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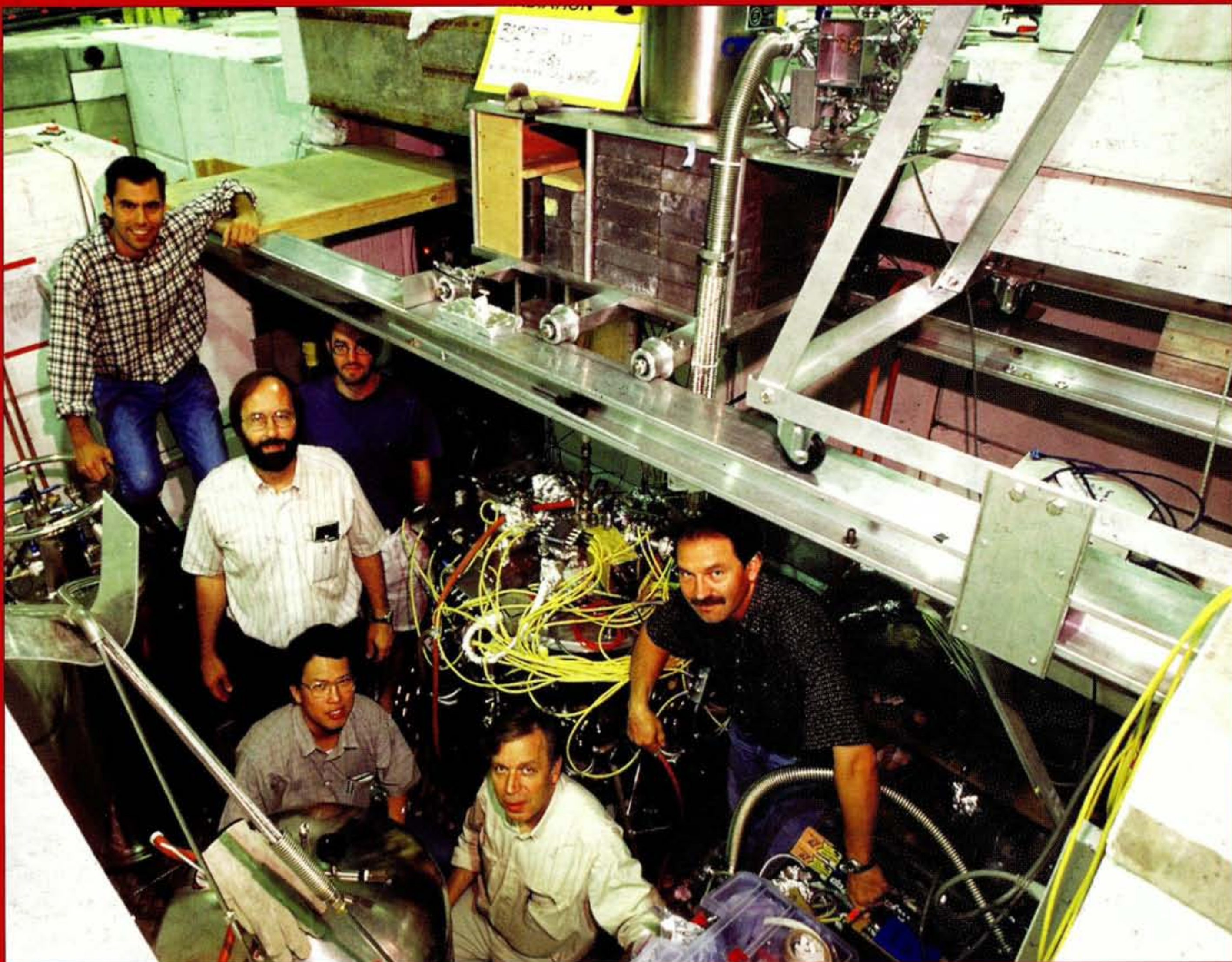
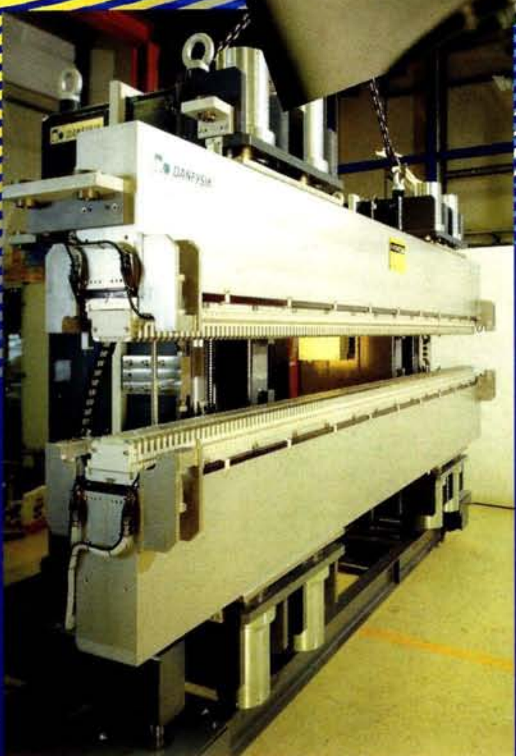


CERN experiment looks inside antiatoms



Covering current developments in high-energy physics and related fields worldwide

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DASI measures CMB p11

A Nobel career p15

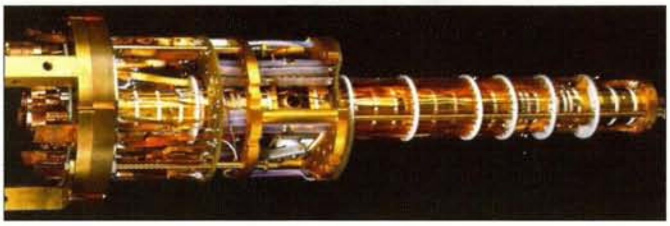
SLAC celebrates 40 years p33

Cover: Members of the ATRAP collaboration with the apparatus that provided the first glimpse inside cold antihydrogen at CERN. Some of the antihydrogen atoms that form inside ATRAP's nested trap structure drift along the axis of the apparatus. These are then ionized, and the antiprotons trapped. Ionizing the antiatoms reveals that they are formed in highly excited states. (p5).

ANTIMATTER

ATRAP looks inside antihydrogen

The ATRAP experiment at CERN's Antiproton Decelerator has detected and measured large numbers of cold antihydrogen atoms. Relying on ionization of the cold antiatoms when they pass through a strong electric field gradient, the ATRAP measurement provides the first glimpse inside an antiatom, and the first information about the physics of antihydrogen.



The ATRAP experiment's Penning trap is the heart of the apparatus that has provided the first glimpse inside an antiatom.

ATRAP's technique relies on trapping positrons between two bunches of antiprotons in a nested trap structure. The positrons are used to cool the antiprotons, and when they both reach a similar temperature, some combine to form antihydrogen atoms (a positron orbiting an antiproton nucleus). Being electrically neutral, these antiatoms drift out of the trap. Those that move along the axis of the apparatus soon find themselves traversing a strong electric field that strips off the positrons, thereby allowing the negatively charged antiprotons to be trapped and counted. "This measurement is completely background-free," explains ATRAP spokesperson Jerry Gabrielse of Harvard University, "since the only way that a signal is detected is if antiprotons escape the nested trap in the form of neutral antihydrogen atoms."

The ATRAP team has measured the field needed to ionize the antihydrogen atoms. The result shows that the antiatoms are formed in highly excited states (between $n = 43$ and $n = 55$). This is being interpreted as pointing to a three-body recombination scheme where a third body carries away the energy and momentum liberated by the antiatom's formation. The ATRAP method has allowed the first measurement of the physics of antihydrogen, and is a step towards the precision measurements that will allow matter–antimatter comparisons to be made. The ultimate goal is to trap antihydrogen atoms and study their spectra with the same precision as for plain hydrogen (a few parts in 10^{14} for an analysis of the transition from the $n = 2$ to the $n = 1$ state).

The news comes shortly after another CERN experiment, ATHENA, announced its observation of cold antihydrogen (*CERN Courier* November p5). Using a completely different detection technique to ATHENA, and providing the first glimpse into the internal structure of antihydrogen, ATRAP has shown that CERN researchers are well on the way to understanding the first entry in the periodic table of the anti-elements. ATHENA and ATRAP use similar techniques for trapping the ingredients of antihydrogen, developed over many years by Gabrielse's team. The fact that they use different detection methods reinforces the result, and is a good omen for future studies of antihydrogen at CERN.

BROOKHAVEN

RHIC limbers up for a new heavy-ion run

Brookhaven's Relativistic Heavy Ion Collider (RHIC) began its cool-down on 1 November ready for the first injection of beam in December. Following a successful run earlier in the year, which included the first polarized proton running (*CERN Courier* April p8), RHIC is set to start the new run with deuterium on gold collisions. This provides a reference point for the gold–gold collisions that RHIC experiments were designed to study, since any departure from simple scaling between proton–gold and gold–gold collisions would point to new physics. Deuterium has been substituted for protons for practical reasons. The large-aperture dipole magnets that bring RHIC's beams into collision would require realignment to handle proton–gold collisions, whereas deuterium–gold can be handled without intervention.

Brookhaven's Relativistic Heavy Ion Collider – ready for a new run. (BNL.)

BES accumulates 14 million $\psi(2S)$ events

This year, the Beijing Spectrometer (BES) experiment running at the Beijing Electron Positron Collider (BEPC) completed a run at the energy of the $\psi(2S)$ resonance. The run began in November 2001 and lasted until March 2002, a total of 111 days. BES accumulated 14 million events, which is the world's largest sample of $\psi(2S)$ events produced from electron–positron annihilation. BES collected the previous largest data sample of 4 million events in 1993–1995. The new sample will allow the properties and decays of the $\psi(2S)$ and other charm quark bound states produced by $\psi(2S)$ decays to be studied with increased precision.

The $\psi(2S)$ resonance was discovered in 1974 by the Mark I experiment at California's Stanford Linear Accelerator Center (SLAC) shortly after the discovery of the J/ψ. Both resonances are composed of a charm quark and an anticharm quark. The discovery of the J/ψ and $\psi(2S)$ particles was crucial in establishing the quark model, in which almost all observed mesons and baryons can be described as composite objects made of quarks held together by the strong force. The theory that describes this is quantum chromodynamics (QCD), in which the carriers of the strong interaction are gluons, and the quarks are held together by gluon exchange.

The $\psi(2S)$ is an excited state of the J/ψ. Although some properties are similar, the $\psi(2S)$ is more massive than the J/ψ, so it can decay into other charm–anticharm states (such as the spin-zero η_c and the three spin-1 χ_c states, as well as the J/ψ itself). This allows the physics of many charmonium states to be studied using the $\psi(2S)$ sample (figure 1). Indeed, the study of the $\psi(2S)$ sample collected in 1993–1995 at BES has proved to be very fruitful and important in testing QCD calculations on quarkonium production and decay dynamics. The clean signature and the large production rates of the χ_c states in $\psi(2S)$ decays are big advantages of this study. Furthermore, the sample can also be used to study light hadron spectroscopy from the decay products of the χ_c states, where the quantum numbers of the initial states are well defined and are different for χ_{c0}, χ_{c1} and χ_{c2}.

The biggest mystery in $\psi(2S)$ decays is the so-called $\rho\,\pi$ puzzle. In perturbative QCD, the decays of the charmonium states, J/ψ and $\psi(2S)$, into light hadrons are expected to be dominated by the annihilation of the charm and anticharm quarks into three gluons. In this simple picture, the partial width for decays into any exclusive hadronic state is proportional to the wave function at the origin squared, $\psi(0)^2$, which is well determined from dilepton decays. Since the strong coupling constant does not change much between the J/ψ and $\psi(2S)$ masses, it is reasonable to expect that for any exclusive hadronic state (h), the J/ψ and $\psi(2S)$ decay branching fractions will scale as $B(\psi(2S)\rightarrow h)/B(J/\psi\rightarrow h) \approx B(\psi(2S)\rightarrow e^+e^-)/B(J/\psi\rightarrow e^+e^-) \approx 12\%$.

This relationship is known as the 12% rule. Although it works reasonably well for a number of specific decay modes, it fails seriously in the case of $\psi(2S)$ two-body decays to the vector-pseudoscalar meson final states, $\rho\,\pi$ and $\bar{K}^*K$. This anomaly was discovered by SLAC's Mark II experiment. In addition, the BES group has reported violations of the 12% rule for vector-tensor decay modes. Although a number of theoretical explanations have been proposed, most of them do not provide a satisfactory solution. The large $\psi(2S)$ event sample will allow more precise measurements of the branching ratios to better test the surviving theories.

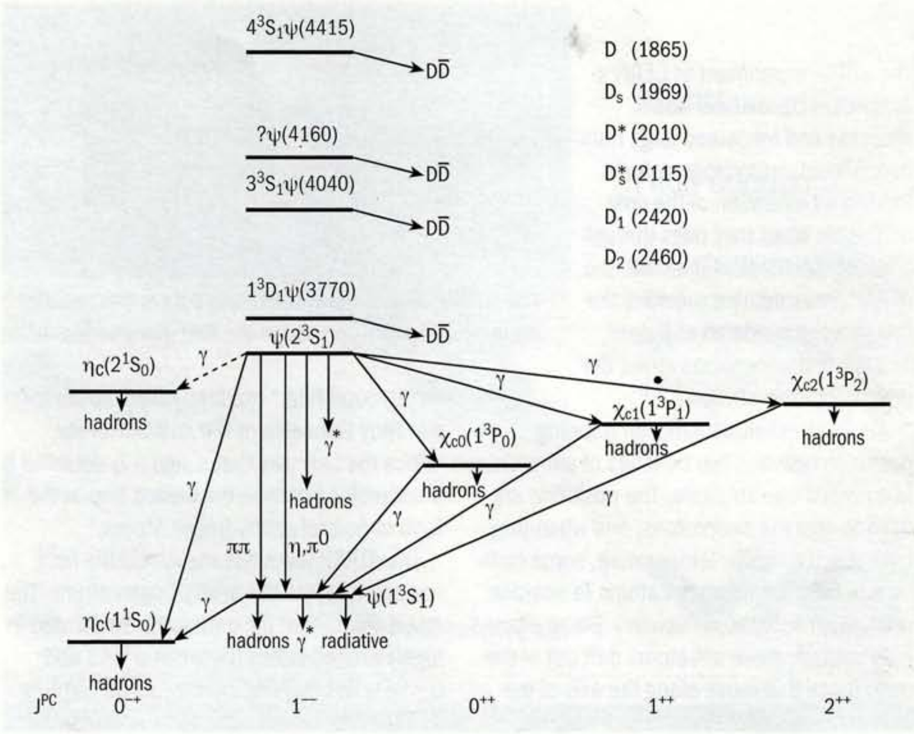


Fig. 1. Charmonium states along with the allowed decays of the $\psi(2S)$.

