. (Xinhua News Agency.)

At the launch of the European Union's sixth research framework programme in Brussels last November, the director-generals of Europe's seven leading international research organizations signed the EIROforum charter. EIROforum was established in 2001 to stimulate collaboration between the organizations. The signing of the charter represents its formal establishment. Left to right: **Hans Hoffmann** representing Luciano Maiani of CERN, **Antonio Rodota** of the European Space Agency, **Fotis Kafatos** of the European Molecular Biology Laboratory, European Commissioner **Philippe Busquin**, **Catherine Cesarsky** of the European Southern Observatory, **William Stirling** of the European Synchrotron Radiation Facility, **Colin Carlile** of the Institut Laue-Langevin, and **Jérome Pamela** of the European Fusion Development Agency.

The Indian prime minister **Shri Atal Bihari Vajpayee** (right) presented the prestigious Homi Bhabha Science and Technology Award for 2001 to **Ajit Kumar Mohanty** at a ceremony in Mumbai on 31 October 2002. This is the highest award of India's Department of Atomic Energy, and recognizes commendable contributions encompassing a very wide range of fundamental studies in the field of nuclear physics. Mohanty, originally from the Bhabha Atomic Research Centre, is currently working in the ALICE offline group at CERN.

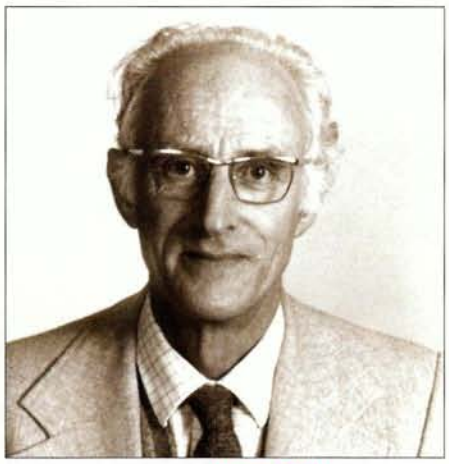




Among the recipients of the 2002 E O Lawrence award are **Keith O Hodgson** (left) and **Saul Perlmutter**. Hodgson, professor of chemistry at Stanford University and director of SLAC's Stanford Synchrotron Radiation Laboratory, was honoured in the chemistry category for his contributions to the development of synchrotron X-rays for the investigation of biological structure and function. Perlmutter, an astrophysicist at the Lawrence Berkeley National Laboratory, received the award in the physics category for his contributions to the discovery, through careful study of distant supernovae, that the expansion of the universe is speeding up rather than slowing down.

The Lawrence Award was established in 1959 to honour the memory of the inventor of the cyclotron, Ernest Orlando Lawrence. It is given in seven categories for outstanding contributions in the field of atomic energy, broadly defined. The awards were presented at a ceremony in Washington, DC on 28 October 2002.

On 7 November, **Margret Becker-Wiik** (left) presented the Bjørn H Wiik Prize 2002 to **Thomas Möller** of DESY's synchrotron radiation laboratory, HASYLAB. This award recognizes Möller's contribution to the first experiments with DESY's free-electron laser. The Wiik prize was established in 2000 and is awarded every two years. It is financed by the proceeds of the donations received following Bjørn Wiik's untimely death in 1999, and serves to acknowledge outstanding contributions to the advancement of research programmes or technical development projects at DESY.

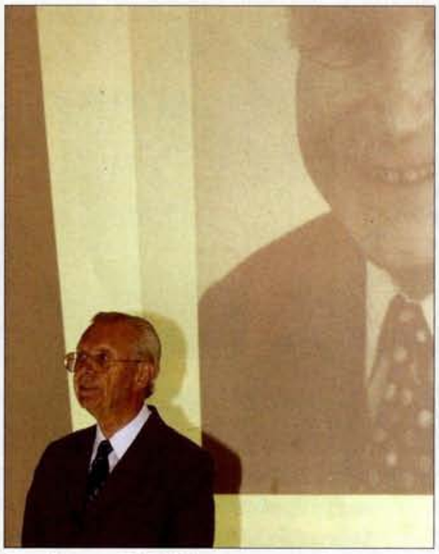


The Nuclear Physics Division of the European Physical Society (EPS) has awarded the Lise Meitner Prize for 2002 to **James Elliot** (picture on right) of the University of Sussex, UK, and **Francesco Iachello** of Yale University, US, "for their innovative applications of group theoretical methods to the understanding of atomic nuclei". The awards, sponsored by the company Canberra-Eurisys, were announced at the EPS general conference in Budapest, Hungary, last August, and presented at the Nuclear Structure with Large Gamma Arrays (NS2002) conference in Padua, Italy, in September. Elliot's description of the spectra of light nuclei in terms of the SU(3) symmetry group in the 1950s opened the way to a reconciliation of the spherical shell model of Maria Goeppert-Mayer and Hans Jensen with the liquid drop model of Aage Bohr and Ben Mottelson. Iachello, working with Japanese physicist Akito Arima, introduced the interacting boson model in 1975. This describes nuclear structure in terms of degrees of freedom of integer spins.

Pictured left at the NS2002 conference are (left to right) **Graziano Fortuna**, director of the Legnaro National Laboratories, Meitner prize winner Francesco Iachello, **Silvia Lenzi** of Padua, and chair of the EPS prize committee **Wolfram von Oertzen**.

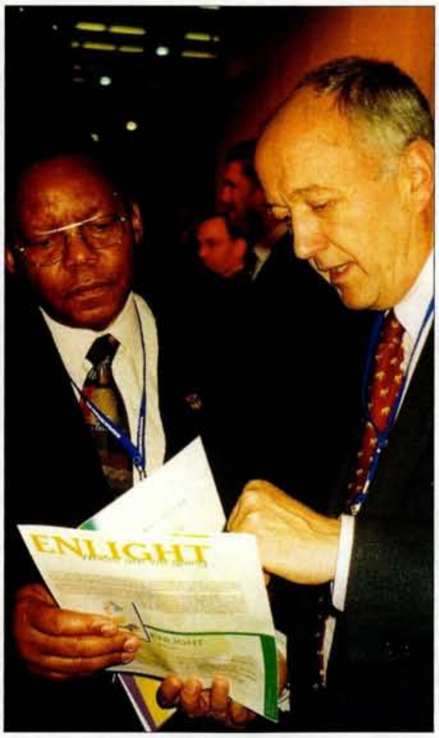
After 38 years in the service of accelerators, **Kurt Hubner**, seen here with his wife **Traudl** during a symposium held in his honour, took his retirement from CERN at the end of November. Arriving at CERN as a Fellow in 1964, Hubner has worked on all of CERN's major accelerator projects from the ISR to the LHC.

CERN enjoyed two high-level Spanish visits last November. Left: on 18 November, **Josep Piqué I Camps** (right), Minister of Science and Technology, visited the magnet test hall in the company of Spanish CERN scientist **Felix Rodrigues Mateos** (left) and head of the minister's office, **Gonzalo Babé**. Right: nine days later, it was the turn of members of the science and technology commission of the Spanish Senate to visit. Left to right: **Mercedes Senen**, **Ramon Antonio Socias**, **Adolfo Abejon**, **Alonso Arroyo** and **Francisco Xabier Albistur** with ATLAS collaboration spokesman **Peter Jenni**.



One former CERN director-general pays tribute to another. **Herwig Schopper** was among the speakers at a symposium held at CERN on 31 October 2002 in honour of Willibald Jentschke, director-general from 1971 to 1975, who passed away last year (*CERN Courier* May 2002 p40).

Bernard Ecoffey (left) in discussion with former president of CERN Council **Hubert Curien** during a visit to the laboratory in November. Ecoffey is the founder and honorary president of the Engelberg Forum association, and Curien is its current president. Established in 1989, the Engelberg Forum provides an international platform for debate and exchange of views on key issues affecting scientific research, technology, economics and philosophy. Each year a different theme is chosen and analysed in depth in relation to its value for humankind. The forum has its origins in the desire to find a philosophical equivalent for CERN's Large Electron Positron Collider, which was operational from 1989 to 2000.



The South African Minister of Arts, Culture, Science and Technology **Ben Ngubane** (left) talks to CERN's **Hans Hoffmann** about the ENLIGHT network of light-ion-based cancer therapy initiatives in Europe. ENLIGHT held its inaugural meeting at CERN in February (*CERN Courier* May 2002 p29).

A CERN delegation visited Islamabad, Pakistan, in November to take part in a meeting organized by the Commission on Science and Technology for Sustainable Development in the South (COMSATS). The delegation presented the CERN Data Grid project and its applications to representatives of COMSATS member states, and encouraged their co-operation with CERN. COMSATS member states are Bangladesh, China, Colombia, North Korea, Egypt, Ghana, Iran, Jamaica, Jordan, Kazakhstan, Nigeria, Pakistan, the Philippines, Senegal, Sri Lanka, Sudan, Syria, Tanzania, Tunisia, Uganda and Zimbabwe. During their visit, members of the CERN delegation took the opportunity to visit Pakistani institutes involved with preparations for the Large Hadron Collider. Here, **Diether Blechschmidt** (left) and **John Ellis** (right) inspect sheet metal work being prepared for the ATLAS experiment.

On 21 October 2002, the Institut d'Etudes Scientifiques de Cargèse in Corsica inaugurated a new amphitheatre named in honour of its founder **Maurice Lévy** (left), seen here with **André Martin**, who also played an important role in the early days. Founded in the 1960s, the institute played host to some 26 schools last year.