During the BEPC run, a peak luminosity of $1.1\times10^{31}\,cm^{-2}s^{-1}$ was reached, and a record 208 000 $\psi(2S)$ events were accumulated in one day. The first round of reconstruction of all $\psi(2S)$ events has been completed. Careful offline calibration of the data shows that the BES detector performed well, with a barrel time-of-flight resolution of 200 ps, dE/dx resolution of 8.5%, and a momentum resolution of $1.7\sqrt{(1+p^2)}\%$ (figure 2 gives a glimpse of detector performance).

Earlier, BES obtained a sample of 58 million J/ψ events (*CERN Courier* December 2001 p6), which is the world's largest J/ψ sample from electron–positron collisions. The J/ψ and $\psi(2S)$ samples are complementary, and together will provide information on a wide range of topics, as well as testing the 12% rule.

Frederick A Harris, University of Hawaii, and Weiguo Li, Institute of High Energy Physics, Beijing.

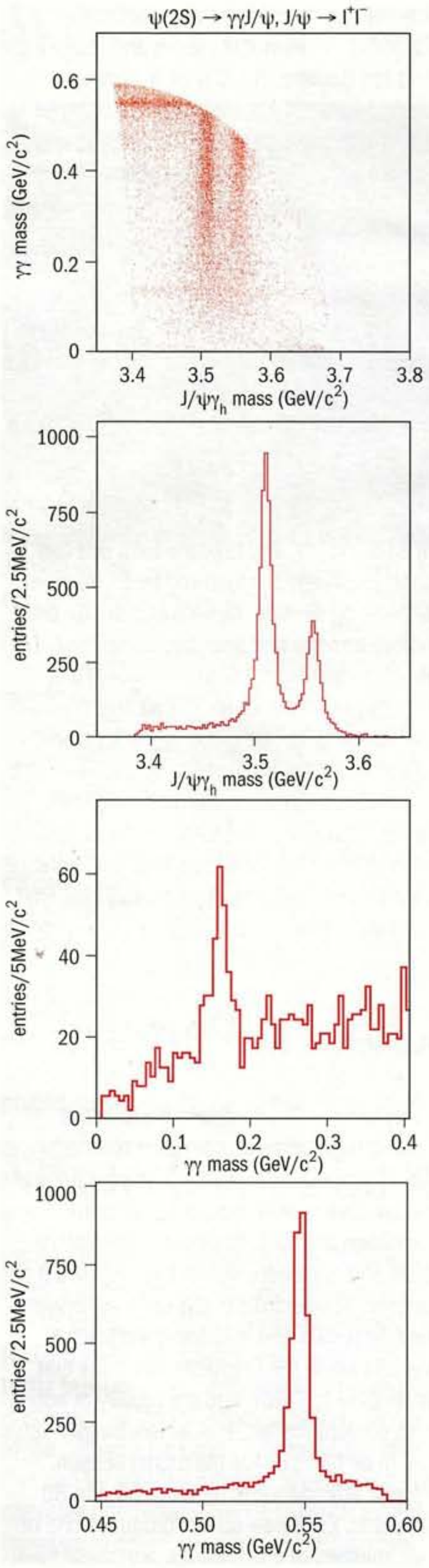
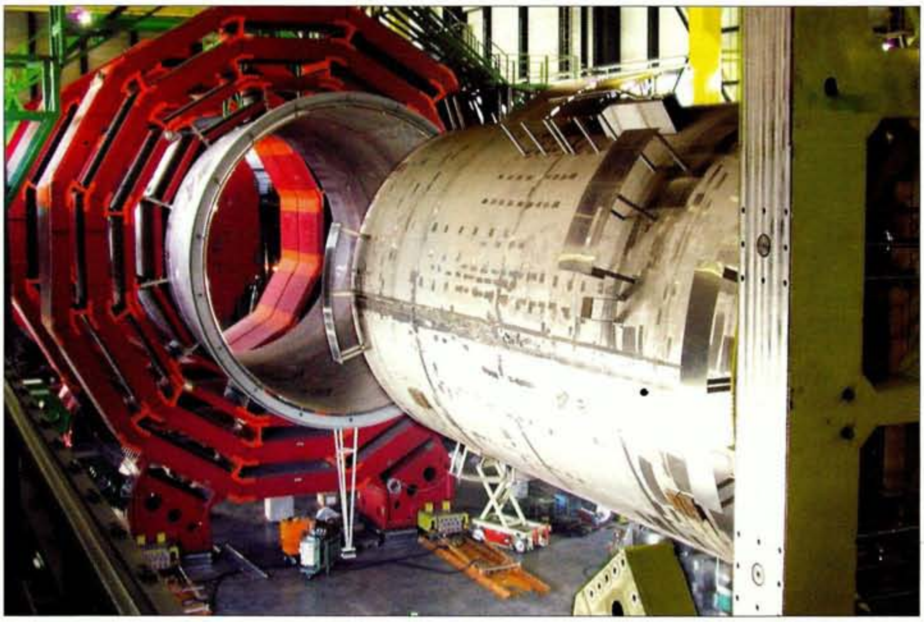


Fig. 2. In this scatter plot (with projections) of $\gamma\gamma$ mass versus high momentum γ J/ψ mass for events with two γs and two leptons, horizontal bands correspond to $\psi(2S)\to\pi^0$ J/ψ and η J/ψ events. The vertical bands correspond to $\psi(2S)\to\gamma\chi_{c1/2}$, $\chi_{c1/2}\to\gamma J/\psi$.

CERN

CMS assembly enters its next phase



In a recent dry run, the inner shell of the vacuum tank, modified to simulate the CMS solenoid coil, was rotated from vertical to horizontal and smoothly inserted into the outer shell.

Assembly of the Compact Muon Solenoid (CMS) detector, being built for physics at CERN's Large Hadron Collider, reached an important turning point in October. The return yoke for the detector's 4 T superconducting solenoid is now completely assembled, with a central section supporting the 7.6 m diameter, 13 m long outer shell of the solenoid's vacuum tank. Attention is now shifting towards installation of the solenoid and sub-detectors.

As components arrive at CERN from around the world, an assembly team coordinated by Zurich's ETH and CERN ensures that each new piece of the puzzle is carefully slotted into place. A magnet test is foreseen for early 2005, by which time several CMS subdetector systems, including the hadronic calorimeter and muon system, will be largely complete, cabled and tested.

So far, this giant 3D puzzle has produced few difficulties, thanks largely to the establishment of an engineering and integration centre, jointly supported by ETH and CERN, 6 years ago. Staffed by designers and engineers from both partners, and supplemented by visiting engineers from other CMS institutes, the centre scrupulously controls the space allocated to each subsystem and the no-go zones separating them, ensuring smooth integration of detector elements.

Work on the hadron calorimeter is well advanced, with the barrel nearing completion and the brass absorber of the first hadron endcap calorimeter gradually taking shape. Barrel and endcap muon chambers were successfully installed during the summer, and a dry run of the solenoid coil insertion was also recently conducted. This involved the inner shell of the vacuum tank, modified to simulate the coil, being rotated from vertical to horizontal and inserted into the outer shell. Particular attention is now being paid to the layout and connections of the hundreds of kilometres of cables, gas lines and water pipes that will supply the CMS detector.

With the first letter of the CMS acronym very much in mind, and hermeticity a watchword for achieving good physics performance, the CMS detector is being built to exacting mechanical tolerances. Muon chamber supports on the 15 m diameter endcap yoke disks, for example, are positioned to an accuracy of 0.2 mm. CMS is placing great emphasis on planning, and so it was with some satisfaction that the collaboration received the news from the committees charged with overseeing installation that "there is every reason to believe that CMS will have a working detector ready for first collisions in April 2007".

THEORETICAL PHYSICS

Extra funding for Perimeter Institute

Canada's Perimeter Institute for Theoretical Physics was awarded C$25 million (€16 million) by the Canadian Federal government at a groundbreaking ceremony in June. Soon after, the province of Ontario, which will host the institute, announced that it would be providing a further C$15 million for the institute, bringing total Canadian public funding for the new institute to slightly more than C$54 million.

The Perimeter Institute was founded in 1999 when Mike Lazaridis, founder and chief executive of the company Research in Motion (RIM), set up a board of directors to determine how best to go about establishing a world-class institute devoted to fundamental physics in the Canadian town of Waterloo. After visiting many institutes for advanced research in physics around the world, the board concluded that the new institute should be independent, focusing on foundational, non-directed research, be resident-based with a flat hierarchy, and should have a strong public outreach programme.

The institute was officially launched on 23 October 2000 with a C$100 million donation from Mike Lazaridis and an additional C$20 million from RIM executives Doug Fregin and Jim Balsillie. The City of Waterloo donated a site for the institute's new building, along with temporary accommodation in a former post office and national revenue building. An international eight-member scientific advisory committee was selected in late 2000, and had its first meeting in Waterloo in spring 2001. Research began in autumn 2001 with a core scientific staff of five and four postdoctoral fellows in quantum gravity, string theory, quantum information theory and quantum computing. More information about the Perimeter Institute is available at http://www.perimeterinstitute.com.

NETWORKING

CERN hosts First Tuesday meeting

CERN played host to a meeting of First Tuesday Suisse romande, a network for innovation and technology in French-speaking Switzerland, in September. Some 250 people came to the laboratory to learn about the latest developments in Grid computing technology. Topics covered Grid development at CERN and in industry, including an insight into the emerging field of Grid economics and an example of how Grid technologies are having an impact in the medical arena. The event also marked the company Hewlett-Packard joining the CERN openlab for DataGrid applications, other sponsors of this industrial collaboration being Intel and Enterasys Networks.

Now in its fourth year of operation, First Tuesday Suisse romande was founded to provide a forum for entrepreneurs, investors and all those interested in new technology. Its Geneva meetings are held on the first Tuesday of each month, and take the form of a few short presentations followed by an informal networking session. CERN's director for technology transfer and scientific computing, Hans Hoffmann, plans to host more First Tuesday events at CERN. "The Large Hadron Collider project," he explains, "is a goldmine of technological innovation, ideally suited for the kind of networking events First Tuesday holds." This first event was broadcast on the Web to ensure a wider international audience could benefit, and can be viewed in the First Tuesday archives at http://www.rezonance.ch.

SCHOOLS

Young physicists attend CERN accelerator school in Portugal

Young accelerator physicists converged on the Portuguese coastal town of Sesimbra in September for the 2002 CERN Accelerator School (CAS) introductory course on particle accelerators. Organized by CAS together with the Laboratório de Instrumentação e Física Experimental de Partículas of Lisbon (LIP), the course covered the basics of accelerator and particle physics, concluding with a series of lectures entitled "Putting it all together". Thirteen European specialists, chosen for their teaching experience, made up the lecture team, while CERN and LIP shared the organizational responsibilities.

Students came from a range of countries – 13 from Germany, and 12 each from Italy and the UK. France, Canada and Russia each sent three students, and two came from South Korea. There were also students from Belgium, Brazil, Iran, Israel, the Netherlands and Poland, as well as 25 from CERN who were too international to declare a specific nationality, but who no doubt came from Europe. More than 60% of the students were under 35, and about the same percentage had a Masters degree, while fewer than 10% had PhDs. Two-thirds came from accelerator and public sector laboratories, with the remainder made up largely of people from universities.

CAS organizes one such introductory course every two years, interspersed with more advanced courses on specialist technology. It has organized more than 40 courses on accelerator physics and technology since its formation in 1983. Its aim is to train physicists and engineers who design, construct and operate accelerators in laboratories, universities, hospitals and in industry worldwide. Venues are in the European countries that contribute to CERN, and are usually at hotels with conference facilities, where bargain rates are to be had outside the tourist season. Typical attendance is between 50 and 80 students. Each new school produces one or two volumes of proceedings, and these have become the principal body of reference material for the field. Details of past, present and future CAS schools are available at http://cas.web.cern.ch/cas/.

Edmund J N Wilson, head of the CERN Accelerator School.

Edited by Archana Sharma

Woven for nanoelectronics

Nanotube networks – this scanning electron microscope picture shows carbon nanotubes draped across silicon pillars. The spacing between pillars is 500 nm.

Japanese researchers have investigated a new technique through which the self-interconnection of nanostructures could lead to nanoscale logic circuits. Carbon nanotubes are self-assembled nanoscale structures with excellent mechanical, electrical and chemical properties, and are useful for a variety of applications. Semiconducting carbon nanotubes can act as a field-effect transistor or a single electron transistor for nanoelectronics. Metallic carbon nanotubes exhibit ballistic conductivity (electrons travel through without losing energy) at room temperature. This, coupled with the mechanical strength of carbon nanotubes, as well as their shape and size, makes them ideal for wiring nanoscale devices.

Employing the chemical vapour deposition technique, the Japanese team has grown nanotube networks on arrays of 100 nm high silicon pillars, confirming an earlier observation using 10 μm pillars. This self-directed growth is a remarkable feature of carbon nanotubes; however, the growth mechanism is not yet fully understood. Further investigation is needed before carbon nanotubes find their way onto our desktops.

Further reading

Y Homma *et al.* 2002 *Appl. Phys. Lett.* **81** 2261–2263.

New technique for non-invasive EEG

UK researchers have reported how advances in the amplification, electronic processing and real-time display of electroencephalogram (EEG) signals can provide a new way of monitoring brain activity. Traditional EEG monitoring is invasive, at the minimum requiring shaving of the patient's hair and abrasion of the skin. This can be avoided by using superconducting quantum interference device (SQUID) magnetometers to detect the magnetic component of the fields generated by the flow of currents in the brain. The resulting magnetoencephalograms can be gathered non-invasively, but the technique has its own drawbacks, not least the cryogenic operation of the SQUIDs.

The new EEG sensors use electric displacement, rather than real charge, current. This means that they do not need real electrical contact with the body, and can produce EEGs non-invasively. The UK team has demonstrated their effectiveness by measuring activity in the region of the occipital lobe, with the sensors being in contact with the hair only, and with no preparation of the scalp. The result shows the well-known phenomenon of alpha-blocking – an alpha-rhythm signal is present when the patient's eyes are closed, but is blocked when the eyes are open.

Further reading

C J Harland *et al.* 2002 *Appl. Phys. Lett.* **81** 3284–3286.

Persuading bosons to behave as fermions

Physicists from Germany and Austria have proposed ways of persuading bosons to act as fermions. The Pauli exclusion governs the behaviour of fermions – many electrons in the same box, for example, must differ from each other in some way. They must occupy a different place, or have a different value of a quantum property such as spin. Bosons (such as photons and the hydrogen atom) have no such restrictions – a limitless number of them can be in the identical quantum state.

Persuading fermions to behave as bosons is nothing new. Superconductivity and superfluidity are examples of phenomena where fermions behave like bosons. By pairing up, as they do in superconductors, fermions possess the same key properties as bosons, and so they act just like bosons.

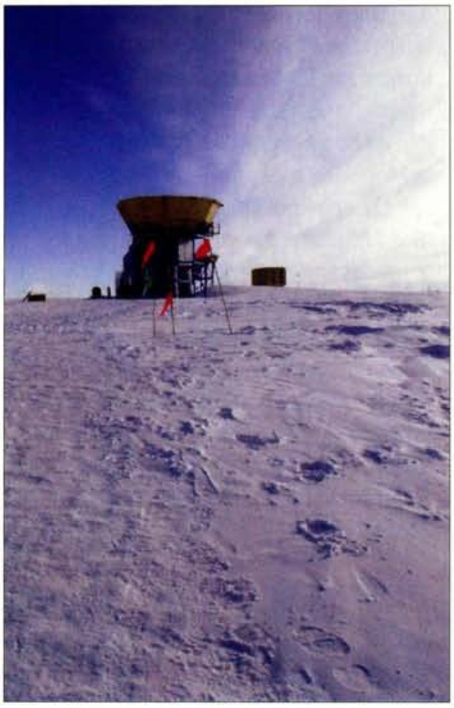
Making bosons behave like fermions, however, is a feat so far unaccomplished. Now, researchers from the Max Planck Institute for Quantum Optics have put forward proposals for doing just this. One way, they suggest, would be to rotate a Bose–Einstein condensate (BEC). In the ground state, a BEC has several different low-energy levels due to different possible values of angular momentum in the atoms. Cancelling the energy gained by angular momentum, and rotating the BEC at just the right rate, causes these levels to become equal to one another in energy. The atoms would then be forced to minimize their repulsion with one another by assuming slightly different values of angular momentum, hence behaving like fermions. Lasers or mechanical devices can be used to rotate a BEC. The caveat is the currently obtainable rotation speeds, requiring researchers to create a BEC with only a handful of atoms instead of the typical 10 000 or so. If this turns out to be unfeasible, the researchers have another proposal: rotate an optical lattice, a light-based web of atom traps containing five atoms in each trap. This is experimentally possible and could produce a stronger signal than that from a single BEC.

Further reading

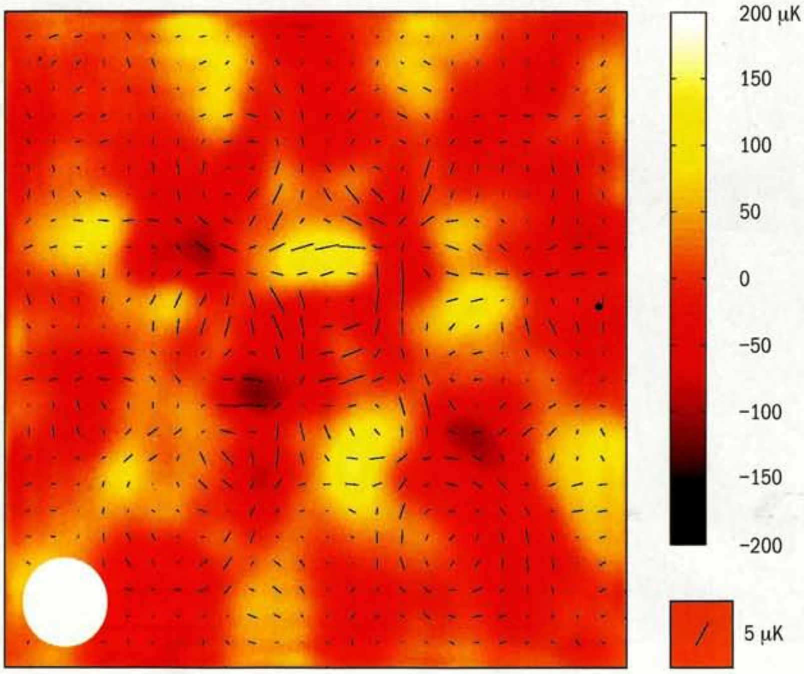
http://arXiv.org/abs/cond-mat/0207040.

Edited by Emma Sanders

DASI measures CMB polarization



Physics at the extremes: the DASI observing station at the south pole. (DASI.)



This map shows the variations in the temperature and polarization (denoted by black lines) of the CMB. The map is 5 degrees square. (DASI.)

Another big step forward has been made in the study of the early universe. The Degree Angular Scale Interferometer (DASI) has announced the first measurements of the polarization of cosmic microwave background (CMB) radiation. The new results are a strong validation of the theoretical framework for the origin of fluctuations in the CMB, and also lend confidence to the values of the cosmological parameters that have been derived from CMB measurements.

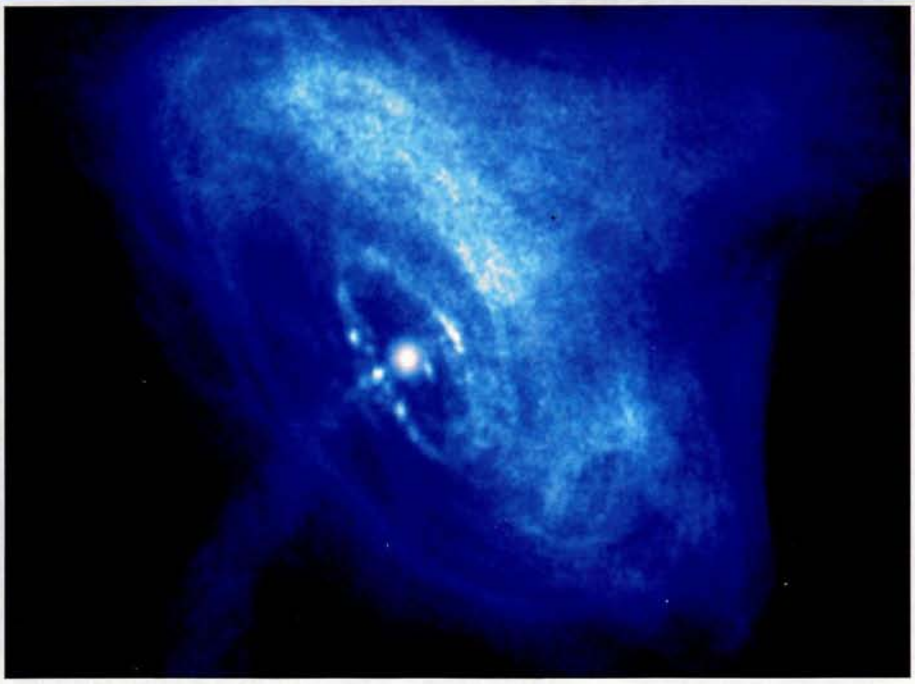
CMB radiation dates from 300 000 years after the Big Bang, when radiation decoupled from matter. Fluctuations in the CMB are evidence for the first clumping of matter particles – the seeds of the galaxies that we see today. The radiation is polarized because atoms moving in the early universe scattered light differently, depending on whether the light was heading towards or away from them. The faster the speed of the atoms, the more pronounced the polarization. Measuring the polarization of the CMB is a direct measure of the dynamics of the early universe.

This exciting field of study has seen many advances in observing capabilities over recent years, and new discoveries have been coming thick and fast. Just last year, DASI and also the BOOMERANG balloon experiment announced measurements of the angular power spectrum of the CMB (*CERN Courier* July/August 2001 p15). Plotting the observed power as a function of the angular size of emitting regions gives a constraint on cosmological parameters, such as Ω – the ratio of matter in the universe to the critical level needed to halt its expansion, and also the amount of ordinary matter and dark matter in the universe. The polarization signal is more difficult to detect. For the temperature measurements, 32 different areas of the sky were observed for relatively short time scales. For the polarization measurements, 271 days of observation were needed for just two areas of sky to reach the required signal level.

DASI is a 13-element interferometer located at the south pole. Observers and the telescope must survive freezing antarctic conditions, not without difficulties. However, their endurance has certainly paid off, with some extremely interesting results.

Further reading:
http://arxiv.org/abs/astro-ph/0209478.

Picture of the month

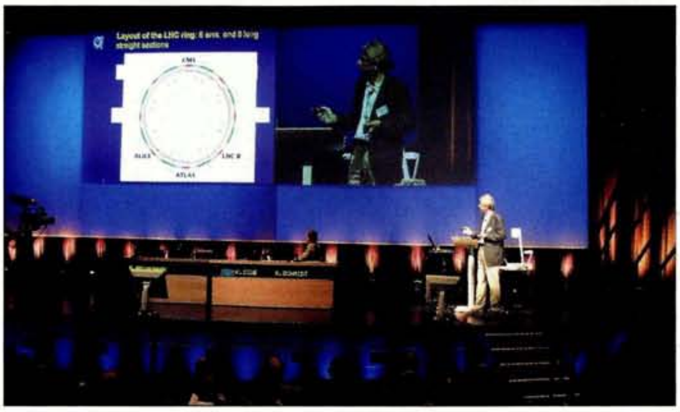


This image shows the X-ray emission from the inner region of the Crab nebula. The disk of material is orbiting the central pulsar, a rapidly rotating neutron star seen as a white dot near the centre of the image. The Chandra X-ray observatory imaged the Crab over a period of several months, and the results have been made into a short film where material can been seen moving outwards from the pulsar at half the speed of light (see http://chandra.harvard.edu).

Thanks to Chandra, and also the XMM-Newton X-ray satellite, X-ray observations now have comparable resolution to those at optical and radio wavelengths, providing a wonderful tool for astronomers who are trying to piece together the different processes at work in some of the most energetic regions of the universe. (NASA.)

Accelerator conference showcases diversity

EPS-IGA chair, Jean-Louis Laclare, presents the 2002 EPS-IGA accelerator award to Kurt Hübner (right) and Frank Zimmermann of CERN. To the left is Ferdinand Willeke of DESY, chair of the 2002 prize selection committee.



CERN's Rüdiger Schmidt reported good progress with CERN's LHC project at EPAC 2002.

This year's European Particle Accelerator Conference, held in Paris, highlighted the growing diversity of particle accelerator technology. **Francesco Ruggiero** and **Leonid Rivkin** report.

The eighth European Particle Accelerator Conference (EPAC'02), held in Paris on 3–7 June, brought an unprecedented number of accelerator physicists and users together. With about 850 participants, including more than 150 from the US and nearly 60 students, and more than 1000 contributed or invited papers, this year's gathering was the biggest EPAC to date. Representatives of the European Union and the high-energy physics community gave the opening and summary talks. Presentations ranged from beam dynamics to technology transfer and industrial spin-off, making the conference a remarkable international and interdisciplinary event.

Looking ahead

One of the highlights of the conference came from CERN, where the Compact Linear Collider (CLIC) study group has been investigating the use of materials other than copper for normally conducting accelerating structures. At the fields that would be needed to produce the high-accelerating gradients that the CLIC project aims to achieve, copper structures suffer severe surface damage. The CLIC team believes that this arises from field-emitted electrons that are accelerated from one side of the structure to the other, causing melting and erosion of the coupling irises (regions of smaller radius separating the cells of an accelerating structure). By replacing copper with tungsten irises, the CLIC team has succeeded in making structures able to withstand very high gradients for several thousands of hours without any surface damage.

CLIC's novel two-beam acceleration scheme is a technology for the long-term future. Closer to the present is CERN's Large Hadron Collider (LHC), and there were reports of activities at the laboratory's existing accelerator complex to prepare for the new machine. Notable among these was a so-called beam-scrubbing run with LHC-type beam in the Super Proton Synchrotron (SPS), which will be the last link in the LHC injector chain. The idea of the scrubbing run, which took place in May, was to bombard the walls of the SPS vacuum chamber with electrons created by ionization of residual gas, accelerated by the beam, and multiplied by secondary emission (the electron cloud phenomenon; *CERN Courier* July/August p15). This had the effect of forcing outgassing and reducing the secondary electron yield, thereby improving the vacuum in the accelerator and allowing the SPS to achieve the beam intensities required for the LHC.

Returning to the present, there were reports outlining the excellent performance of the KEK-B and PEP-II B factories in Japan and the US, as well as from the Italian Frascati laboratory's DAPHNE accelerator, which supports the KLOE CP-violation experiment. Significant progress was reported from Brookhaven's Relativistic Heavy Ion Collider (RHIC), where polarization levels of 40% have been maintained to top energy with proton beams.

Reports from Germany's DESY laboratory and Fermilab in the US brought home the challenges of major luminosity upgrades. At DESY, background problems arising partly from back-scattering from masks behind the interaction points are limiting beam intensity, ▷


Brookhaven's RHIC (at the top of the picture) has achieved polarization of up to 40% with proton beams.

while at Fermilab's Tevatron, growth of emittance (a measure of beam size times divergence) in the antiproton accumulator coupled with long-range beam–beam encounters are factors currently limiting the machine's luminosity. Fermilab's recycler ring, designed to retrieve, store and recycle antiprotons that would otherwise have been lost, is still in the commissioning phase. When it is fully operational, Tevatron luminosity is set to improve.

Light sources

Other news from DESY concerned the TESLA Test Facility (TTF), which has been established with the goal of providing a test bed for the TESLA linear collider concept and a free-electron laser. The TTF has achieved lasing down to a wavelength of 80 nm. This follows the announcement at last year's particle accelerator conference (PAC) in Chicago that the low-energy undulator test line at Argonne National Laboratory's advanced photon source had lased from the visible down to 130 nm. It marks a significant milestone on the road towards a free-electron laser in the hard X-ray region.

Other highlights from light sources include the first observations of steady state coherent synchrotron radiation in the far infrared at Berlin's BESSY II synchrotron, and the successful commissioning of the Swiss Light Source (*CERN Courier* April p24). Emerging trends in this area are the growing number of free-electron laser projects, and many third-generation synchrotron sources under construction. Reports were given from Soleil in France, the Spanish synchrotron that will be built in Barcelona, and the UK's Diamond machine.

Novel techniques

Several interesting new possibilities were reported from the Stanford Linear Accelerator Center (SLAC) in California, where work on bunch compression is under way at the laboratory's 2 mile linac. This is motivated by the linear coherent light source proposal to build a 1–15 Å free-electron laser using linac beams of up to 15 GeV. The bunch compression work will allow the study of light emission in the so-called self-amplified spontaneous emission mode in a free-electron laser. It also opens up avenues for studies of plasma acceleration and wakefield studies, as well as the intriguing possibility of adding an "after-burner" to the linac. According to this idea, a dense plasma could double the energy of SLAC's electron beams.

Fourth-generation light sources were a strong theme at the conference, with many proposed machine architectures being put forward. A light source for fast X-ray science proposed by Berkeley would be based on a recirculating linac and on dipole RF cavities plus gratings for photon pulse compression. Furthermore, short-pulse generation schemes based on energy recovery linacs, advanced by Cornell in particular, promise levels of performance well exceeding the present third generation of synchrotron light sources.