Daniel Denegri (left) of the CMS collaboration is pictured with Croatian science and technology minister **Gvozden Flego** (centre) and his deputy **Davor Butkovic** at the opening ceremony for the LHC days in Split 2002, which took place on 8–12 October 2002. This meeting, hosted by Split University, has become a traditional biannual meeting devoted to Croatian participation in LHC projects.

British Prime Minister **Tony Blair** opened The Ogden Centre for Fundamental Physics at the University of Durham, UK, on 18 October 2002. This multimillion-pound science complex has been created to form a world-leading centre of excellence in fundamental physics, combining research into the building blocks of the universe and the large-scale structure of the universe, coupled with a mission to inspire a new generation of young scientists.

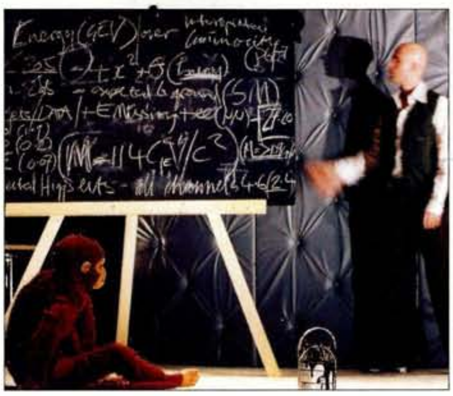
MEETINGS

An international conference on "**20 Years of SUGRA and Search for SUSY and Unification**" will be held at Northeastern University, Boston, US, on 17–20 March 2003. The conference will assess the progress since the discovery of SUGRA unified models in 1982, and will provide a critical assessment of the progress in the search for supersymmetry and unification beyond the Standard Model. Registration costs \$300 (€285) if paid before 1 March, and \$350 thereafter. Further details are available at http://www.sugra20.neu.edu, or email sugra20@neu.edu.

The **9th Pisa Meeting on Advanced Detectors** will be held at La Biodola on the island of Elba on 25–31 May 2003. The meeting will review progress in detector technology, with an emphasis on application to future experiments. Participation is limited. Details are available at: http://www.pi.infn.it/pm/2003/.

CULTURE

European project plays matchmaker to art and science



Above: in the centre of Max Neuhaus's sound installation in Geneva's Promenade du Pin are (left to right) Manuela Denogent of the state of Geneva, which financed the work, Renilde Vanden Broeck and Rolf Landua of CERN, and the artist himself. Right (top): artist Sylvia Wyder (left) and physicist Michael Doser at the Nothing...Nada symposium in Lisbon. Right (bottom): the central character of Life's a Monkey *is the mysterious B (played by Andrew Byron), a writer and KGB agent seen here with the monkey (Clea Smith) of the play's title. (Talula Shepherd.)*

Ever since C P Snow lamented the gulf between literary intellectuals and scientists, sparking the two cultures debate in 1959, science and art have seemed irreconcilable. Over recent years, however, a European Union-supported initiative of the London Institute, Europe's largest art school, has been making a serious effort to bring the two to the altar. Some believe the match can be successful, while others still hold that art and science are too divergent to have a long-term future together.

The first concrete results of the initiative saw the light of day in 2001 with the "Signatures of the Invisible" exhibition (*CERN Courier* May 2001 p23), based on artists' experiences at CERN. The follow-up to this was a series of events organized for the European science and technology week in November 2002 under the banner of "Shadows of the Infinite".

Five events were held across Europe – a symposium in Lisbon, a play in London, a textile show in Milan, the unveiling of a sound installation in Geneva, and the opening of the Signatures of the Invisible exhibition in Lisbon. "It is all about scientists and artists working together in new and exciting ways," said Michael Benson, initiator of the project and co-author of the play, *Life's a Monkey*, that ran at London's Cochrane Theatre during the science and technology week. Inspired by conversations between the authors and theoretical physicists at CERN, *Life's a Monkey* plays mischievously with the flow of time in a plot that weaves an unlikely tapestry of cold war intrigue and particle physics.

In Lisbon, the Signatures of the Invisible exhibition opened at the Calouste Gulbenkian Foundation, which also hosted the "Nothing... Nada" symposium at which artists and scientists discussed the concept of nothingness. In Milan, textile designers from the Chelsea College of Art and Design exhibited "Particle Fabric" – intricate patterns in non-woven fabric inspired by diffraction. And in Geneva, a sound installation by the American minimalist artist Max Neuhaus was unveiled. A permanent work in a small park in Geneva's old town, this work aims to "remove sound from the boundaries of time and relocate it in another place". If you would like to judge for yourself whether or not it succeeds, and to decide if you feel the London Institute's matchmaking is a success, you can visit the Shadows of the Infinite website at http://www.infinite.linst.ac.uk.

The annual Rutherford summer school for young high-energy experimentalists took place in its traditional setting of the Cosenor's House, Abingdon, UK, in September 2002. Long established as the principal school for first-year experimental particle physics graduate students in the UK, the school welcomed 48 students from 13 UK institutes.

The DESY laboratory's physik.begreifen@desy.de (understanding physics) programme for schools reached the ripe old age of five in 2002. To mark the occasion, a special event was held at DESY on 18 November. **Uta Langenbuch** (right) of the physik.begreifen project team, and DESY's director of administration **Christian Scherf** demonstrated one of the programme's experiments to pupils who attended the event. Details of the programme are available at http://www.desy.de/physik.begreifen/.

UK Minister for science and innovation **Lord Sainsbury** addressed a meeting held in London last November to provide a showcase for the country's new Centre of Expertise in Accelerator Science and Technology (ASTeC). Speaking ahead of the event, Lord Sainsbury said: "Centres of excellence such as ASTeC are essential if we are to stay at the leading edge of world-class research." ASTeC brings together a critical mass of accelerator expertise at the Daresbury and Rutherford Appleton laboratories. The design and construction of the Diamond synchrotron is already part of the ASTeC programme. Other themes that ASTeC will tackle include high-power proton accelerators for transmutation of nuclear waste and possible use in sub-critical nuclear reactors, and accelerators for medical applications.

OBITUARIES

Claude Bovet 1935 – 2002

When Claude Bovet came to CERN in 1963 as a Fellow, he had just finished his studies of Physical Sciences at the University of Neuchatel, Switzerland, and a few months later he received his doctor's degree. Like many young physicists in those days, he stayed on as a staff member for a life-long career, and his would be particularly fruitful.

Bovet entered the accelerator field in the machine proton synchrotron (MPS) division. Under the guidance of Hugh Hereward, a mentor of many young accelerator physicists, he studied slow ejection from the PS. In the mid-1960s a PS improvement programme was conceived for a ten-fold increase in intensity. Helmut Reich realized Bovet's talent, and brought him into the study team. Bovet contributed substantially to the choice of an 800 MeV Booster as the best way of attaining the goal and to the concept of four superposed separate-function rings. The synchrotron injector (SI) division, with Giorgio Brianti as its leader, was created for the construction of this unique accelerator. The challenge of the project and the intense collaboration forged a lifelong friendship between the members of the core team. Bovet made an impact on nearly all aspects of the Booster's design, in particular its optics and the intricate recombination scheme for the beams from the four rings. He gave courses in accelerator physics for newcomers, and co-authored a famous booklet with handy formulae, which many people still carry in their pockets today.

In the midst of the preparations for the Booster, in 1970, Bovet went to the Lawrence Berkeley Laboratory for 6 months of intense studies in accelerator physics. This broadened his professional horizons and provided him with international contacts, which he maintained throughout his career.

In 1972, Bovet followed Brianti to the Super Proton Synchrotron (SPS) project (then called the 300 GeV underground accelerator), to the group responsible for the west and north experimental areas. The secondary beams had to be equipped with beam instrumentation and particle identification, and Bovet was entrusted with the most challenging part – particle identification using the newly invented Ring-Imaging Cerenkov Counter. Its use in the hostile environment, with high precision and reliability, required solutions to a number of difficult optical, mechanical and electronics problems. Bovet applied of all his diverse expertise and plunged deeply into each aspect. The CEDAR, as it was called, was a resounding success.

Later, Bovet became leader of a super-group (comprising five CERN groups) responsible for all SPS external beams and experimental areas, and was SPS deputy division leader to Bas de Raad. In that position, he was fully involved in the preparation for the proton–antiproton collision experiments UA1 and UA2. In 1983, Bovet became responsible for LEP beam instrumentation, and was LEP deputy division leader to Guenter Plass. When in 1986, CERN-wide technical boards were established, Bovet was the natural choice to head the technical board for beam instrumentation.

However, Bovet was not only a physicist with a broad spectrum of interests and expertise. His concern for matters affecting all staff at CERN made him chairman of the Joint Commission for Reclassification and Disability, and a very active member of the Investment Committee of the Pension Fund.

In the last part of his career, Bovet was the founding father of the "European Workshop for Beam Instrumentation and Diagnostics for Particle Accelerators". The first workshop was held in Montreux in 1993. Its success was such that a "DIPAC" is now held every other year, moving from country to country, with the sixth one coming up.

After a fulfilled career, Bovet retired at the end of April 2000, full of plans for many more active years. It was not to be. Soon after retirement, he fell ill, and on 10 August 2002 he passed away. Not only have we lost a colleague of great competence in many fields, we also mourn the loss of a great friend.

Giorgio Brianti and Heribert Koziol.

NEW PRODUCTS

Leybold Vacuum has announced that its range ECODry M piston vacuum pump is now offered with a frequency converter built into the motor to allow use in all AC electrical systems worldwide. Details are available from guido.van-der-velde@layboldvakuum.com.

The **Kurt J Lesker** company has launched the AXXIS modular thin film deposition tool, which supports processes including sputtering, thermal evaporation, electron beam evaporation, PECVD plasma, ion cleaning and others. Details are available from David Collins (email davidc@lesker.com) or at http://www.lesker.com.