Induction accelerating devices (in which acceleration is achieved by changing the strength of a magnetic field in magnetic material encircling the beams) are being developed for high-intensity proton synchrotrons. Such devices could also create long super-bunches colliding with large crossing angles in future machines such as a very large hadron collider. They could also be used for a luminosity upgrade at the LHC.

Superconducting magnet developments based on the so-called wind-and-react technique for niobium-3 tin superconductor, or on new high critical temperature (Tc) materials were reported from Fermilab, Berkeley and Brookhaven. The wind-and-react technique overcomes the intrinsic brittleness of niobium-3 tin by winding the coil before inducing the reaction that forms the superconducting compound.

Beam dynamics

Among the hot topics presented in beam dynamics, several speakers reported new theoretical and experimental studies of the beam–beam interaction, including long-range encounters. These covered multiparticle simulations, wavelet approaches and observations at the B-factories. The associated reduction of dynamic aperture and the possible loss of collisionless (Landau) damping for coherent beam–beam modes may limit the performance of present and future hadron colliders. Compensation schemes based on nonlinear lenses have been proposed and are being tested at Fermilab and at CERN. Electron cloud effects have been observed and are being intensively studied at the B-factories, at CERN accelerators and recently also at RHIC. Weak solenoids can successfully cure the problem in the field-free regions. Sophisticated simulation codes for electron cloud build-up and associated beam instabilities have been developed in several labs, and comparisons of predictions and observations were reported in many contributions.

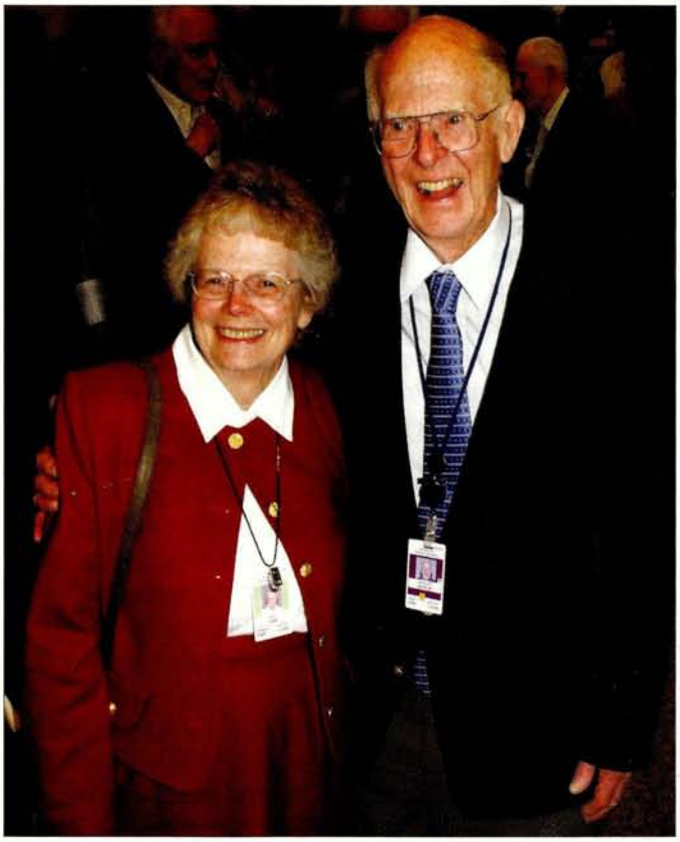
The EPAC conferences, which cover all aspects of accelerator physics, technology and applications, are organized by the Interdivisional Group on Accelerators of the European Physical Society (EPS-IGA), an active group currently with about 200 members. The next conference, EPAC'04, will be held in Lucerne, Switzerland, on 5–9 July 2004. Next year's major accelerator conference, PAC 2003, will be held on 12–16 May in Portland, Oregon, US.

Further reading

Proceedings are available on the Joint Accelerator Conference website (JACoW) at http://accelconf.web.cern.ch/accelconf/.
Selected papers will form a special issue of *Physical Review Special Topics – Accelerators and Beams* (PRST-AB). See http://prst-ab.aps.org/.

Leonid Rivkin, *Paul Scherrer Institute, and* **Francesco Ruggiero**, *CERN.*

Memories of a Nobel laureate



Ray Davis celebrates his Nobel prize with his wife of 54 years, Anna, at a reception held in his honour at Brookhaven on 14 October. (BNL.)

Raymond Davis Jr looks back over the career that led to a share of the 2002 Nobel Prize for Physics.

I started working on neutrino detection early in my career. I had rather broad interests in other fields of the physical sciences and worked on a number of other projects. Usually, an experimentalist develops a number of skills and applies them to solving new problems that appear interesting. I was fortunate to live at a time when there were many interesting new developments, and fundamental science was well supported.

In 1942, I received my PhD from Yale in physical chemistry, and went directly into the army as a reserve officer. After the war, I decided to look for a research position with a view to applying chemistry to studies in nuclear physics. After two years with the Monsanto Chemical Company in applied radiochemistry of interest to the Atomic Energy Commission, I was very fortunate in being able to join the newly created Brookhaven National Laboratory, which was dedicated to finding peaceful uses for the atom in all fields of basic science: chemistry, physics, biology, medicine and engineering.

I became a member of the chemistry department in 1948 and remained there until my retirement in 1984. In 1948, a scientist at Brookhaven was able to choose an independent research programme consistent with the laboratory's effort. After reading a stimulating review paper by H R Crane (Crane 1948), I decided to begin by selecting an experiment in neutrino physics, a field of physics that was wide open to exploration, and a suitable one for applying my background in physical chemistry. So, how lucky I was to land at Brookhaven, where I was encouraged to do exactly what I wanted, and get paid for it!

First experiments

My first experiment was a study of the recoil energy of a lithium-7 nucleus resulting from the electron capture decay of beryllium-7. In a beryllium-7 decay, a single monoenergetic neutrino is emitted with an energy of 0.862 MeV, and the resulting lithium-7 nucleus should recoil with a characteristic energy of 57 eV. A measurement of this process provides evidence for the existence of the neutrino, postulated by Wolfgang Pauli in 1931. An experiment of this nature had been carried out much earlier, but the result was inconclusive. In my experiment, the energy spectrum of a recoiling lithium-7 ion from a surface deposit of beryllium-7 was measured. The energy spectrum of the recoiling lithium-7 was found to agree with that expected from the emission of a single 0.862 MeV neutrino (Davis 1952).

Later, I began working on a radiochemical experiment for detecting neutrinos using a method that was suggested by Bruno Pontecorvo in 1946 (Pontecorvo 1946). Louis Alvarez proposed carrying out the experiment at a reactor, but lost interest in the project (Alvarez 1949). Since no-one else appeared interested in attempting the chlorine–argon neutrino detection method, it seemed a natural and timely experiment for me to work on.

The Pontecorvo method makes use of the neutrino capture reaction, $\nu + {}^{37}Cl \rightarrow {}^{37}Ar + e^-$. The reaction produces the isotope argon-37 that decays back to chlorine-37 by the inverse of the capture process, with a half-life of 35 days. In my experiment, carbon tetrachloride served as the target material. After exposing a tank of this liquid to a neutrino source for a month or two, the radioactive argon-37 atoms produced by neutrino capture were removed and counted in a small Geiger counter. The neutrino capture cross-section is extremely small. Therefore, one must use a very large volume of carbon tetrachloride. To observe the argon-37 decays, it was necessary to develop a miniature counter with a very low background counting rate. There are background effects that must be studied as well, particularly those from cosmic rays. ▷

The technology for carrying out the experiment on a relatively large scale, using 1000 gallons of carbon tetrachloride, was developed with the Brookhaven Graphite Research Reactor as the neutrino source. That reactor did not have a high enough neutrino flux to detect with this target size, so neutrinos were not observed. Furthermore, a reactor emits antineutrinos, and the Pontecorvo reaction requires neutrinos. It was not clear in 1952, however, whether neutrinos and antineutrinos were different particles, nor was it clear how they could differ. After all, there are other instances in nature where the particle is its own antiparticle, for example the photon and the neutral kaon.

So, in 1954, I built an experiment using 1000 gallons of carbon tetrachloride in the basement of one of the Savannah River reactors, the most intense antineutrino source in the world. One can calculate the total capture rate from all fission-product antineutrinos by chlorine-37, presuming neutrinos and antineutrinos are equivalent particles. The sensitivity for detecting neutrinos and the flux at this location was sufficiently high to provide a critical test for the neutrino–antineutrino identity. However, the experiment failed to observe a clear signal from reactor neutrinos. The Savannah experiment demonstrated that the argon-37 production rate was a factor of five below the rate expected if neutrinos and the antineutrinos were identical particles (Davis 1957).

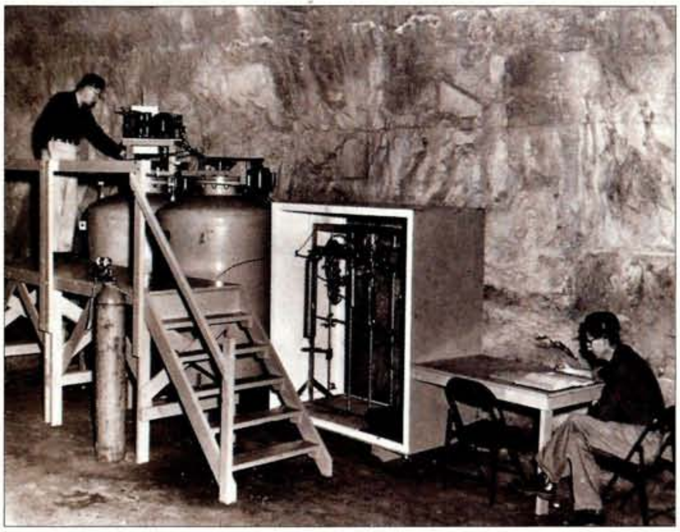
Discovery

While I was at Savannah River doing these experiments, Fred Reines, Clyde Cowan and their associates were performing a beautiful experiment, the first detection of a free antineutrino (Reines and Cowan 1956). Their experiment was a clear demonstration that the neutrino postulated by Pauli was indeed a real particle. They observed antineutrinos being captured by a hydrogen nucleus (proton) producing a positron and a neutron. The measured cross-section was consistent with that expected from Fermi's theory of β-decay.

In 1957, T D Lee and C N Yang suggested that the neutrino was a two-component particle whose interactions violated the principle of parity conservation. This concept was confirmed in a β-decay experiment by Chien-Shiung Wu of Columbia and her associates at the National Bureau of Standards. The two-component theory postulates that all neutrinos have spins rotating in a left-handed helicity with respect to their direction of motion. Right-handed antineutrinos will not interact with the chlorine-37 nucleus and produce argon-37 because they have the wrong helicity. The Reines and Cowan experiment should and did observe reactor antineutrinos. All was explained. But this was not the end of the matter.

Pauli and many others did not believe all was as it seemed, and urged that another and more sensitive chlorine-37/argon-37 experiment be performed. To complicate matters, many physicists measured the spins of electrons from many β-decay sources. They found that the electrons were not necessarily polarized as expected. After a couple of years of improved experiments, these polarization studies ultimately found that the two-component theory was correct.

Don Harmer from Georgia Tech and I set about building a three-times larger chlorine-37/argon-37 experiment. After several years, we obtained a greatly improved result. We found that the argon-37 production rate was a factor of 20 below the expected rate for neutrinos and antineutrinos being identical particles. In this experiment, our sensitivity was limited by the production of argon-37 in our liquid by cosmic rays.



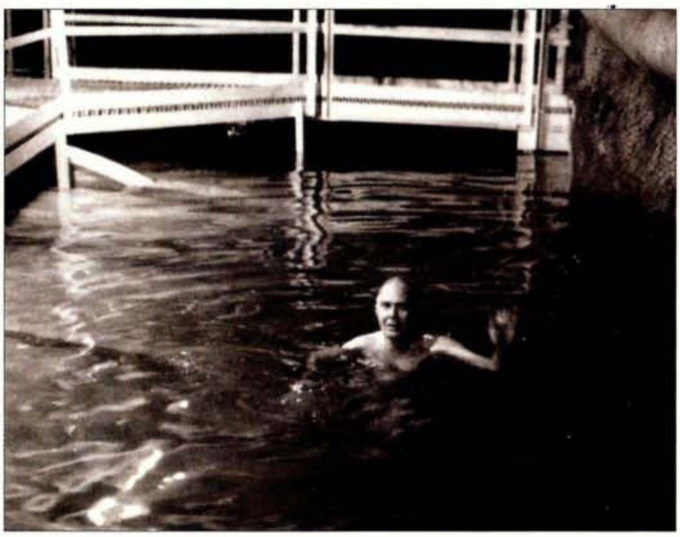
In 1963 this detector, 2300 feet underground at a limestone mine in Barberton, Ohio, established the techniques used in the much larger Homestake mine detector. (BNL.)

Solar neutrinos

After the Savannah River experiments were terminated, I started thinking about an experiment to measure neutrinos from the Sun. The first step in the plan was to set up one of our detectors as a pilot experiment in a deep mine to measure the background effects and determine the ultimate sensitivity for observing solar neutrinos. The measurements of argon-37 activity could be made more sensitive and specific by using proportional counters. The Sun emits only neutrinos, so the chlorine–argon method was the simplest means of studying solar neutrinos. In 1959, we located a mine near Akron, Ohio, to begin these studies.

Observing the neutrinos from the Sun had the potential of testing the theory that the hydrogen–helium thermal fusion reactions are the source of solar energy. However, the proton–proton chain of reactions in the 1950s was regarded as the principal source of the Sun's energy, and this chain emitted only low-energy neutrinos from the primary proton–proton reaction. These neutrinos were below the energy threshold of the chlorine–argon reaction. We were saved from this impossible situation, however, by a new development.

In 1958, two nuclear physicists, H D Holmgren and R I Johnston at the Naval Research Laboratory measured the $^{3}He + ^{4}He \rightarrow ^{7}Be + \gamma$ reaction, and found it had a higher than expected cross-section. It was immediately recognized that this reaction could be important in the terminal stages of the proton–proton cycle. Furthermore, the beryllium-7 could react with a proton and become boron-8. These two radioactive products, beryllium-7 and boron-8, would be the source of energetic neutrinos, ones that could be measured by the chlorine–argon radiochemical method. W A Fowler and A G W Cameron immediately relayed to me these developments. They pointed out that the neutrino flux from these neutrino sources could perhaps be easily observed by the chlorine–argon detector! I might



Davis takes a dip in the water shielding the Homestake detector in 1971. With temperatures in the mine soaring to over 32°C, swimming must have been a popular pastime. (BNL.)

add that Fred Reines was also stimulated by the new findings and immediately embarked on a program of solar neutrino research (Reines 1967). There was also a very active programme in the Soviet Union in solar neutrino research under M A Markov and G T Zatsepin.

Homestake

These events ultimately led Brookhaven, with support from the chemistry office of the Atomic Energy Commission, to build a 100 000 gallon chlorine–argon neutrino detector in the Homestake Gold Mine at Lead, South Dakota. The scale of the experiment was determined by a theoretical estimate of the expected neutrino flux and the neutrino capture cross-sections for each solar neutrino source in the Sun. It was necessary to measure the production cross-sections of the neutrino-producing reactions, and derive their rates in the interior of the Sun. The aim was to forecast as accurately as possible the rate of solar neutrino capture in the Homestake detector.

This great effort was largely carried out at the California Institute of Technology under the leadership of Fowler. During this period, John Bahcall calculated the neutrino capture cross-section to produce argon-37 in excited states (Bahcall 1964). Of particular interest was the analog state in argon-37 and a means of calculating other excited states by studying the decay of calcium-37. The effect of these states was to greatly increase the expected neutrino capture rate of the energetic boron-8 neutrinos with energies extending to 15 MeV. Bahcall and I wrote an account of these activities in a volume of papers dedicated to Fowler. As outlined in the article, very many nuclear physicists and astronomers contributed to the basic physics that supported this early effort in solar neutrino astronomy. Our task at Brookhaven was far simpler, and we (Don Harmer, Kenneth Hoffman and myself) had the fun of building a large detector and making it work.

We were very fortunate that the Homestake Mining Company accepted our project. They assisted us in many ways with the building and operation of the experiment. The great depth of the experiment (4850 feet or 1560 m) turned out to be a crucial element.

The observed neutrino capture rate was much lower than was anticipated from the solar model calculations (Davis *et al.* 1968). In fact, we did not observe a solar neutrino signal at all, and our results were expressed only as upper limits. The low neutrino capture rate was a result that many theorists found difficult to accept. They believed that there must be some chemical inefficiency in the recovery of a few atoms of argon-37 in the massive Homestake detector. We made numerous tests to check the chemical efficiency, and found that the chemical procedures were reliable.

The main difficulty was experimental: the argon-37 counting needed to be improved to search in a more sensitive way for a solar neutrino signal. Brookhaven electronic engineers Veljko Radeka and Lee Rogers solved this problem by devising a pulse rise-time system to discriminate argon-37 decay events from background events. We began using this new system in 1970. After about a year of observations, a clear solar neutrino signal was observed. The signal was smaller than the earlier limit, but we were convinced that the Homestake experiment would in time make a valid measurement of the solar neutrino capture rate in chlorine-37 to compare quantitatively with the solar model calculations.

The pulse rise-time system development gave the Homestake experiment a new life. The solar neutrino production rate was indeed lower than the solar model predictions by a factor of about three. The most likely explanation, in my view at the time, was that the solar model was in error.

Fred Reines organized an in-depth conference on all aspects of solar neutrino research at the University of California's Irvine campus in 1972. There was an excellent discussion of the theoretical and experimental matters, and new experiments (Trimble and Reines 1973). This conference was of great importance in defining many basic problems and new directions in this new field. Another conference of a similar nature was held at Brookhaven five years later, in 1978. Trevor Pinch made an interesting sociological and historical study of the reaction of the scientific community to the Homestake experiment in his book *Confronting Nature* (Pinch 1982). We had to wait 18 years for another experiment, the Kamiokande experiment in Japan, to confirm that the solar boron-8 neutrino flux was low.

Further reading

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Raymond Davis Jr.

Multiparticle dynamics goes to Crimea

The 32nd International Symposium on Multiparticle Dynamics was held on 7–13 September in Alushta, Ukraine. Since the first symposium in Paris 30 years ago, these meetings have covered the problems of multiparticle production in high-energy physics.

More than 100 physicists convened at JINR's Black Sea retreat for the 32nd International Symposium on Multiparticle Dynamics.

This year's International Symposium on Multiparticle Dynamics (ISMD), which took place in the Crimean town of Alushta, Ukraine, was the first to be held in the Commonwealth of Independent States. It was organized by the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, and the Bogoliubov Institute of Theoretical Physics (BITP) of the National Academy of Sciences of the Ukraine. JINR's vice-director, Alexei Sissakian, and László Jenkovszky of BITP co-chaired the organizing committee.

More than 100 scientists from 20 countries, as well as CERN and JINR, took part in the symposium. Topics covered a wide range of problems in elementary particle-production physics: particle fluctuations and correlations; diffraction processes; soft and hard processes in quantum chromodynamics; heavy-ion physics, production of particles with large multiplicity; and cosmology problems of elementary particle dispersion.

The symposium opened with a special session dedicated to the memory of Bo Andersson (*CERN Courier* May p40), an outstanding scientist as well as an active organizer and a participant in a number of ISMD meetings, who died in March. Gösta Gustafson, now a professor at Andersson's home university of Lund, Sweden, spoke first about his former supervisor's works and latest papers. He was followed by Fredrik Soderberg of Lund, Mike Seymour of the ▷

University of Manchester, UK, and Alessandro de Angelis of Udine University, Italy, who all paid tribute to Andersson.

The success of research in heavy-ion physics at CERN's SPS, and more recently at the Brookhaven Laboratory's Relativistic Heavy Ion Collider in the US, was thoroughly discussed at the meeting, with sessions being devoted to experimental and theoretical aspects of the field. In the area of electron–positron physics, the penetrating analysis of the data obtained in the experiments at CERN's Large Electron Positron collider, which closed down in 2000, were still at the fore. Several speakers, including Sissakian, Jenkovszky, and Joseph Manjavidze of JINR, stressed that it is most important in modern physics to consider theoretically those problems that are associated with high-multiplicity particle production. Many speakers talked about the kind of experiments that might build on such theoretical work, making proposals for experiments at existing and future accelerators. JINR's Vladimir Nikitin proposed studies of low-energy direct photons in multiparticle hadronic interactions at the U-70 proton synchrotron in Protvino, Russia. Yuri Kulchitsky, also of JINR, proposed a study of energy correlations in very high multiplicity at CERN's Large Hadron Collider, while Andrey Korytov of the University of Florida discussed similar possibilities for Fermilab's Tevatron.

Much interest was aroused by reports on the problems of strong interactions and diffraction in modern elementary particle physics presented by Dmitrij Shirkov of JINR, Nikolai Nikolaev of Julich, Lev Lipatov of St Petersburg, Alexei Kaidalov of Moscow's Institute of Theoretical and Experimental Physics, Victor Fadin of Novosibirsk, and Paul Laycock of Liverpool University, UK. Sissakian presented a new vision of the process of thermalization processes in hadron interactions at high energies. Closing talks were given by Viatcheslav Kuvshinov of the Institute of Physics at the National Academy of Sciences, Belarus (for theory) and by Korytov (for experiment).

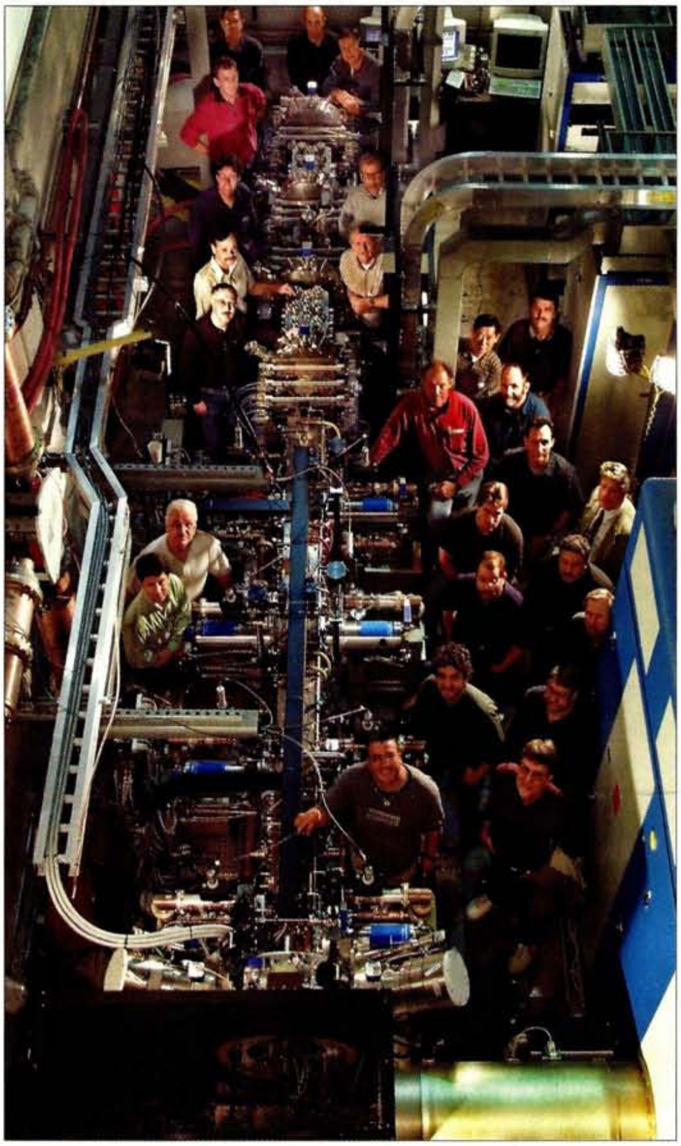
Following tradition, the conclusions of the symposium were brought in by the committee of elders, which consists of an international group of scientists involved with initiating the research that ISMD meetings cover, and who continue to actively influence these meetings. The committee, chaired by Norbert Schmitz of Munich, remarked upon the high scientific quality of the presentations and professional organization of the symposium. To bring the meeting to a close, the committee of elders endorsed the continuing relevance of the ISMD meetings, and set the venue for the 33rd symposium, which will be held in September 2003 in Kraków, Poland.

Further reading

All presentations are available at http://thsun1.jinr.ru/ISMD2002/. Proceedings to be published by World Scientific in 2003.

Guennadi Kozlov *and* **Boris Starchenko**, *JINR.*

LBNL delivers front end of SNS



Staff at Berkeley Lab with the recently completed SNS front end just before it was shipped to Oak Ridge.

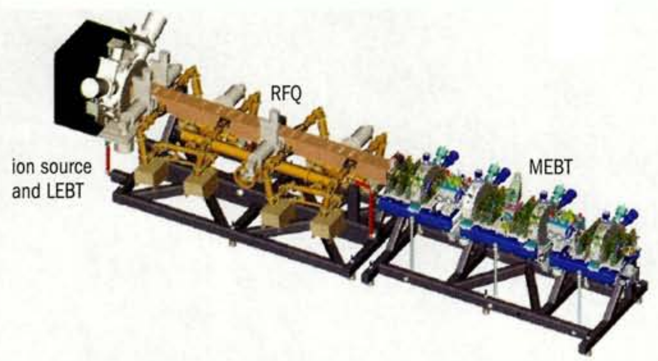
After four years of construction, the linear accelerator injector that will form the front end of the US SNS has been commissioned at LBNL. Fulfilling all its major design requirements and performing reliably, the system was shipped by July.

The US Spallation Neutron Source (SNS) project involves no fewer than six US national laboratories. Its accelerator systems consist of the front end built at Lawrence Berkeley National Laboratory (LBNL), a linear accelerator (linac) being built by Los Alamos National Laboratory (LANL) with superconducting radiofrequency (RF) cavities supplied by Jefferson Laboratory, and an accumulator ring and associated transfer lines being built by Brookhaven National Laboratory (BNL). The target system and conventional facilities are the responsibility of Oak Ridge National Laboratory (ORNL) in Tennessee, and the initial complement of experimental stations is to be supplied by Argonne National Laboratory (ANL) and ORNL. The front end creates an intense negative hydrogen-ion beam, chops it into "minipulses", and accelerates it to 2.5 MeV. The linac then brings the beam to its full energy of 1 GeV, and the accumulator ring compresses the macropulses into sub-microsecond packets to be delivered to the spallation target.

The SNS front end represents a prototypical injector for the kind of so-called proton driver accelerators that are under construction or being planned worldwide. Accelerators that include an accumulator ring, such as the SNS, typically use negative hydrogen-ion beams, but the design approach lends itself to genuine proton beams as well.

Beamline elements

The two-chamber ion source was developed from an earlier model built for the Superconducting Super Collider. A magnetic dipole filter reflects energetic electrons from the main plasma and allows only low-energy electrons to pass into the second chamber, thus favouring the creation of negative hydrogen ions. The discharge is sustained by a 2 MHz RF system and requires up to 45 kW pulsed power at 6% duty factor (1 ms, 60 Hz). The main RF power, as well as low-amplitude 13.56 MHz power used to facilitate ignition at the beginning of every discharge pulse, is delivered through a porcelain-coated antenna immersed in the plasma. A newly developed coating technology brings the uninterrupted running time between services in reach of the desired value of 3 weeks; in fact, one single antenna was used over a period of 2 months during the final commissioning phase. The creation of the negative hydrogen ions is enhanced by a minute amount of caesium dispensed on the ▷



This illustration shows the layout of the 9 m long front end built at Berkeley Lab for the US Spallation Neutron Source project.

inside of the secondary discharge chamber surrounding the outlet aperture. When negative ions are extracted from a plasma, a copious amount of electrons is extracted as well, and a second dipole magnet configuration deflects most of them to a dumping electrode inserted in the main extraction gap, thus keeping the power of the removed electrons at manageable levels.

The low-energy beam-transport (LEBT) system makes use of purely electrostatic focusing by two einzel lenses (ring-shaped electrodes that at first slow the beam down, make it expand, and then, upon reaccelerating, squeeze it into a converging envelope). The second of these lenses is split into four quadrants to provide DC beam-steering as well as pre-chopping capabilities, dividing the 1 ms macropulses into 645 ns packets separated by 300 ns gaps. The rise and fall times of these minipulses were measured to be less than 25 ns, and the beam-in-gap current is reduced to less than 0.1–1% of the pulse amplitude. The electrostatic focusing principle allows for a very short LEBT length of 120 mm, and avoids time variations in the degree of space–charge compensation generally encountered with pulsed beams in magnetic focusing structures. It also provides for a short transition length between the LEBT and the subsequent RF quadrupole (RFQ) accelerator.

The RFQ is the main accelerator of the front end, and boosts the beam energy from 65 keV to 2.5 MeV. The RFQ fields are applied to four modulated vanes, and parasitic dipole modes are eliminated by π-mode stabilizers (straight bars running across the RFQ that shift the resonant frequency of the dipole modes and eliminate steering forces on the beam). The four RFQ cavities are built as hybrid structures, with high-conductivity copper on the inside brazed to a stiff outer shell. Dynamic tuning is achieved by regulating the temperature difference between the cavity walls and the vane tips, and the RFQ can be operated at full power (about 750 kW pulsed) within 2 minutes of a cold start. The 402.5 MHz klystron system used for front-end commissioning at LBNL was provided by LANL, and will be replaced by a more modern system that is part of the series procured by LANL for the first part of the linac.