Thermo Vacuum Generators has introduced its new UHV SoftShut gate valves for beamlines, accelerators, and other ultra-high vacuum (UHV) applications. They provide quiet, low-particle operation, up to 100 000 cycles between maintenance, and are suitable for use in the pressure range from 1500 to 10^{-11} torr. See www.softshut.com for details.

René Turlay 1932 – 2002

René Turlay, one of the four discoverers of charge–parity (CP) violation, died on 29 November 2002 after battling with serious illness for more than a year.

Following the advice of Jean Teillac, whom he met at the Radium Institute, Turlay joined the French Atomic Energy Commission (CEA) at Saclay as a research physicist where he was to have a brilliant career. In 1957, he joined the CEA's high-energy physics laboratory (created by André Berthelot), where he was welcomed by Paul Falk-Vairant and Georges Valladas. His first work with the Saturne synchrotron concerned the study of π meson production in nucleon–nucleon collisions at 2.3 GeV. In 1962, after completing his doctoral thesis on $\pi^- p \rightarrow \pi^0 n$ and $\pi^- p \rightarrow \pi^0 \pi^0 n$ reactions, he went to Princeton as a postdoc to work with Alan Clark, Jim Cronin and James Christenson on the resonant production of ρ^0 in $\pi^- p \rightarrow \pi^+ \pi^- n$ reactions. He subsequently played a major role in all phases of the memorable experiment at Brookhaven's AGS accelerator, where he, Christenson, Cronin and Val Fitch discovered the CP violation phenomenon in weak interactions. This unexpected discovery, made a year before that of relic radiation at 3 K, gave Andrei Sakharov a key to explaining the predominance of matter over antimatter at the extreme edge of the universe, and sowed the seeds of the model of the three quark families. Shortly before returning to France at the end of 1964, Turlay wrote to Falk-Vairant to underline that it was important to invest in the construction of two low-field wide-aperture magnets for the study of K mesons at Saturne. He was already demonstrating a talent for persuasion: when he arrived back, the magnets were ready, and between 1964 and 1967 he and his first students embarked on a series of experiments on long-lived neutral kaons. He invited his old friend Cronin to join them, and together they made preparations for the experiment to ensure that the Saclay Laboratory would benefit from the finest talents.

Turlay's widely established reputation brought him as a matter of course to CERN, where he undertook a series of experiments on rare disintegrations of K^+ mesons as part of an international collaboration. The results obtained so long ago still stand, and serve as a reference for new experiments. 1973 saw the beginning of a long and fruitful collaboration with Jack Steinberger in the construction of the major CDHS (WA1) experiment for the study of interactions of high-energy neutrinos produced at the SPS accelerator. Turlay secured key participation in the CDHS collaboration for his group, and was tireless in his efforts to ensure undisputed quality in all fields. Over this productive period at CERN, he left an indelible imprint on the many students who came to work on their doctoral theses under his supervision. To ensure that the scope of their training was fully comprehensive, he joined Fitch in an experiment on the study of charmed mesons at Fermilab, which was followed by two others with Cronin and Bruce Winstein to measure the direct CP violation effect. From 1978 to 1979, he headed a group studying the physics potential of what were to become the HERA collider experiments at Hamburg.

When the decision was taken in 1980 to build LEP, CDHS formed the embryo of the future ALEPH experiment. Turlay played an active part in the difficult and stimulating R&D phase, so that his group would be involved in the great LEP adventure. It was he who advocated the advantages of the superconducting technology that would be successfully used in the design of the ALEPH solenoid. In 1984 he was appointed to head the department of elementary particle physics (DPhPE). Although this managerial challenge distanced him somewhat from the hands-on physics research that he loved, Turlay devoted himself wholeheartedly to this new task, ever mindful of the need to ensure that Saclay brought the best to the collaborations in which it was involved, especially in the case of CERN. CERN director-general Herwig Schopper's invitation to become chairman of the LEP Committee gave Turlay the opportunity to become actively involved in science once again, and to serve the interests of the high-energy physics community. Between 1991 and 1992, under the aegis of Robert Aymar, head of the CEA's sciences of matter directorate (DSM), he oversaw the transformation of the DPhPE into a larger department, DAPNIA, covering astrophysics, particle physics, nuclear physics and instrumentation. On reaching retirement age, Turlay was appointed scientific adviser to DAPNIA and joined the NA48 collaboration at CERN, applying his passion and expertise to ensure participation by the best teams. With NA48, he took part in the precision measurement of direct CP violation in the neutral kaon system.

Turlay was a member of numerous international committees and learned societies (LEPC, SPC, SSC, IUPAP and SFP), often becoming their chair. He also helped to promote science among the young, and the recognition of the role of women in physics. He was awarded the Holweck Prize, and was made Chevalier de la Légion d'Honneur at the behest of the French Ministry of Research for the decisive role he played in the experiments, committees and associations in which he was involved. Turlay managed to arrange for the ceremony to be held at Saclay as a way of publicly expressing his heartfelt gratitude to the technicians, engineers and physicists who had made his work possible.

Turlay was not only a great and highly exacting physicist; he was equally capable of warm and sincere friendship. His worldwide stature as a physicist went hand in hand with enormous integrity and a genuine nobility of character. He continued to serve the cause of Saclay until the final days of his life, and will be sadly missed by all those who had the privilege of coming into contact with him.

Bernard Peyaud, on behalf of René Turlay's friends and colleagues.

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UNIVERSITY OF OXFORD

Professorship of Experimental Physics

Applications are invited for the above post, tenable from 1st October 2003, or such later date as may be arranged. A non-stipendiary fellowship at Balliol College is attached to the professorship. The post will be in the Sub-department of Particle Physics, within the Department of Physics. The professor will be required to deliver lectures and give instruction in Physics, and to undertake original work and the general supervision of research and advanced work in his/her subject. The successful candidate will have an international reputation in scholarship and research, and will be expected to contribute, through personal research endeavour and through leadership, to maintaining a programme of research and teaching at the highest level in experimental particle physics at Oxford, and to exercise leadership in the subject in the UK.

The Sub-department of Particle Physics has a wide research programme covering experiments at accelerators and in particle astrophysics. This includes preparations for the ATLAS, LHCb, and MINOS experiments. CDF is taking data at the Tevatron, ZEUS is running with an upgraded detector at HERA II, and analysis of DELPHI data is being completed. The sub-department is engaged in R&D for a neutrino factory, including the HARP experiment to measure hadron production rates and the MICE experiment to demonstrate muon cooling. It is also participating in the LCFI collaboration to develop new CCDs for a vertex detector for the next linear collider, as well as schemes for collider beam alignment. The SNO solar neutrino detector is taking data and results of the first phase have recently been announced. The CRESST collaboration is preparing its second phase search for dark matter. The sub-department is engaged in all aspects of particle physics projects, from design through to final physics analysis. An important part of its programme consists of major responsibilities in hardware development carried out with the help of its excellent support staff in computing, electronics and mechanical design and construction.

Further particulars, including details of how to apply, are available from http://www.admin.ox.ac.uk/fp/ or from the Registrar, University Offices, Wellington Square, Oxford OX1 2JD, tel. (01865) 270200. The closing date for applications is 17th March 2003.

The University is an Equal Opportunities Employer.

PARTICLE BEAM DIAGNOSTIC PHYSICIST

Competition #887

Located in Vancouver, British Columbia, **TRIUMF** is Canada's national research facility for particle and nuclear physics. We are currently accepting applications for a Physicist or Engineering Physicist experienced in beam diagnostic instrumentation. The successful applicant will join our current team of engineers and technologists who are involved with the evaluation of diagnostics requirements and the design, construction and testing of state-of-the-art devices aimed at the measurement of beam properties for very low intensity ion beams for the ISAC exotic ion facility, and for high intensity beams at the 500MeV cyclotron.

Essential requirements for the position include a post-graduate degree in Physics or Engineering Physics, familiarity with particle beam optics, and at least three years of practical experience in the field of beam diagnostics acquired at a major particle accelerator laboratory. Demonstrated knowledge of accelerator controls, RF electronics and nuclear physics detection systems will be considered an asset during the selection process.

Consideration will be given to applicants in the following categories: Junior candidates with at least the above minimum required experience who have a strong interest and proven aptitude for the field; Senior beam Diagnostic Physicists who have a strong proven track record; and Senior experts employed by other institutions who would be willing and available to collaborate with **TRIUMF** for a one- or two-year term.

TRIUMF is an equal opportunity employer and invites qualified applicants to submit resumes, including 3 reference letters to: **TRIUMF Human Resources, (Comp. #887). Fax (604) 222-1074. Closing date for applications is February 28th, 2003.** *Please note that in the event where 2 final applicants are equally qualified, preference will be given, if applicable, to the Canadian Citizen or Landed Immigrant.* Only those individuals being considered will be contacted.

SLAC

Experimental Research Associates

The Stanford Linear Accelerator Center (SLAC) is one of the world's leading laboratories supporting research in high energy physics. The laboratory's program includes the physics of high energy electron-positron collisions, high luminosity storage rings, high energy linear colliders and particle astrophysics.

Post-doctoral Research Associate positions are currently available with research opportunities in the following areas:

- **B physics with the BABAR detector at the PEP II Asymmetric B Factory, analysis of 100 fb-1+ data set and preparations for detector improvements.**
- **Particle Astrophysics program especially the construction and preparation for launch in 2006 of the gamma ray telescope GLAST which will map out gamma sources to probe active galactic nuclei and pulsars, and other topics.**
- **R&D toward a future linear collider detector.**

These positions are highly competitive and require a background of research in high energy physics and a recent PhD or equivalent. The term for these positions is two years and may be renewed.

**Applicants should send a letter stating their physics research interests along with a CV and three references to
Jan Louisell, janl@slac.stanford.edu, Research Division,
M/S 75, SLAC, PO Box 4349, Stanford, CA 94309.
Equal opportunity through affirmative action.**

Post-doctoral Position in Experimental Particle Physics

The ZEUS group at the Physical Institute of Physics of the **University Freiburg** has an opening of a **post-doctoral position for experimental high energy physicists.** The temporary position (up to 5 years) is "Wissenschaftlicher Mitarbeiter (Verg. Gr. BAT IIa)".

The field of activity is the participation in the running of the ZEUS detector during the interesting high luminosity phase, the analysis of data from the ZEUS detector at the HERA collider, Hamburg. A participation on detector development for the future TESLA experiments is possible.

Longer periods of stay at DESY in Hamburg are welcome. The participation of supervision of students also at the University Freiburg is expected.

For the position a PhD in experimental particle physics or an equivalent University degree is required. Desirable are experiences in the field of particle detectors, and in the physics analysis of data from particle physics experiments.

Interested candidates should send the usual information (CV, list of publications, exam grades, the name of three referees) to:

**Prof. Dr. A. Bamberger
Universität Freiburg
Physikalisches Institut
Hermann-Herder-Str. 3
D-79104 Freiburg
Tel. +49 761 203-5714, Fax. +49 761 203-5931
until January 31, 2003.**

The University of Freiburg is seeking to increase the proportion of female research staff and therefore particularly welcomes applications from female candidates.

More information via: ***bamberger@physik.uni-freiburg.de***
See also: ***http://frzsun.physik.uni-freiburg.de:8080/***

FACULTY POSITION IN ACCELERATOR PHYSICS

The Department of Physics at the University of California, Riverside, invites highly qualified applicants to apply for a new faculty position in accelerator physics. This position may be filled at either the assistant professor or tenured associate professor level. The appointment will be effective July 1, 2003.

The Department is seeking outstanding candidates with exceptional research records and demonstrated excellence in teaching. The successful candidate is expected to establish a leading edge research program involving graduate students in what will be a new area in the Department and contribute to Department teaching at all levels. The Department currently carries out research in experimental and theoretical condensed matter physics, astrophysics, and high-energy physics.

Candidates for this position are required to have a Ph.D. or equivalent degree in physics. Salary will be competitive and commensurate with qualifications and level of appointment. Candidates should submit a letter of application, curriculum vitae, list of publications, evidence of teaching skills, and evidence of an outstanding research program. Candidates should also provide evidence of leadership and initiative since accelerator physics will be a new area in the Department. They should arrange to have three letters of reference sent to the Department and be willing to submit additional references on request. Letters should be sent to:

Chair, Accelerator Physics Search Committee
Department of Physics
University of California, Riverside
Riverside, CA 92521-0413
U.S.A.

Full review of applications will begin January 20, 2003.
Applications received after this date will be considered on a case-by-case basis until the position is filled.

UCR
UNIVERSITY OF CALIFORNIA, RIVERSIDE

The University of California is an Equal Opportunity/Affirmative Action Employer

Deutsches Elektronen-Synchrotron
Particle/Accelerator Physics

DESY

DESY is one of the leading accelerator centers worldwide. The research spectrum ranges from elementary particle physics and solid state physics to molecular biology.

For the experiments H1 and ZEUS, HERMES and HERA-B at the HERA storage ring and the preparation of the linear collider TESLA and its physics programme several

DESY Fellowships

are announced. The place of work is Hamburg or Zeuthen. Young scientists who have completed their Ph.D. and who are younger than 33 years are invited to submit their application including a resume and the usual documents (curriculum vitae, list of publications and copies of university degrees) and should arrange for three letters of recommendation to be sent to DESY.
The DESY-fellowships are awarded for a duration of 2 years with the possibility for prolongation by one additional year.

Salary and benefits are commensurate with public service organisations (BAT IIa / BAT IIa-O). DESY operates flexible work schemes, such as flexitime or part-time work.
DESY is an equal opportunity, affirmative action employer and encourages applications from women.

Deutsches Elektronen-Synchrotron DESY
member of the Helmholtz Association
code: 1/2003 • Notkestraße 85 • D-22603 Hamburg • Germany
Phone +49 (0) 40 8998-2524 • www.desy.de
email: personal.abteilung@desy.de

Deadline for applicants: 31.03.2003

Stanford Linear Accelerator Center

Accelerator Physics Faculty Search

The Stanford Linear Accelerator Center (SLAC) invites applications for a faculty appointment in Accelerator Physics with specialization in Beam Dynamics. The search is for a tenure-track or early-career tenured appointment. We are looking for candidates with significant accomplishments and promise for important future achievements. SLAC offers unique opportunities that include:

- Operating accelerators which support research in particle physics and synchrotron radiation-based sciences.
- Accelerators, high power test stands, and extensive instrumentation and facilities for accelerator research.
- A world-class faculty and staff working towards accelerators of the future.

The successful candidate is expected to take a leadership role in the ongoing activities, in developing new initiatives, and in creative scholarship. There are opportunities to teach and supervise undergraduate and graduate students as a member of the academic Council of Stanford University.

Candidates should submit a curriculum vitae, publication list, a statement of research interests, and the names of four references to: **Prof. T. Raubenheimer, SLAC — MS 66, 2575 Sand Hill Rd, Menlo Park, CA 94025**.

The deadline for receipt of applications is **March 1st, 2003**.

SLAC is an equal opportunity employer and welcomes nominations of women and minority group members and applications from them.

WESTFÄLISCHE
WILHELMS – UNIVERSITÄT MÜNSTER
-Department of Physics-

The Institute for Nuclear Physics invites applications for a
Professorship (C4) for Experimental Physics
with emphasis on Nuclear and Particle Physics
to begin on **October 1st, 2003**

The successful candidate is expected to fully represent the field of experimental physics in research and education. The field of research for the present position is defined within the research programme "Subatomic Physics" of the Department. It covers the area of fundamental physics of nuclei and particles and their interactions at highest possible energies. The successful candidate will take a leading role in the execution of Big Science projects as defined by the Science Programme of the German Ministry of Science and Education BMBF. Participation in all teaching acti vities and academic administration duties of the Department is expected.

Qualification requirements are a proven record of scientific achievements, either through a habilitation or equivalent accomplishments. The latter may also be obtained through a profession outside the university.

Qualified women are strongly encouraged to apply. Women with equal qualifications and scientific performance will be given preference, unless there are prevailing reasons within the person of a particular candidate. Preference will be given to candidates with disabilities.

Applications together with the curriculum vitae, the scientific career, a list of publications with up to 5 recent reprints and a description of teaching experiences should be sent by **April 1st, 2003** to:-

Dekan des Fachbereichs Physik
der Westfälischen Wilhelms-Universität Münster
Wilhelm-Klemm-Str. 9
D – 48149 Münster
Germany

COUNCIL FOR THE CENTRAL LABORATORY
OF THE RESEARCH COUNCILS

RESEARCH ASSOCIATES IN EXPERIMENTAL PARTICLE PHYSICS

3-year fixed-term contracts
Rutherford Appleton Laboratory (RAL)

CCLRC Rutherford Appleton Laboratory has vacancies for researchers in the Particle Physics Department.

The department is involved in a broad programme of experiments, both data-taking and in construction, in computing for particle physics, and in computer system management. The successful applicants will be based at RAL, but may have the opportunity to spend time at the experiment's host laboratory. Appointments will be for three years.

Further information about the opportunities available can be found at:
http://www.cclrc.ac.uk/Activity/ACTIVITY=Jobs

Applicants should have a PhD in experimental particle physics, or have equivalent experience.

The starting salary for these posts is up to £25,790, depending on experience, on a pay range of £20,630 to £28,370. An excellent index-linked pension scheme and a generous leave allowance are also offered.

An application form can be obtained from Operations Group, HR Division, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, telephone +44 (0)1235 445435 (answer-phone), or e-mail recruit@rl.ac.uk, quoting reference VN2355. More information about CCLRC is available from http://www.cclrc.ac.uk

All applications must be returned by 17th February 2003.

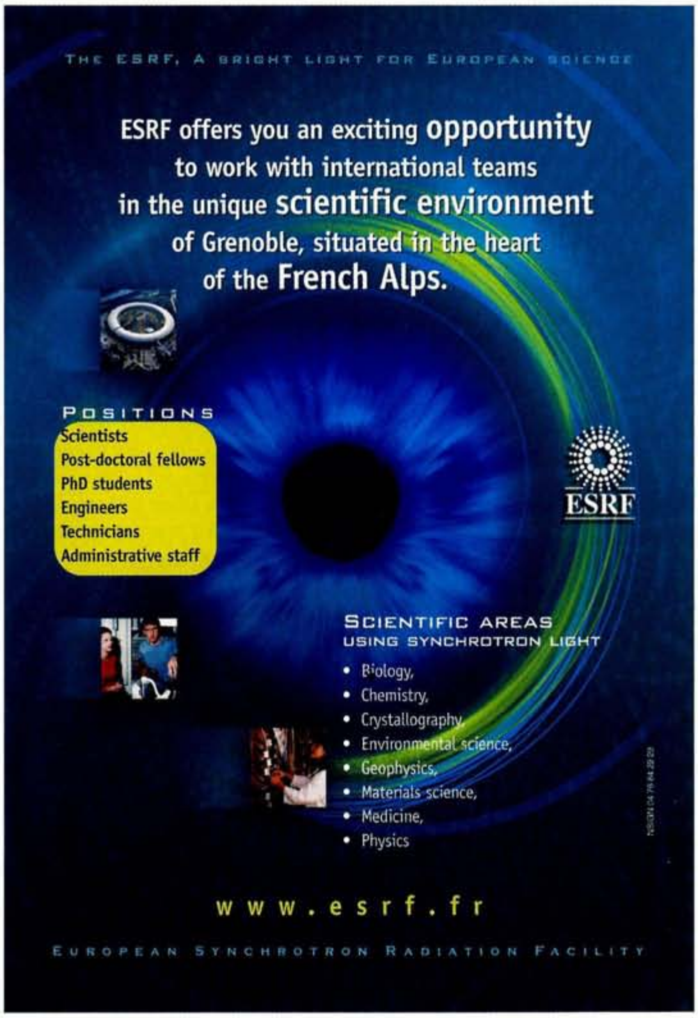
Interviews will be held from 4th to 6th March 2003.