After the RFQ, the medium-energy beam-transport (MEBT) system receives the beam and hands it over to the subsequent drift-tube linac (DTL). The MEBT includes the main travelling-wave chopper system designed to give the minipulses sharp flanks of 10 ns rise and fall times, and to attenuate the chopped/unchopped beam-current ratio to the nominal value of 0.01%. The active deflector plates and power switches of the MEBT chopping system were supplied by LANL, and have not yet been commissioned. A water-cooled molybdenum target is installed at the centre of the MEBT to absorb the chopped beam fraction, and a so-called "anti-chopper" guides those particles back to the beam axis that missed the chopper target during the pulse ramping. Fourteen quadrupole magnets provide transverse matching, and four rebuncher cavities control the bunch length.

Beam diagnostics were built and commissioned by LBNL, ORNL, LANL, and BNL members of the SNS Diagnostics Collaboration; they include two current monitors, six beam-position monitors that provide input for six steerer pairs, and five wire scanners to measure horizontal and vertical beam profiles. For the commissioning activities at LBNL, an external slit/harp emittance device was added at the end of the MEBT to assess the transverse beam quality. This type of emittance scanner uses a movable entrance slit to select various locations across the beam and a 32-wire detector system to measure the local beam divergence at each of these positions. The external scanner will be used during the recommissioning period at ORNL, and might later be replaced by an in-line device. The front-end beam was also used to test a laser-based profile-monitor prototype, and the results are promising for the possible use of this type of monitor in the superconducting linac sections. It is planned to eventually install beam-scrapers in the MEBT that can be used to clip beam halo and reduce beam spill in the high-energy part of the linac. Five units of a newly designed low-level RF system were built by LBNL, and supported the phase-synchronized operation of the RFQ klystron and the MEBT rebuncher cavities. The EPICS control system (*CERN Courier* May p23) was supplied by the LBNL members of the SNS Global Controls group, and even allowed remote read-out of operational parameters from ORNL; remote operation would have been possible, but was not exercised in this period.

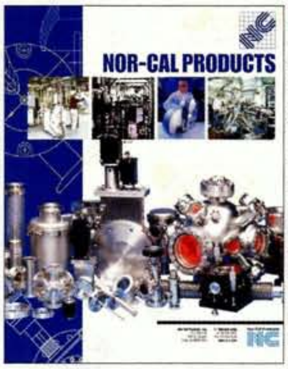
As a result of the front-end commissioning effort, several facts were established. The ion source reliably produces beams at the nominal duty factor of 6% with intensities exceeding 50 mA and uninterrupted periods of operation expected to reach 2 weeks or more. Electrostatic focusing works well with high-intensity beams in the LEBT. The RFQ transmission ranges above 90%, and the RFQ clips most of the low-intensity emittance wings generated by LEBT aberrations. All MEBT subsystems function as designed (only the main chopper system was not tested) – about 99% transmission was achieved without using any steerer, and the sensitivities to quadrupole and rebuncher tuning closely mirror simulation results. The transverse MEBT output emittances are just slightly above the nominal value, and can be reduced further by halo-scrapers. The most spectacular result is represented by the 50 mA pulsed beam-current measured at the end of the MEBT, almost 30% above the design goal of 38 mA.

Starting on 31 May, the SNS front end was partially disassembled and shipped to ORNL by 15 July. It is now fully installed at the SNS site, and recommissioning is planned to begin later this year.

Further reading

More information about the SNS front end is available at http://www.sns-fes.lbl.gov.

Roderich Keller, *Berkeley Lab.*



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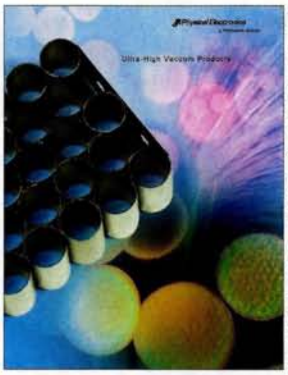

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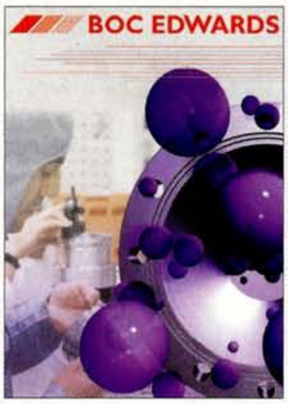

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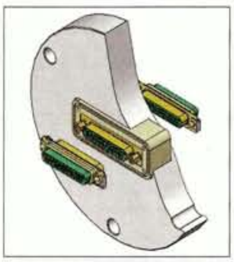

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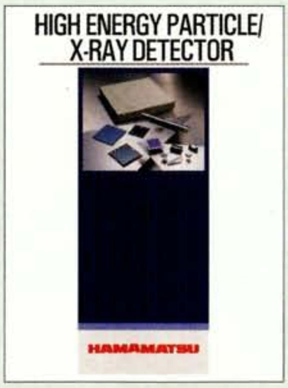

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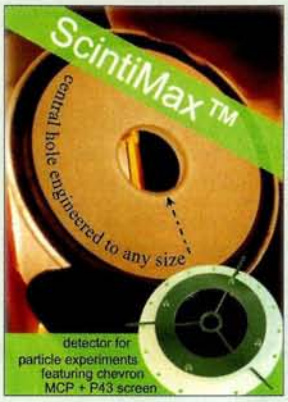

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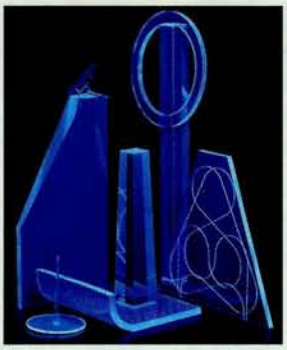

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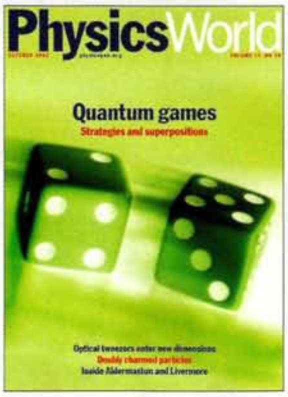

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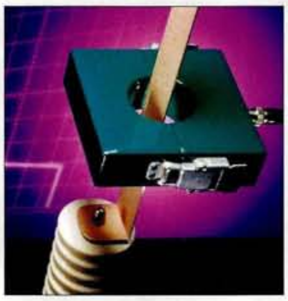

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Researchers observe two-proton radioactivity

Teams from France, Germany and Poland have recently observed two-proton radioactive decay from iron-45 nuclei. **Bertram Blank** explains how this opens up exciting new research avenues in nuclear physics.

An atomic nucleus is an ensemble of nucleons – protons and neutrons. To bind these nucleons and to form a stable nucleus, a subtle equilibrium of the number of protons and the number of neutrons is needed. For light species, a stable nucleus is formed from an equal number of protons and neutrons. Above the nucleon number A = 40, more neutrons than protons have to be added to form a stable atomic nucleus to overcome the Coulomb repulsion of the charged protons.

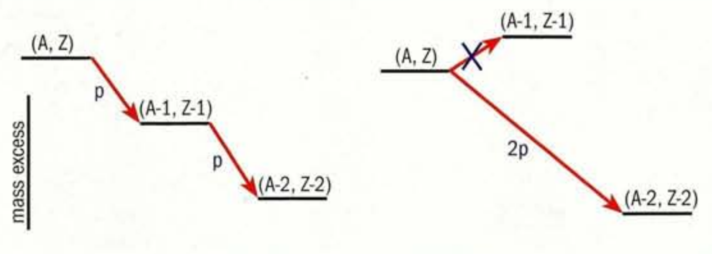


Fig. 1. The sequential emission of two protons is possible if the mass of the one-proton daughter nucleus is smaller than the mass of the two-proton emitter but larger than the mass of the two-proton daughter (left). If the intermediate state is higher in mass than the initial state, one-proton emission is energetically forbidden, and the decay occurs directly to the two-proton daughter (right).

If the equilibrium between protons and neutrons is disturbed, a nucleus becomes unstable and decays; for a slight imbalance it decays by β-decay (transformation of a proton into a neutron or vice versa), whereas for a large disequilibrium it will emit nucleons. This kind of particle emission from a nucleus was first observed for heavy nuclei, which may emit α particles (helium nuclei) to gain stability. For lighter very proton-rich nuclei with an odd number of protons (Z), proton emission was observed for the first time during the early 1980s at the GSI laboratory in Darmstadt, Germany. According to theoretical predictions, simultaneous two-proton emission from nuclear ground states should occur for even-Z nuclei. This two-proton radioactivity is only observable if the sequential emission of two independent protons is energetically forbidden (figure 1). This is the case for medium-mass proton-rich nuclei around A = 40–50. Due to the gain of stability from the pairing energy, the mass of the even-Z two-proton emitter is smaller than the mass of the odd-Z one-proton daughter, and therefore one-proton emission cannot occur. The only open decay branch is simultaneous two-proton decay.

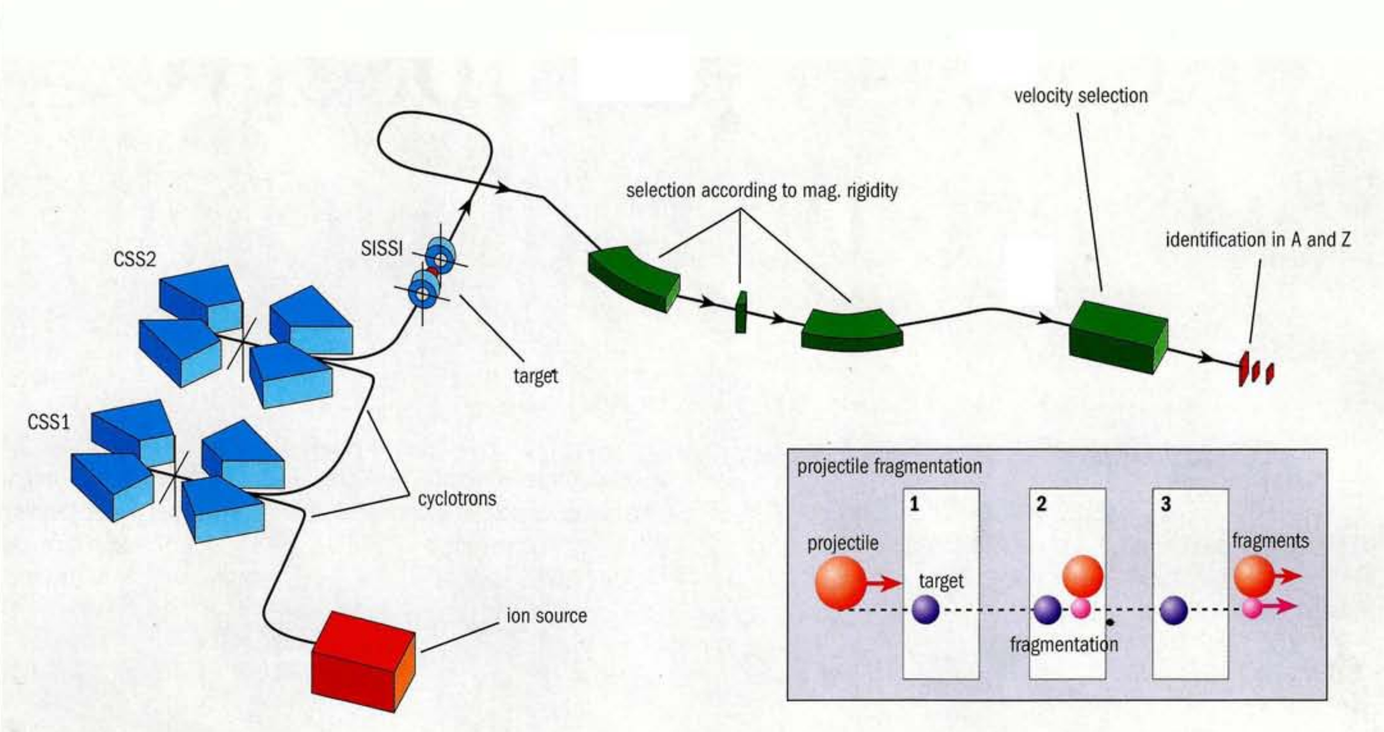
First observations

Experimental efforts have focused on the observation of this decay mode since its theoretical prediction in the 1960s, and in particular since the first observation of two-proton emission from excited states after β-decay in the 1980s. The first case of two-proton emission was that of aluminium-22, observed at Berkeley, US. However, the decay of this nucleus as well as those of all other β-delayed two-proton emitters turned out to be sequential (the decay proceeds via a well defined intermediate state in the one-proton daughter). No direct two-proton emission could be observed.

The situation is similar for the very-light, even-Z, proton drip-line nuclei beryllium-6 and oxygen-12, studied during the 1990s (a drip line is the boundary beyond which nuclei decay by proton or neutron emission). Although for these light nuclei, the intermediate one-proton daughter state may lie higher in energy than the two-proton emitting state, the sequential branch is always found open, because all the states involved are very broad, a consequence of the small Coulomb barrier for these light nuclei.

Theoretical predictions therefore pointed rather to medium-mass proton drip-line nuclei, and found iron-45, nickel-48 and zinc-54 to be the most promising candidates for direct two-proton ground-state decay. For these nuclei, the energy available for the two protons (the Q value) was found to be large enough to yield a reasonable probability for the two protons to traverse the Coulomb barrier fast enough so that two-proton radioactivity could dominate over β-decay (the competing decay), but not too large to make the decay too fast to be observed.

Following recent observations of iron-45 and nickel-48, experiments were planned to study their radioactive decay. Due to the fact that iron-45 is somewhat less exotic (less far away from stability) than nickel-48, and therefore its production rates are about an order of magnitude higher, iron-45 turned out to be the prime candidate for two-proton radioactivity. Its decay by this new type of radioactivity has now been observed in two independent experiments at the GANIL laboratory in Caen, France, and at GSI (see ▷



In projectile fragmentation (see insert), a high-energy stable-particle beam impinges on a solid target where the projectile nuclei are fragmented and smaller nuclear species are created. The fragments of interest leaving the target are selected by a sequence of filters (dipole magnets, energy absorbers and velocity filters), identified by different detectors and finally implanted in a detection set-up where their decay can be observed. This figure shows the installation used in the GANIL experiment.

further reading).