CCLRC is committed to Equal Opportunities, and is a recognised Investor in People.
A no-smoking policy is in operation.

CLRC

INVESTOR IN PEOPLE

COUNCIL FOR THE CENTRAL LABORATORY
OF THE RESEARCH COUNCILS



POSTDOCTORAL RESEARCH PHYSICIST POSITION IN EXPERIMENTAL HIGH ENERGY PHYSICS

UNIVERSITY OF CALIFORNIA, RIVERSIDE

The Department of Physics at the University of California, Riverside invites applicants for a Postdoctoral Research Physicist position to work with the high energy physics group on the CMS experiment at CERN.

At the University of California, Riverside we are carrying out a multi-faceted program of detector development and production and preparation for physics in the CMS experiment. We are seeking a Postdoctoral Research Physicist to work on CMS tracking software, with an emphasis on physics, based at U.C. Riverside. The Postdoctoral Research Physicist would also work on studies for the CMS Physics TDR and serve as a leader and resource for others in the U.S. who want to work on tracking software. The Postdoctoral Research Physicist would make frequent trips to CERN and U.S. locations for meetings and consultations.

Applicants should have experience with high energy physics analysis and software. Applicants who are already knowledgeable about CMS software are preferred. Candidates must have a Ph.D. degree. Applications, including vitae, list of publications, and three reference letters should be sent to:

Professor Gail G. Hanson
Department of Physics
University of California, Riverside
Riverside, CA 92521-0413
U.S.A.

or by e-mail to Gail.Hanson@ucr.edu or Gail.Hanson@cern.ch. The position will be filled as soon as an appropriate candidate is identified.

UCR
UNIVERSITY OF CALIFORNIA, RIVERSIDE

The University of California is an Equal Opportunity/Affirmative Action Employer

POSTDOCTORAL AND SCIENTIST
Positions in Supernova Cosmology Program

The Supernova Cosmology research group of Berkeley Lab has multiple Postdoctoral and Scientist positions available on SCP, SN Factory, or SNAP. These are two-year term positions with the possibility of renewal and offer an exciting opportunity for a wide range of investigations concerning cosmological parameters, the acceleration of the universe, and the "dark energy" explanations for the acceleration.

Projects include high-redshift supernova studies of the cosmological parameters (SCP), intensive discovery and follow-up of low-redshift supernovae to understand these cosmological tools (SN Factory), and the development, design, and instrument-prototype construction of a dedicated space-based telescope facility (SNAP). Candidates should have interests and abilities in any of the following: observation and analysis related to cosmology or supernovae, astronomical instrumentation (ground- and space-based), and/or novel real-time data analysis techniques for large-dataset projects.

Requires a PhD or equivalent experience in Physics and/or Astronomy. Find out more at http://supernova.lbl.gov and http://snap.lbl.gov. Applications, including CV, list of publications, description of research interests and skills, and three letters of recommendation should be sent to: Berkeley Lab Search Committee, c/o Ms. Madelyn Bello, Berkeley Lab, One Cyclotron Road, Mailstop 50A-4037, Berkeley, CA 94720 or e-mailed to gensciemployment@lbl.gov. Please cite job number PH/015554/JCERN for the Postdoctoral positions and PH/015555/JCERN for the Scientist positions. Applications will be considered beginning by 1 February 2003. Berkeley Lab is an AA/EEO employer. We are located in the hills above the UC Berkeley campus.

BERKELEY LAB

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

POSTDOCTORAL POSITION

The Max-Planck-Institut für Physik (Werner-Heisenberg-Institut) invites applications for ***a postdoctoral position for studies for the HERA 3 project, a possible new experiment at DESY.***

The HERA 3 initiative is investigating the possibility of a new experiment at the ep-collider HERA at DESY. The goals are the precise measurement of structure functions at low x and low Q^2 as well as exclusive processes in order to investigate the transition between perturbative and non-perturbative QCD, the comparison of the parton densities in the proton to those in light nuclei, the measurement of valence quark densities and a precision measurement of the strong coupling constant. We are also considering the possibility of studying the spin structure of nucleons with polarized beams in HERA. Current work is aiming to provide the foundation for a letter of intent.

The Max-Planck-Institut is one of the lead institutes in the project. We will initially focus on the design of the detector, with emphasis on the tracking. The successful candidate is expected to contribute to this effort.

Salary and benefits are commensurate with public service organisations (BAT IIa). The contract is initially limited to 2 years, with the possibility of extension of up to five years. Candidates should have good knowledge of experimental high energy physics, and should hold a PhD or equivalent in physics. They should not be older than 32 years. The MPI hires on the basis of merit and encourages applications from women.

Interested applicants should submit an application letter, a statement of research interests, a curriculum vitae, a list of publications, and arrange for three letters of support to be sent to

Kristiane Preuss, Max-Planck-Institut für Physik,
(Werner-Heisenberg-Institut),
Föhringer Ring 6, D-80805 München

Further information can be obtained from Prof. Allen Caldwell ***(E-Mail: caldwell@mppmu.mpg.de)***. Applications should be sent as soon as possible, at the latest 6 weeks after publication.

Australian Synchrotron Project – Lighting the Path to Innovation

A major national facility, to be located in Melbourne, the Australian synchrotron will provide researchers both from within Australia and overseas, with a powerful new tool for scientific and industrial research including the fields of structural molecular biology, molecular environmental science, materials science and medical diagnostics and therapy.

A number of experienced Managers, Engineers and Physicists are now required to work with a large team of world leading experts in managing the design and construction of this project, from conceptual design to final inspection and testing activities. We have employment opportunities in the following fixed term roles:

- Lead Accelerator Physicist
- Technical Manager
- Accelerator Physicist
- Lead Mechanical Engineer
- Lead Electrical Engineer
- Lead Computer Control Systems Engineer

Relocation assistance will be provided. Please enquire in strict confidence by contacting Rohan Christie or Graham Gough on +61 (03) 9670 1220 or +61 0413 592 882 or by sending an email to address shown below. Please send a concise CV (max 5 pages) and cover letter to the following address: Rohan Christie, Gough Partnership, "Bourke Place" Level 9, 600 Bourke Street, Melbourne VIC 3000 Australia Fax: +61 (03) 9670 1575 Email: *rc@goughpartnership.com.au* *www.goughpartnership.com.au*

Further information on the project can be obtained at
http://www.synchrotron.vic.gov.au

Department of Infrastructure

Victoria The Place To Be

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

LABORATOIRE EUROPÉEN POUR LA PHYSIQUE DES PARTICULES
EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN invites applications for the position of

EDITOR

CERN Courier

Published ten times a year in English and French, the CERN Courier serves the global particle physics community. It carries news and opinion on developments in particle physics, nuclear physics and accelerator science. The readership of around 25,000 is broadly divided between the particle physics community and scientists in other disciplines. Production of the magazine is outsourced, currently to IOP Publishing in the UK.

Candidates are expected to have a doctorate in particle physics and a proven track record in written science communication, with experience at international level. Further requirements include experience of scientific publishing coupled with the ability to transform scientific information into terms that can be understood by non-specialist audiences. Impeccable written English and a good working knowledge of French are necessary.

The post will involve independent researching, commissioning, editing and writing. The Editor will work closely with the external publisher to ensure timely delivery of an accurate and relevant magazine. He/She will also have supervisory responsibility for the Laboratory's other non-technical publications.

Interested candidates are asked to send an application letter and a CV including the names of three referees to Mr Pierre Gildemyn, Human Resources Coordinator, CERN, CH @ 1211 Geneva 23, email: Pierre.Gildemyn@cern.ch, by 15 March 2003. Nationals of CERN's Member States may apply for this vacancy*.

This position is also published on the vacancy list at CERN, which can be consulted at www.cern.ch/jobs/

CERN is an equal opportunity employer and encourages both men and women with the relevant qualifications to apply.

*** AT, BE, BG, CH, CZ, DE, DK, ES, FI, FR, GR, HU, IT, NL, NO, PL, PT, SE, SK, UK**

UNIVERSITAS BERGENSIS

Associate Professor in Microelectronics

Department of Physics

University of Bergen, Norway

The Department invites applications for a tenure position in microelectronics with an emphasis on ASIC design as applied to analogue devices/circuits/systems, computer systems and digital signal processing. The position is available immediately and will be at Associate Professor level. More information on the Department is available at ***http://www.fi.uib.no/***

The Department of Physics has substantial expertise and experience in the development of electronics for high-energy physics and space physics instrumentation and for industrial applications. Activities within microelectronics include design, simulation, production and testing of analogue and digital VLSI systems, where integration with detector/sensor technology is a prime focus.

The successful applicant must have a doctorate in electrical or computer engineering or applied physics or corresponding qualifications. He or she will have a special responsibility towards teaching and research within analogue and mixed circuits, with emphasis on modeling and design of sub micron integrated circuits. The applicant should demonstrate excellence in teaching, outstanding communication skills, and commitment to working with students and developing collaborative research. The candidate should demonstrate the ability or potential to carry out research at an advanced international level, and the ability to initiate and conduct research projects. Industrial experience as an ASIC designer is desirable.

A complete description of the position can be found at ***http://www.uib.no/info/english***. Applications must be written and submitted in strict agreement with the guidelines given in the full description. On-line/electronic applications will not be considered.

Closing date for applications is February 22nd, 2003.

Informal enquiries can be made to: Associate Professor Kjetil Ullaland, Department of Physics, phone +47 55 58 28 71, email ***kjetil.ullaland@fi.uib.no***

PAUL SCHERRER INSTITUT

research for the future

Experimental Physicist

Postdoc Position

With a broad research program in experimental phisics and with large research facilities such as the neutron spallation source SINQ and the synchrotron light source SLS, the Paul Scherrer Institute PSI offers a wide and attractive spectrum of experiments, an increasing number of them at low temperatures.

Your tasks

You will be a member of the Low Temperature Facilities group. You will study the process of dynamic nuclear polarization of nuclei around paramagnetic centres as a function of space and time. The transfer of spin ordering to the nearby protons and by spin diffusion to the bulk protons is investigated using both NMR and small angle neutron scattering of polarized neutrons. Further you will participate in experiments and general tasks of the group.

Your profile

You completed recently your PhD thesis in physics. Preferably, you are familiar with the use of liquid helium and you acquired experience in two or more of the following fields: dynamic nuclear polarization, NMR, ESR, small angle neutron scattering, polarized neutrons, low temperature techniques below 1 K. You like to work in a small team of physicists and technicians collaborating with user groups of the PSI facilities. A good command of English is required.

For further information please contact Dr B. van den Brandt, telephone +41 56 310 40 27, e-mail: ben.vandenbrandt@psi.ch.

Please send your application to PAUL SCHERRER INSTITUT, Human Resources, Mr. Thomas Erb, ref. code 3012, CH-5232 Villigen PSI, Switzerland.

Further jobs: www.psi.ch

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

isn Grenoble

Accelerator physicist or Engineer

ISN (Institut des Sciences Nucléaires), located in Grenoble, is one the French laboratories which have acquired a rich experience in studying and building particle accelerators . Among the recent projects ISN has been involved in , one can quote : ETOILE (a synchrotron for hadron therapy), GENEPI (a pulsed neutron generator for hybrid reactors) and HIPHI (a high intensity proton accelerator).

ISN is now taking major commitments in the Advanced Detailed Project of LINAG : a high intensity deuteron linac for SPIRAL at GANIL . In this context, we are seeking a high level accelerator physicist or engineer .

Applicants should either have a Ph. D. in physics or an engineer diploma of a renowned school . They should be knowledgeable in the investigation of RF systems. A deep competence in beam dynamics will also be appreciated.

The position will be open for 3 years (starting at the beginning of May 2003) with a high probability to get converted into a permanent position at CNRS.

Salaries are commensurate with the French public service organizations.

Detailed information can be obtained by contacting our project leader :
Jean-Marie De Conto at ISN Grenoble : ***Jean-Marie.De-Conto@isn.in2p3.fr***
+33 4 76 28 40 98

Applicants should send a resume, a letter of motivation and a short description of their recent scientific activities to :
Jean-Marie de Conto , ISN Grenoble , 53 avenue des Martyrs , F-38026 Grenoble Cedex, before 3 March 2003.

CNRS is an Affirmative Action/ Equal Opportunity Employer

6 POSTDOCTORAL POSITIONS IN EXPERIMENTAL HIGH ENERGY PHYSICS

The PRSATLHC Research Training Network, funded by the European Commission's 5th Framework (contract HPRN-CT-2002-00326), is offering 6 post-doctoral positions to study the physics of the LHC and to design and implement algorithms for event selection. The positions will be given for 2 to 3 years with a highly competitive salary determined according to qualification and place of appointment. The institutions belonging to the Network, along with the contact person are:

- **University of Athens (Greece), P. Sphicas, Paris.Sphicas@cern.ch (coordinator)**
- **INFN-Pisa (Italy), F. Palla, Fabrizio.Palla@cern.ch**
- **University of Padova (Italy), U. Gasparini, Ugo.Gasparini@cern.ch**
- **University of Karlsruhe (Germany) T. Mueller, mullerth@ekp.physik.uni-karlsruhe.de**
- **Imperial College (U.K.), T.Virdee, Tejinder.Virdee@cern.ch**
- **University of Louvain (Belgium), V. Lemaitre, Vincent.Lemaitre@cern.ch**

More information on the network can be found at ***http://cms.phys.uoa.gr/ PRSATLHC/***.

Qualifications required include a PhD or equivalent in High Energy Physics, and a clear demonstration of the ability to carry out a research program, whether on hardware or software. Knowledge of modern programming techniques, Object-Oriented software and C++ will be an asset (but not obligatory). Applicants must be (a) age 35 or less at the time of their appointment to the network (b) be nationals of an EU Member State or Associated State or have resided in an EU Member State for at least five years and (c) they must not be a national of the state in which the institution is located. The full set of eligibility requirements can be found on the network website. Applications should be sent directly to the contact person, with a copy sent to the network coordinator as well. All positions will remain open until suitable candidates are found.

The member institutions of this network are all Equal Opportunity/Affirmative Action Employers and particularly encourage applications from women and minorities.

Postdoctoral Fellowships – Experimental Neutrino Astrophysics at Queen's University

SNO

The Department of Physics at Queen's University invites applications from qualified candidates to join the exciting research program at the Sudbury Neutrino Observatory (SNO) and participate in the development of new projects at the new expanded underground facility. Candidates must have a PhD in a related area of experimental physics or radiochemistry. Applicants should forward a curriculum vitae, a statement of research interests, and arrange for letters from three referees to be sent to:
Prof A. J. Noble,
Department of Physics, Stirling Hall,
Queens University, Kingston, Ontario,
Canada, K7L 3N6

Post Doc Position

in Beam Dynamics and Dynamical Systems for 1+1 years starting 4/1/03.

Emphasis on studying the Vlasov equation, as it arises in collective effects in modern accelerators, using tools from dynamical sytems and high performance computing.

http://www.math.unm.edu./jobs/employment.html

James Ellison, Math/Stat, UNM, Albuquerque, NM 87131

The Lawrence Langer Research Fellowship

This special research fellowship is named after Lawrence Langer who performed pioneering research on beta decay and neutrino mass measurements. The fellowship is awarded to an outstanding post-doctoral scientist who is at an early point in a promising career.

Candidates for this fellowship must have displayed outstanding potential in subatomic physics research, and must show definite promise of becoming leaders in the academic research community. A Ph.D. in experimental subatomic physics is required. Fellowships will be awarded for a three-year term. Langer Fellows, who will be competitively selected, are given the freedom of associating with IUCF faculty members in a research area of common interest.

The I.U. subatomic 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 involve leadership roles in studies of parity violation in thermal neutron-proton capture at LANSCE, flavor and spin structure of the nucleon at RHIC with the STAR detector, neutrino oscillations with the miniBooNE experiment at Fermilab, and low energy solar neutrinos with CLEAN. Local facilities include a 200 MeV cyclotron and a 240 MeV synchrotron. While the major programs on these no longer include nuclear physics, they do provide excellent facilities for development and testing. The laboratory also provides excellent 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.

The Lawrence Langer Research Fellowship carries a stipend of $55,000 per annum, with an additional allocation of up to $20,000 per annum for research support and travel

Send résumé, bibliography and contact information for three references by March 28 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

IU is strongly committed to achieving excellence through cultural diversity. The university actively encourages applications and nominations of women, persons of color, applicants with disabilities, and members of other underrepresented groups.

Indiana University is an Affirmative Action/Equal Employment institution.

Deutsches Elektronen-Synchrotron

RF-system

DESY

In international cooperation the research center DESY plans and develops an innovative future project: TESLA, a 33 km long, superconducting linear accelerator with integrated X-ray lasers.

Our group -MHF-p- in Hamburg is responsible for the operation of the RF systems for the proton accelerators and the development, installation and operation of the RF system of TESLA Test Facility, a superconducting linear accelerator, which serves as a testbed of components for the future Linear-Collider with integrated free electron laser. We are looking for a

scientist (m/f)
BAT Ib according to qualification

You are expected to play a key role in the design and commissioning of the rf control system for the 64 superconducting cavities of the TESLA-Test-Facility. The basic concept is based on a state of the art fast digital IQ controller which controls the vector-sum of up to 32 cavity voltages in presence of severe Lorentz force detuning, microphonics, and bunch charge fluctuations. In order to meet the requirements for TTF II and the TESLA linear collider you will continually improve existing designs and, as a member of a multidisciplinary team, you will be responsible for the commissioning of the rf control for the free electron laser at the TTF II.
You should have a Ph.D. in physics, equivalent science or comparable qualifications. Further you should have a working knowledge in at least one of the following areas: accelerator physics, control theory, digital signal processing, radio frequency systems for accelerators, programming languages and operating systems (such as UNIX, C, C++). Experience with particle accelerators, superconducting cavities or simulation programs such as MATLAB and SIMULINK are desirable. Furthermore your work would partly consist of shift work. Your health should also permit the use of a breath protection mask. If you fulfil all these requirements, please send your letter of application to our personnal department.