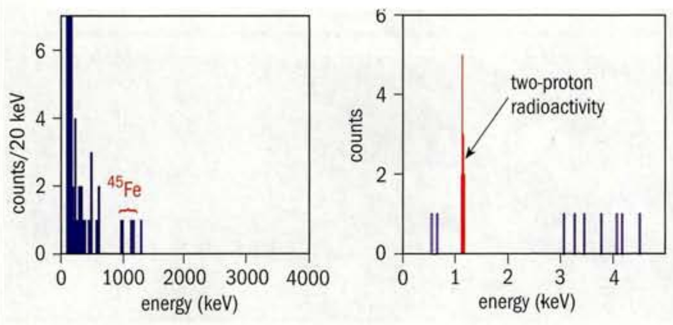
Both experiments used projectile fragmentation of a stable nickel-58 beam on a beryllium (GSI) or nickel (GANIL) target. The fragments of interest were selected by a fragment separator and directed to a detection station, where the decay of iron-45 was observed after its implantation in a stack of silicon detectors. The GSI experiment identified four decays of iron-45 with decay energy of about 1.1 MeV, whereas in the GANIL experiment 12 correlated decays were measured with the same energy. The half-lives determined in both experiments agree nicely and yield an average value of about 3.8 ms. The decay energy and half-life are in beautiful agreement with theoretical predictions using a shell-model approach combined with Coulomb-barrier penetration calculations. However, the most important piece of evidence comes from the fact that both experiments looked for β particles from a possible β-decay of iron-45. In the GSI experiment, a sodium iodide barrel would have detected the 511 keV photons from annihilation of the β particles, whereas in the GANIL experiment, a silicon detector was used to observe any β particles directly. No such coincident radiation was observed for any of the events consistent with two-proton radioactivity. Therefore both experiments excluded the possibility that the 1.1 MeV decay signal of iron-45 is due to a β-delayed decay branch, the concurrent decay possibility of this nucleus.

> It is commonly felt that a deeper understanding of nuclear structure can only be obtained by studying nuclei far away from stability.

Both experiments observed only the total energy released in the decay. Neither was designed to identify the individual protons and measure their energies and relative emission angles. However, from theoretical predictions it is clear that the emission must have taken place simultaneously. None of the commonly used models predicts any significant sequential emission branch. But even in the case of simultaneous emission, two extreme pictures can be designed. One is an emission process whereby the two protons are emitted independently and therefore fill the whole phase space (there is no particular energy or angular correlation between the two protons). This decay mechanism is usually referred to as three-body decay. The other decay mechanism is known as helium-2 emission, where the two protons are strongly correlated and one could expect an angular and/or energy correlation between them. For both pictures, theoretical descriptions are available. However, a complete model should accommodate both pictures simultaneously and describe them as extremes of a more realistic modelling of the process. These types of descriptions are now being developed, mainly in close connection with the models used for two-neutron halo nuclei on the opposite side of the valley of stability.

Testing the models

To test these models in more detail, better experimental data and more theoretical development are needed. It is of particular importance, for example, to go beyond a measurement of only the total decay energy. By measuring the individual proton energies and their relative emission angles, conclusions about the decay mechanism can probably be drawn. However, for these kinds of measurements,



These spectra from the GSI (left) and GANIL experiments both show the energy released in the decay of iron-45 implanted in silicon detectors.

the silicon detection set-ups used in the GANIL and GSI experiments can no longer be used. In such set-ups, the decay protons cannot escape from the detector, and therefore no information about the individual energies and the proton–proton angles can be gained. This problem can be overcome by using gas tracking detectors, so that the tracks of the emitted protons can be observed. A development recently started at the Centre d'Etudes Nucléaires (CEN) Bordeaux-Gradignan, whereby a time-projection chamber (TPC) will be used to visualize the tracks of the two protons in three dimensions. With such a set-up, the two-proton emitter will no longer be implanted deeply into a silicon detector, but will be in the centre of a gas cell used as the active volume of the TPC.

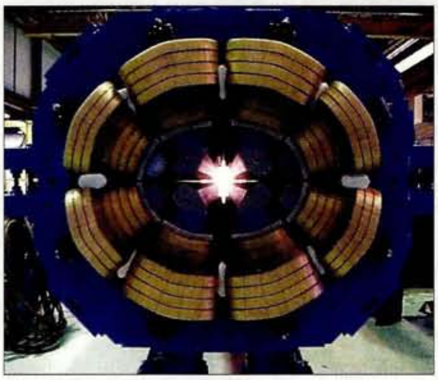
Another research direction will be to identify new two-proton emitters. Nickel-48 and zinc-54 are especially accessible for experiments, and are ready to be studied. These investigations may then allow the decay mechanism of two-proton radioactivity to be studied. In particular, two-proton decay may open an original route towards studying pairing in the atomic nucleus. In addition, masses will be determined for nuclei beyond the limits of stability via the measurement of the two-proton Q value, which then allows mass-model predictions far away from the stability line to be tested. By comparing experimental results and theoretical calculations, the single-particle structure of extremely proton-rich nuclei might become accessible. It is commonly felt that a deeper understanding of nuclear structure can only be obtained by studying nuclei far away from stability. Two-proton radioactivity is now set to provide an interesting probe for this endeavour.

Further reading

J Giovinazzo *et al.* 2002 *Phys. Rev. Lett.* **89** 102501.
M Pfützner *et al.* 2002 *Eur. Phys. J.* **A14** 279.

Bertram Blank, *Centre d'Etudes Nucléaires, Bordeaux-Gradignan.*

PEOPLE



On 8 October, Alan Shotter, director of Canada's TRIUMF laboratory, and Ewart Blackmore, the Canadian responsible for coordinating CERN–Canada collaboration, signed an extension to Canada's agreement to contribute to the Large Hadron Collider (LHC) project with CERN director-general Luciano Maiani. Worth C$11.5 million (€7.4 million), the largest and most important item in this extended contribution is a series of double-aperture warm quadrupoles for LHC beam cleaning. These magnets, of which the 33rd to be produced is pictured here at ALSTOM Canada in Quebec, have a unique pole structure. (Photo: Yvon Langevin, ALSTOM Canada.)

Peter Paul, interim director of the US Brookhaven National Laboratory (centre) and **Eberhard Jaeschke** (right), technical director of Germany's BESSY synchrotron radiation research institute, signed a memorandum of understanding in September. Under this new agreement, the two laboratories will share expertise in the science and technology of high-brightness electron beams. **Ilan Ben-Zvi** (left), director of Brookhaven's accelerator test facility, and Wolfgang Eberhardt, scientific director of BESSY, also signed the memorandum.

Russian minister for science and technology, **Mihail P Kirpichnikov**, came to CERN in October to see first-hand the progress being made on the ATLAS and CMS experiments, both of which have significant Russian participation. Left: visiting the ATLAS experiment, Kirpichnikov (second from left) was accompanied by (left to right) **Alexey Dudarev** of CERN, **Lev Riabev**, first deputy-minister, and **Alexander Skrinsky**, director of the Budker institute in Novosibirsk. Right: the minister also visited the CMS crystal laboratory with (left to right) CERN's **Philippe Bloch** and **Nicolas Koulberg**, **Lev Riabev**, **Felix Grishaev**, scientific attaché at the Russian mission in Geneva, and **Alexander Skrinsky**.

APS AWARDS

APS announces winners for 2003

The American Physical Society has announced its awards for 2003. Among the recipients are many researchers in fields covered by *CERN Courier*.

The Tom W Bonner prize for outstanding experimental research in nuclear physics goes to **Art McDonald** of Queen's University, Canada, "for his leadership in resolving the solar neutrino problem with the Sudbury Neutrino Observatory".

Sudbury figures again in the awards, with the prize for a dissertation in nuclear physics going to **Karsten Heeger** of the University of Washington "for his role in the generation and analysis of the data from the Sudbury Neutrino Observatory, and the resulting resolution of the solar neutrino problem".

The Bethe prize for outstanding work in astrophysics, nuclear physics, nuclear astrophysics or closely related fields goes to **Michael Wiescher** of the University of Notre Dame "for his contributions to the experimental foundation of nuclear astrophysics, especially the delineation of the processes involved in explosive hydrogen burning in novae and X-ray bursters; and for providing an intellectual bridge between experimental nuclear astrophysicists and their theoretical colleagues".

The Edward A Bouchet award recognizes a distinguished minority physicist who has made significant contributions to physics research. It has been awarded to **Homer Neal** of the University of Michigan "for his significant contributions to experimental high-energy physics, for his important role in formulating governmental science policy, for his service as a university administrator at several universities, and for his advocacy of diversity and educational opportunity at all levels".

The Einstein prize for gravitational physics goes to Princeton's **John Wheeler**, and **Peter Bergmann** of Syracuse University "for pioneering investigations in general relativity, including gravitational radiation, quantum gravity, black holes, space–time singularities, and symmetries in Einstein's equations, and for their leadership and inspiration to generations of researchers in general relativity".

Fermilab's Helen Edwards has been awarded the 2003 Robert R Wilson prize. (Fermilab Visual Media Services.)

The Dannie Heineman prize for mathematical physics goes to **Yvonne Choquet-Bruhat** of the Université Pierre et Marie Curie in Paris and **James York** of Cornell University "for their separate as well as joint work in proving the existence and uniqueness of solutions to Einstein's gravitational field equations for a variety of sources, and for formulating these equations so as to improve numerical solution procedures with relevance to realistic physical systems".

The Julius Edgar Lilienfeld prize for a most outstanding contribution to physics is awarded to **Frank Wilkzek** of MIT "for his role in the development of asymptotic freedom and other aspects of quantum chromodynamics (QCD), a cornerstone of the Standard Model; for his remarkable versatility in research in condensed matter and astrophysics as well as particle physics; and for his outstanding ability to lecture and write with clarity, profundity, and enthusiasm".

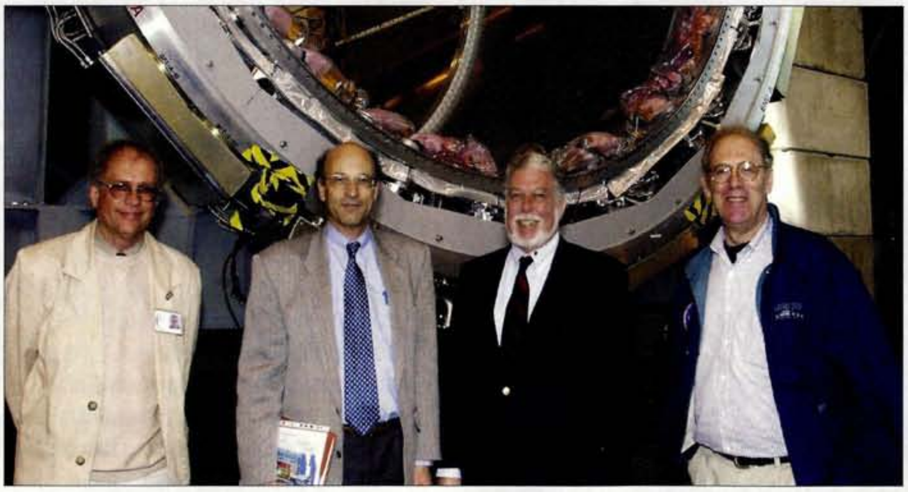
The Maria Goeppert-Mayer award for outstanding achievement by a female physicist in the early years of her career goes to **Chung-Pei Michele Ma** of the University of California, Berkeley, "for her important contributions to theoretical astrophysics, particularly in the areas of relativistic evolution of density perturbations, testing of structure formation models with massive neutrinos, and the clustering and dynamics of dark matter halos around galaxies".

The W K H Panofsky prize in experimental particle physics is awarded to **William Willis** of Columbia University "for his leading role in the development and exploitation of innovative techniques now widely adopted in particle physics, including liquid argon calorimetry, electron identification by detection of transition radiation, and hyperon beams".

The Francis M Pipkin award for accomplishments by a young scientist in the interdisciplinary area of precision measurement and fundamental constants goes to **Eric Hessels** of York University, Canada, "for a wide range of high-precision measurements to test fundamental interactions in atomic physics, especially fine-structure splittings in helium as a measure of the fine structure constant, and for an innovative experimental technique to create atoms of antihydrogen".

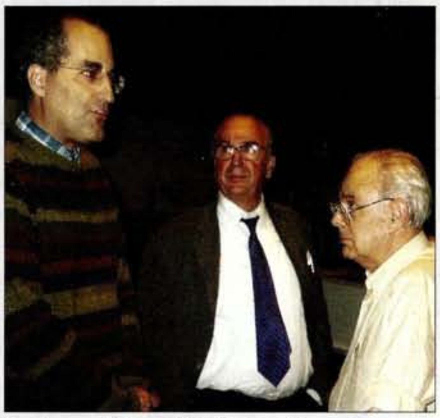
The J J Sakurai prize for outstanding achievement in particle theory goes to **Alfred Mueller** of Columbia University and **George Sterman** of the State University of New York at Stony Brook "for developing concepts and techniques in QCD, such as infrared safety and factorization in hard processes, which permitted precise quantitative predictions and experimental tests, and thereby helped to establish QCD as the theory of the strong interactions".

Finally, the Robert R Wilson prize for achievement in the physics of particle accelerators goes to Fermilab's **Helen Edwards** "for her pivotal achievement and critical contribution as the leader in the design, construction, commissioning and operation of the Tevatron, and for her continued contributions to the development of high-gradient superconducting linear accelerators as well as bright and intense electron sources".



Pierre Perrolle (second from right) of the US National Science Foundation (NSF) visited CERN on 23 September. The purpose of his visit was to pursue a study of ways in which prominent European research organizations integrate their research activities with education. Standing with him in front of the ATLAS experiment's liquid argon barrel cryostat are (from left) **Randy Ruchti** of the University of Notre Dame, ATLAS spokesperson **Peter Jenni**, and **Robert Eisenstein** of the NSF. The cryostat has been designed and delivered under the full responsibility of the US Department of Energy and NSF teams of ATLAS.

Members of the International Committee for Future Accelerators (ICFA) visited the Large Hadron Collider magnet assembly hall during the October ICFA meeting held at CERN.

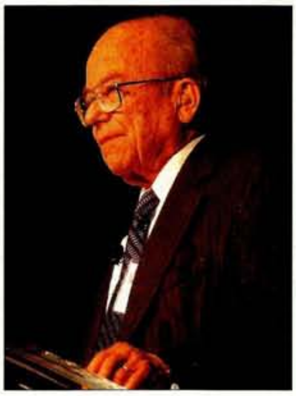


During a visit to CERN in October, string theorist **Ed Witten** (left) of the Princeton Institute for Advanced Study gave a talk about old and new approaches to quark confinement. Witten is seen here in conversation with CERN director-general **Luciano Maiani** (centre) and **Lev Okun** of Moscow's Institute of Theoretical and Experimental Physics.