Salary and benefits are commensurate with public service organisations. DESY operates flexible work schemes, such as flexitime or part-time work.
DESY is an equal opportunity, affirmative action employer and encourages applications from women.

Deutsches Elektronen-Synchrotron DESY
member of the Helmholtz Association
code: 4/2003 • Notkestraße 85 • D-22603 Hamburg • Germany
Phone +49 (0) 40 8998-3918 • www.desy.de
email: personal.abteilung@desy.de

Deadline for applicants: 16.02.2003

UNIVERSITY of GLASGOW

www.gla.ac.uk

DEPARTMENT OF PHYSICS & ASTRONOMY

Research Associate in Experimental Particle Physics

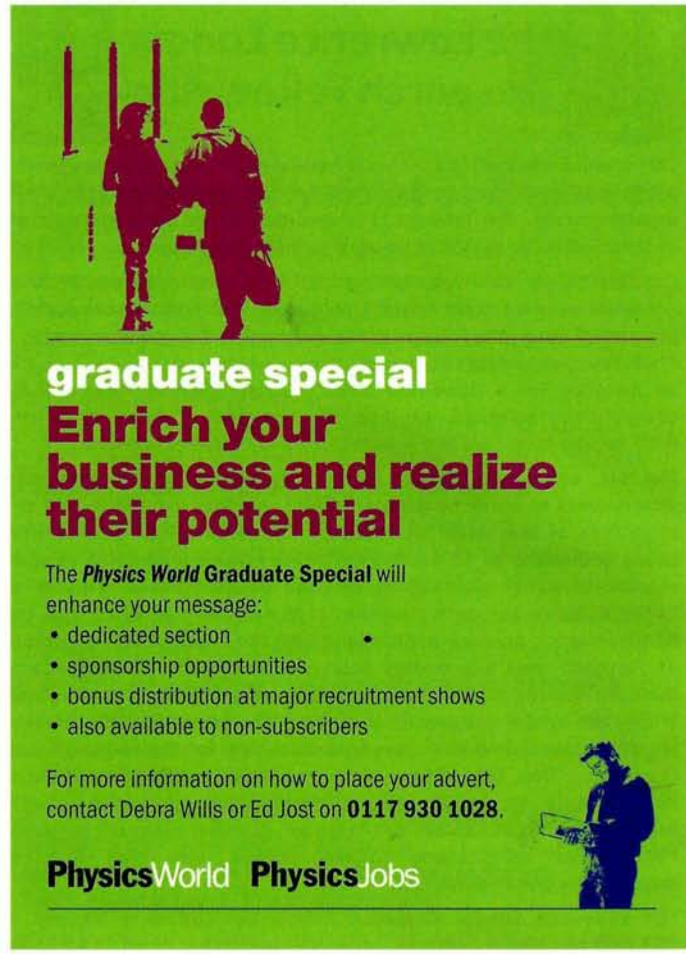
RA1A £18,265 – £27,339

You will work on the ZEUS experiment, taking part in the operation of the experiment and the analysis of the data. It is hoped that you will be able to spend extended periods at DESY. You will have, or shortly expect to gain, a PhD along with experience in the field of particle physics data analysis or simulation. This post is available from 1 May 2003 or from an alternative date by agreement until 30 September 2006. Informal enquiries to Dr PJ Bussey (p.bussey@physics.gla.ac.uk). For further particulars see http://ppewww.ph.gla.ac.uk/

Applications, quoting Ref: 603/02, should be sent to Professor D.H. Saxon, Kelvin Building, University of Glasgow, Glasgow G12 8QQ.

Closing date: 19 February 2003.

The University is committed to equality of opportunity in employment.



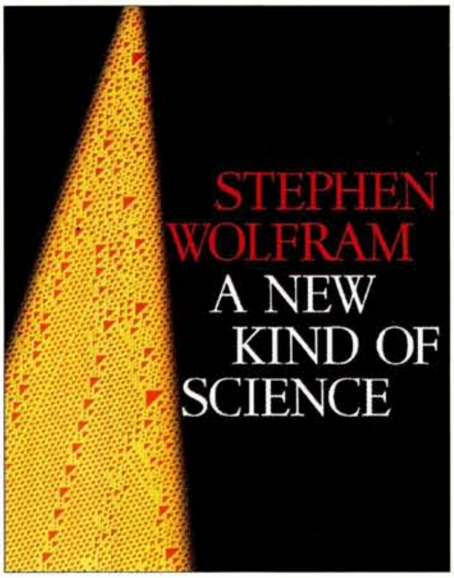
INDEX TO DISPLAY ADVERTISERS

The index is provided as a service and, while every effort is made to ensure its accuracy, *CERN Courier* accepts no liability for error.

A New Kind of Science by Stephen Wolfram, Wolfram Media, Inc. ISBN 1579550088, $44.95 (US); £40 (UK).

"Three centuries ago, science was transformed by the dramatic new idea that rules based on mathematical equations could be used to describe the natural world. My purpose in this book is to initiate another such transformation, and to introduce a new kind of science that is based on the much more general type of rules that can be embodied in simple computer programs." Thus begins *A New Kind of Science*, in a probably self-conscious reference to Newton's *Principia*. Ambition is certainly not lacking; this work claims to give us a radically new view of a large number of natural and social sciences. The author says that the discoveries he has made with his new kind of science will transform many fields of scientific endeavour, including the theory of evolution; the interpretation of genetic information; the origin of morphology in biological systems; embryology; the very notions of space and time; elementary particles; quantum mechanics; a fully fledged complexity theory; and brain function. A deeper understanding of things like free will and extraterrestrial intelligence are thrown in for good measure.

Wolfram was a child prodigy who also worked on particle physics and cosmology, making important contributions. He is well known as the author of *Mathematica*, a magnificent software package that allows sophisticated symbolic manipulations. This provides the basic tool for the investigations presented in this volume. When the program was released, it was an instant success, and most high-energy physicists are almost as addicted to it as they are to Paul Ginsparg's archives. Nearly 20 years ago, Wolfram decided to study systems known as cellular automata. The simplest of these consists of an array of cells that can be in two states – say black and white – whose evolution generates a pattern in a two-dimensional array. The update rule that allows us to determine the state in the next row is (in the simplest variety) determined by the state of the cell and that of its two nearest neighbours. In this case the total number of possible rules is just 256, and one can program a computer to study their evolution for a variety of initial conditions. A particularly important program is rule 110, which states that if the cell is white, it will only turn black if its right neighbour is



black, and if it is black, it will remain black unless its two neighbours are also black, in which case it will turn white. Given the initial condition, one can apply the rule and follow the two-dimensional pattern that is generated after many iterations. Wolfram discovered in the early 1980s that in spite of the simplicity of these rules, the patterns generated can contain great complexity – simple rules can generate complex behaviour. By thoroughly studying many kinds of cellular automata, he proposed their classification into four categories according to the long-term patterns they generate: uniformity, periodicity in time, fractals, and genuine complex non-repetitive patterns. With this principle, he begins his study of how to understand the complexity we observe in nature.

After making the basic observation by looking at computer experiments with linear cellular automata, Wolfram presents many other systems leading to complex behaviour, including higher-dimensional cellular automata, tag-systems, substitution systems, continuous automata and Turing machines. His conclusions always seem to be that once complex behaviour is achieved, the addition of new rules (complicating the initial program) will not significantly change the level of complexity. He also presents a plethora of natural phenomena that at first sight look complex. Traditional intuition might lead to the belief that the underlying rules are complicated, but Wolfram can produce simple automaton rules that visually reproduce their pattern of complexity. This includes snowflakes, leaves in plants, mollusc shells, iterated maps, pigmentation patterns throughout the animal world, the breaking of materials, earthquake patterns, and many others. Some of these phenomena have been studied by others, but since the main body does not include references, it is hard for the reader to know this.

In some instances, Wolfram's case is convincing; in others it looks more like a good guess. In chapter 9, for example, he offers his view of the origin and exceptions of the second law of thermodynamics, together with a speculative model of the physical universe based on discrete causal networks where elementary particles are identified with localized structures of the universal automaton. The model is far from being testable, and furthermore, the way in which quantum mechanics is incorporated may have difficulties with the Bell inequalities.

The last two chapters on the notion of computations and the principle of computational equivalence are the natural conclusion of previous arguments. Like others (in particular Edward Fredkin), Wolfram proposes that the universe is a computation ("it for bit", as John Wheeler would say). The fact that running simple programs roughly reproduces a large variety of complex patterns leads him to formulate his principle of computational equivalence (p720): "The principle of computational equivalence introduces a new law of nature to the effect that no system can ever carry out explicit computations that are more sophisticated than those carried out by systems like cellular automata and Turing machines." In fact, in chapter 11 a proof is presented showing that rule 110 is a universal Turing machine – a universal computer. On p1115 we learn that the proof comes from one of Wolfram's former employees, Matthew Cook, who was asked to work on it by Wolfram himself. The fact remains that to codify other universal computers as initial conditions to rule 110 so that it can simulate them seems extraordinarily complicated. Assuming the proof to be correct, and Wolfram is aware that a few errors may remain, it provides the simplest universal Turing machine constructed to date. However, a more unsettling conclusion can be drawn. Since humans are more processes than beings (we are gene survival kits, as Richard Dawkins colourfully puts it), we can describe our existence as an ongoing computation. Hence according to the principle of computational equivalence, we are ▷

computationally equivalent to rule 110. Ever since Copernicus, our place in the universe has diminished. Wolfram's conclusion seems the epitome of Copernican recession. "But the Principle of Computational Equivalence also implies that the same is ultimately true of our whole universe," Wolfram reassures us on p845. The problem may also be in the details of the initial conditions, and the devil is always in the detail.

If we follow the previous arguments, the same principle seems to lead inevitably to the conclusion that the whole universe, with all its subtle and wonderful features, can be encapsulated in a few lines of computer code (for example in *Mathematica*). The book ends with a humbling thought: "And indeed in the end the Principle of Computational Equivalence encapsulates both the ultimate power and the ultimate weakness of science. For it implies that all the wonders of our universe can in effect be captured by simple rules, yet it shows that there can be no way to know all the consequences of these rules, except in effect just to watch and see how they unfold."

Wolfram has very high expectations for his new kind of science. No doubt many of his ideas and analyses will be incorporated in scientific discourse, but whether they will have the power to truly solve basic open questions in so many fields of knowledge (even in just one would be a great accomplishment) remains to be seen.

The book is often vague, which is in part due to the style of exposition chosen by the author, who is writing for a general audience. In (traditional) scientific practice, the identification of precise definitions and features of a given problem often takes us a long way towards its resolution. It is clear that much more work will be done following the methods of this book, and in a few years' time, we will know whether they have become commonplace.

Apart from the controversial and speculative aspects of this book, it is worth mentioning that it provides an excellent expository account of large areas of physics, mathematics, computer science and biology in the main text and in the notes. The latter contain lucid presentations of vast areas of human knowledge. There is a lot to be learned from this book, and without a shadow of doubt, it will not leave you indifferent.

Luis Alvarez-Gaume, CERN.

LETTERS

CERN Courier welcomes feedback but reserves the right to edit letters. Please email cern.courier@cern.ch.

Particle physics in New Zealand

You described a plan for New Zealand to contribute to instrumentation for the LHC that is being built primarily to search for the Higgs boson (*CERN Courier* August 2002 p29). It might have been mentioned that not all New Zealanders believe in the existence of the Higgs boson, even though some basic concepts of the Standard Model were proposed here. The profile did of course refer to Rutherford, although he may not have done much nuclear physics in New Zealand. It is, however, perhaps noteworthy that astronomers in New Zealand are currently using a gravitational microlensing technique that is comparable to Rutherford scattering to search for terrestrial extra-solar planets. The main difference is that whereas in Rutherford scattering electrons decelerate the projectile, in gravitational microlensing, the projectile is deflected by planets. The mathematics is otherwise quite similar.

Philip Yock, University of Auckland, New Zealand.

Alick MacPherson replies:

It was with great pleasure that we were able to report in *CERN Courier* the development of a New Zealand particle physics initiative that will contribute to the CMS pixel detector and the CMS heavy-ion programme. By design, NZ_CMS (now elected a full member of CMS) will contribute to CMS, while building on existing research strengths within New Zealand physics research (astro-particle physics, astronomy, electronics, materials science and solid state). It is expected that NZ_CMS will foster developments with the wider research community, the New Zealand government and industrial sector, which will benefit both New Zealand and CMS.

In short, a crucial factor in the success of NZ_CMS will be its ability to develop synergies within the New Zealand research community, and to extend these through the strengthening of international links. As such, we see it as a healthy sign that New Zealand physicists are not in uniform agreement on the structure of our underlying particle theory, and that the NZ_CMS programme has renewed interest amongst New Zealand researchers and students in high-energy particle physics. Indeed in the last year, guided visits to CERN and to the CMS experiment by New Zealand-based staff and students have been made on five occasions, compared with none in the previous year.

The NZ_CMS programme, with a combined thrust of fundamental HEP and instrumentation technology, should create a strong and well-balanced New Zealand-based particle physics research initiative that builds on our existing strengths, while opening research, technology and industrial opportunities for young New Zealanders. This will allow New Zealanders to develop and participate fully in CMS, without adding to the "brain drain" of human resources that has plagued New Zealand since the time of Rutherford.

Growing internationalism at Fermilab

I enjoyed your piece on Fermilab (*CERN Courier* November 2002, p32), but unfortunately, a small error crept into your description of D0's evolution. The French Saclay laboratory was indeed the only non-US founding member of D0, but this happened in 1984 (not 1996). By 1995, the author list on the top quark discovery paper had grown to include groups from Brazil, Colombia, France, India, Korea, Mexico and Russia, together with visitors from Argentina, China and Ecuador, who later went on to become the nuclei of full member groups in those countries. Now the list of countries affiliated with D0 also includes the Czech Republic, Germany, Ireland, the Netherlands, Sweden, the UK and Vietnam. Western European involvement is substantial – instead of one French member group, we now have seven. More than half of our collaborators are now from non-US institutions.

John Womersley, co-spokesman, D0 experiment.

Comment:

The internationalization of D0 has indeed been impressive, reflecting a growing trend in particle physics in general. From one foreign institution to over 50% non-US participation in two decades is certainly substantial, and CERN is undergoing a similar evolution, with over 40% of collaborating institutes being in non-member states.

Another error crept into the profile. The Tevatron is, of course, a proton–antiproton collider, and not a proton–proton machine.

James Gillies.

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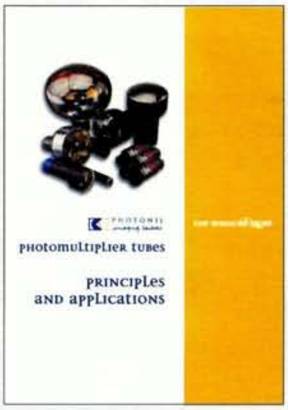

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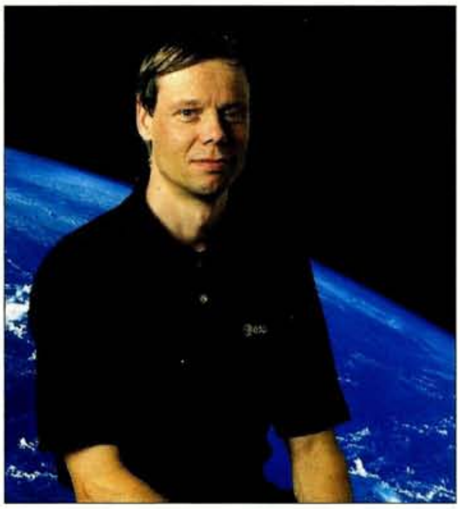
VIEWPOINT

From research at CERN to working in space

European Space Agency astronaut **Christer Fuglesang** explains how his training in particle physics at CERN prepared him for a career in space.

In June 1990, while I was a Fellow at CERN in experimental particle physics, a friend told me that the European Space Agency (ESA) was recruiting new astronauts. Although I loved (and still love!) the physics research work I was doing, and being at CERN in particular, I had always dreamed of going into space one day. It did not take me long to decide that at the very least I should inquire further, though I was concerned that my background was quite unlike the kind of research that is typically performed during manned space flights. I discussed this with the Swedish Space Board before asking them to send me the application papers (a densely written 16 page form), but they confirmed that I was the kind of person that could be of interest to ESA.



The selection process for just six new ESA astronauts took almost two years. Initially, each ESA member state selected up to five candidates, and then ESA chose from the 60 pilots, engineers, medical doctors, physicists and other scientists whose names were put forward. The selection process involved extensive medical screening, as well as several interviews. My CERN background was invaluable – though it is not space science per se, particle physics is closely related to astrophysics and cosmology, and also to radiation, which is a problem for humans and technology in space. My hands-on experience with experimental hardware was useful, but even more important, I believe, was my experience of working in a highly international environment, and the language skills I had gained there.

During one interview, a member of the selection panel remarked that although I had a fairly long publication list, he had noticed that the publications had up to 100 names on them. How could he be sure of my contribution? I had to explain how particle physics experiments are generally performed by large collaborations from many countries. This is increasingly true today, with as many as a thousand collaborators being involved in a single experiment. Fortunately, I was able to point out one or two papers that I had produced myself.

It should be noted that astronauts rarely perform their own experiments in space, and therefore a broad background is important. The exception is when so-called "payload specialists" fly on dedicated science missions, having been selected because of their expertise in a particular scientific field. A mission crew has to deal with technically advanced equipment on a daily basis, and must be able to operate various experiments as well as spacecraft systems. Having worked with particle physics experiments that demand high technology in many fields, I had already been exposed to several areas that one encounters in space activities.

Astronauts are among the prime communicators for the space programme – one could say they are "space ambassadors". My scientific background has been extremely useful to me during many talks and presentations – in particular during the question-and-answer sessions that often ensue.

The International Space Station (ISS) is certainly "big science", very much as CERN is. I recognize many similarities, although the ISS is more politicized. There are often complaints that ISS science is too expensive, and that the money could be better spent elsewhere. This is a misunderstanding of the real goals of the ISS, which are to learn how to build and live in space, and to prepare for future space developments. In some ways, it is like the basic science carried out at CERN – we do it out of curiosity, and we do not know what the eventual outcome will be. However, we are convinced that one day we will achieve results that will be of great benefit for all humankind. In the meantime, we take this great opportunity to carry out experiments in a unique environment, and to learn as much as possible about it, in particular how humans react to long periods in space.

I have always tried to combine my interest in particle physics with being an astronaut. I was dreaming of having my own experiment to work on in space, when I heard about the light flashes in the eyes that most astronauts experience in space. It was clear that these are from particles that penetrate the eyes, but until then no-one had put an active detector in space, in front of the eyes, in an effort to correlate particles and light flashes. This eventually led to the Italian-Russian-Swedish SilEye project, based on silicon strip detectors. The collaboration flew two detectors to the Russian space station Mir, and now also has one on the ISS. I hope to get a chance to use it in the summer of 2003, when I am finally scheduled to fly on the space shuttle and spend a week on the ISS.

Christer Fuglesang, ESA.