On 30 September – 1 October, Moscow's Institute of Experimental and Theoretical Physics (ITEP) organized a celebration to mark the 80th birthday of the great Russian theoretical physicist of Armenian origin Karen Ter-Martyrosian, who recently became a corresponding member of the Russian Academy of Sciences. It is impossible to describe all of Ter-Martyrosian's achievements because his interests are multiple, from the three-body problem to diffractive scattering and particle production, as well as heavy-flavour physics and weak decays. He has also been – and still is – a great teacher. Among his students was the late Vladimir Gribov, one of Russia's most famous theoreticians. It was impressive and touching to see that representatives of all the great research centres of the former Soviet Union were present, from St Petersburg to Kiev, and from Yerevan to Novosibirsk. I was the only westerner, representing CERN, and in fact the rest of the world! Left to right: **Karen Ter-Martyrosian**, **Igor Dremin** of the Lebedev Institute, and **Alexei Kaidalov** of ITEP, a long-time collaborator of Ter-Martyrosian. (From André Martin, CERN.)

SLAC celebrates 40 years of physics research

Guests in a huge tent erected for the occasion to celebrate SLAC's first 40 years. Among the speakers were SLAC's three directors, all of whom are still active in the life of the laboratory.



SLAC's founding father and first director, Pief Panofsky (left), recalled the early days of the California laboratory, while current SLAC director, Jonathan Dorfan (centre), looks forward to another 40 years of front-line research. Right: SLAC's second director and 1976 Nobel laureate, Burton Richter, discussed the laboratory's role in accelerator development. (Photos: Diana Rogers.)

The Stanford Linear Accelerator Center (SLAC) celebrated 40 years of outstanding research into fundamental particle physics and synchrotron radiation with a special anniversary event on 2 October. More than 1300 people – including SLAC staff, US government representatives and research scientists from around the world – gathered to celebrate the laboratory's accomplishments and contributions to science.

SLAC director Jonathan Dorfan underlined the crucial contribution of SLAC's staff to the success of the laboratory over the last 40 years. "I proudly and gratefully dedicate this entire celebration to the SLAC staff gathered here today," he said. "It is their skill and work that makes all this possible."

Highlights of the afternoon celebration included a series of speeches outlining the historic contributions that SLAC has made to scientific research. The series featured a keynote address written by Ray Orbach, director of the US Department of Energy's Office of Science, and delivered by Peter Rosen, associate director for high-energy and nuclear physics in the Office of Science. "SLAC is famous for innovative and bold projections into the unknown," wrote Orbach. "We celebrate extraordinary scientific achievements. We also celebrate contributions to our country, for the service of the men and women who have been and are associated with SLAC is legendary. Unselfishly, they have contributed to science, education, government, national security and world peace."

Among many letters of congratulations from around the world was one from CERN director-general Luciano Maiani, congratulating SLAC on its first 40 years and looking forward to the next. Leon Lederman of Fermilab adopted a similar line. "I certainly wish you a very successful celebration," he said. "Even though SLAC is only half my age, you have many achievements about which to be proud. And just think, when SLAC is 80, I'll be 160!"

In September, a 6 m long full-scale model of the Large Hadron Collider (LHC) was inaugurated in CERN's Microcosm exhibition centre. This is the start of a new exhibition looking at the challenges, technologies and physics of the LHC.

Sergio Calatroni of CERN demonstrates some of the wonders of superconductivity to visitors at an evening of experiments organized by CERN for the French national science week, Fête de la Science. In total, CERN organized eight activities in five different French communes during the week. (Emma Sanders.)

Tran Thanh Van celebrates 65th birthday at Collège de France

The Collège de France held a two-day multi-disciplinary conference on 4–5 October to celebrate the 65th birthday of Tran Thanh Van. Some 250 people came to Paris to pay tribute to the man who founded the famous Rencontres de Moriond winter meetings, the Rencontres de Blois and the Rencontres de Vietnam.

Following the Moriond tradition, the speakers were not only established scientists (including several Nobel laureates), but also a number of people at the beginning of their careers.

The Moriond meetings have taken their place alongside the major summer conferences as a place to present new results. Since they began in 1966, they have taken place annually in the French Alps. In launching the series, Tran Thanh Van had two goals in mind. One was to facilitate contacts between theoretical and experimental particle physicists by bringing them together, away from their laboratories, and providing them with a forum for discussions. The second was to alleviate the psychological barrier that tends to exist between young researchers and their senior colleagues. In the Moriond forum, young physicists are encouraged to present their work.

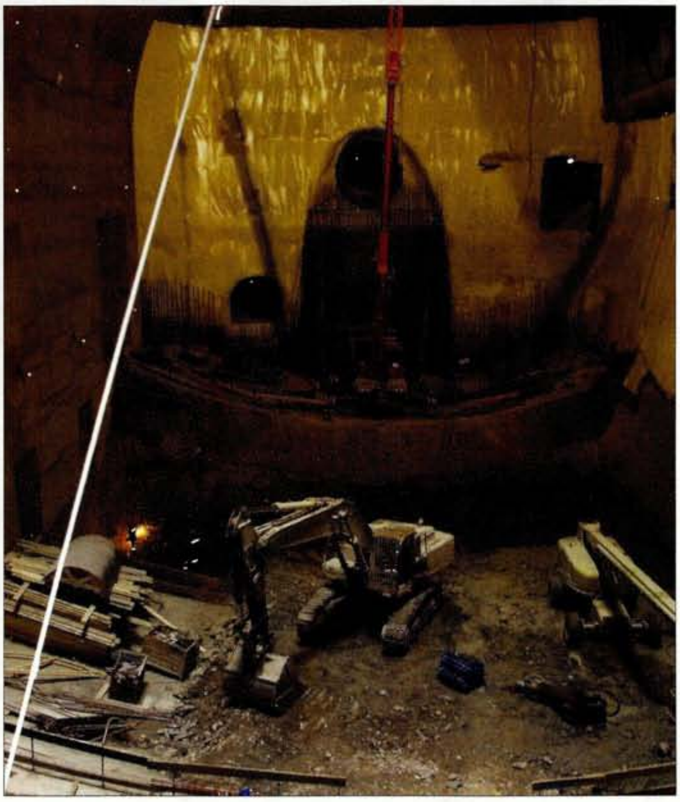
Tran Thanh Van (centre) is pictured here with Ecole Polytechnique students of Vietnamese origin.

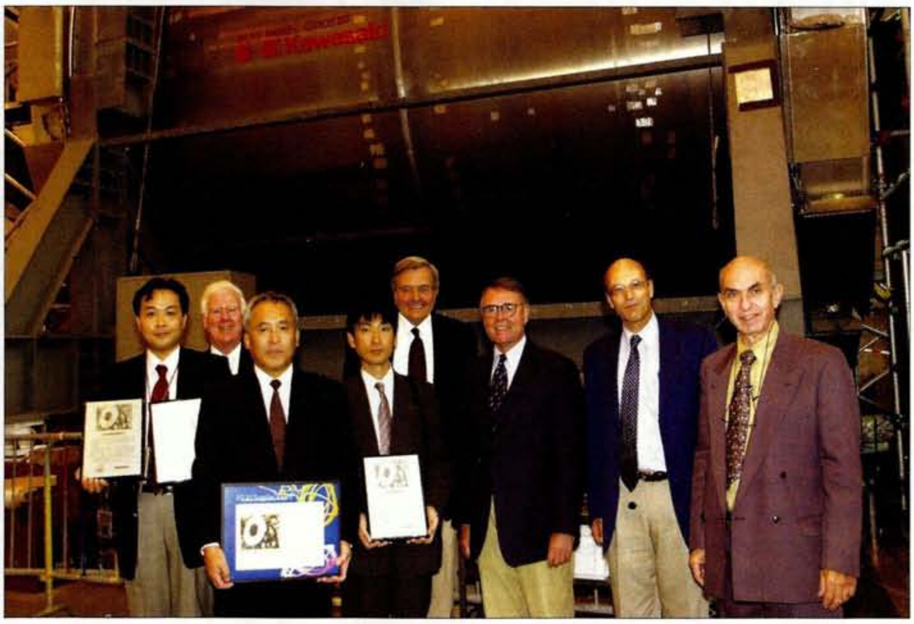
Left to right: Carlo Rubbia, Tran Thanh Van, Giorgio Bellettini and Jerome Friedman in the courtyard of the Collège de France.

The Moriond spirit has percolated through the meetings, which have proliferated in both number and subject. There are now several Moriond meetings each year. Among the recurrent themes are particle physics, cosmology, astrophysics, condensed-matter physics and biology. Participants come from all over the world, and the "curtains" that have in the past separated nations have never been present at Moriond.

The conference highlighted the invaluable services rendered to science and society by Tran Thanh Van and his wife Kim. *CERN Courier* joins the participants in wishing both Tran Thanh Van and the Rencontres de Moriond many happy returns. Conference details are at http://events.lal.in2p3.fr/conferences/bandf/.

Right to left: Thomas Wobmann and Markus Zemp visit the LHC tunnel at CERN with Günther Dissertori and Marcel Wyler of ETH Zurich. Their visit was part of the top prize for a competition organized by the ETH department of physics to coincide with its open day in June. Residents of Zurich and surrounding Swiss cantons were invited to answer five physics questions broadcast on local radio and the Internet the week before the open day. The two winners' reward for knowing who did not believe that God plays dice, among other things, was a flight offered by Swiss International Air Lines to Geneva and a VIP tour of CERN. One highlight was a trip to the underground site of the future CMS experiment, where the scale of the enormous cavern makes construction machines look like children's toys.





Right: a delegation from Kawasaki Heavy Industries, led by **Syuichi Nose** (third from left), accepted an award for exceptional performance from the ATLAS collaboration at CERN in September. Above: two months earlier, collaboration spokesperson **Peter Jenni** (left) had presented a similar award to **Hirohisa Takano** of the Toshiba Corporation in Japan.

Kawasaki received the award for producing the cryostat for the experiment's liquid argon barrel calorimeter and central solenoid. A pressure vessel 5.55 m in diameter and 6.81 m in length, the cryostat was designed and constructed under the responsibility of the US Brookhaven laboratory as an in-kind contribution of US ATLAS groups. The ultrathin superconducting solenoid, manufactured by Toshiba, has a bore of 2.4 m and is 5.3 m long. It will provide a 2 T field for the experiment's inner tracking detector. It was designed and constructed under the responsibility of the KEK laboratory, and is an in-kind contribution from Japanese ATLAS groups.

A CERN delegation went to Beijing, China, and South Korea in July. In Beijing, they visited the Institute of High Energy Physics (IHEP) of the Academia Sinica, Peking University and the Chinese National Natural Science Foundation (NSFC). IHEP and Peking University are involved in building the muon detector system for the CMS experiment, which is currently being prepared for CERN's Large Hadron Collider. At NSFC, a new Chinese contribution to CMS was confirmed. In the particle physics laboratory of Peking University, members of the delegation inspected newly built components of the resistive plate chambers that will be used in the CMS endcap muon system. Left to right: **Diether Blechschmidt** of CERN, **Yanlin Ye**, director of Peking University's physics school, CERN research director **Roger Cashmore**, CMS spokesperson **Michel Della Negra**, CMS deputy technical coordinator **Austin Ball** and **Sijin Qian** of Peking University.

Left to right: **Manuel Aguilar-Benitez**, Spanish delegate to CERN's governing Council, **Antonio Ferrer**, chairman of the Spanish National Programme for Particle Physics and Large Accelerators, ATLAS collaboration spokesperson **Peter Jenni** and cryostat vessel project engineer **Lluis Miralles Verge** with the first of the ATLAS experiment's barrel toroid cryostat vacuum vessels delivered to CERN. The air-core ATLAS barrel toroid magnet system will consist of eight large superconducting coils, each in its own vacuum vessel. The company Felguera Construcciones Mecanicas SA is producing these as a Spanish in-kind contribution. By October, four of the eight vessels had arrived at CERN and been made ready to receive the toroid cold masses.

OBITUARIES

Martin Deutsch 1917 – 2002

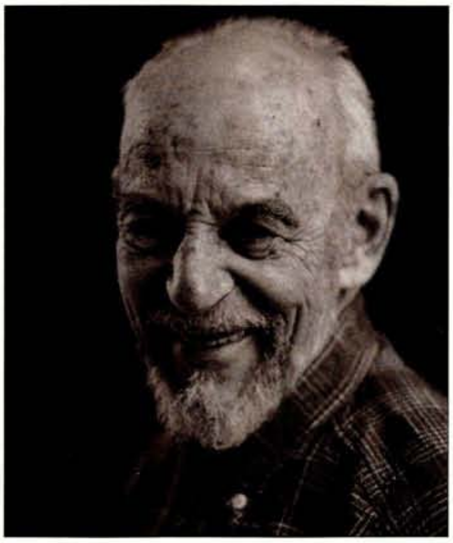


Photo courtesy of MIT.

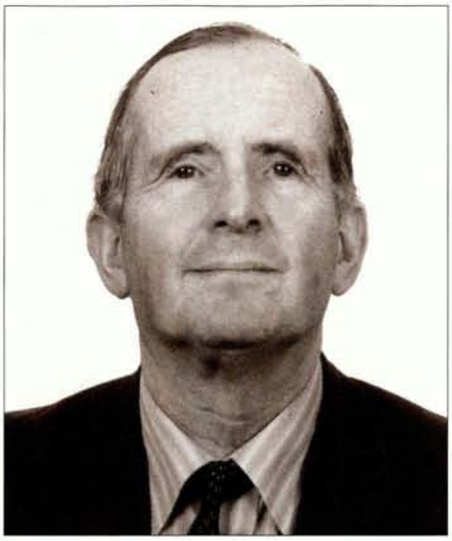
Martin Deutsch, professor of physics at MIT, died at his home in Cambridge, Massachusetts, on 16 August. Born in Vienna (where he studied at the same real gymnasium as Victor Weisskopf), he emigrated to the US in 1935. He did his graduate work at MIT, where he subsequently spent his whole professional life, except for two years of work at Los Alamos during the war.

Deutsch had a great flair for interesting experiments and for instrumentation. He was the physicist who first realized the importance of Kallmann's discovery of organic scintillators (1947) and introduced their use in the US. With these means, he performed many nuclear spectroscopy experiments that had been previously almost impossible. In 1951, he discovered positronium, the "ultimate atom", consisting of a bound electron–positron system. Between 1951 and 1954, he and his associates measured the most important properties of its ground state, namely its hyperfine splitting (the singlet–triplet energy difference) and the lifetime of the triplet state. That splitting, about twice as large as one would conclude from naive arguments, is one of the most striking manifestations of quantum electrodynamics. It is fair to say that Deutsch, in a remarkable outburst of creative energy, largely cleaned up the field. Several decades passed before anything substantially new was learned about positronium.

After positronium, Deutsch switched to particle physics, in particular to work at the Cambridge electron accelerator. This field did not quite correspond to his personal style, as he was used to doing everything down to the last detail with his own hands. Nevertheless, he remained active throughout his later years, participating in the preparation and set-up of the BOREXINO solar neutrino experiment in the Gran Sasso laboratory.

Deutsch was a great teacher, both in the classroom and as a thesis advisor. Among his many students was the Nobel laureate Henry Kendall. He was also a sharp debater, mixing incisive criticism with Viennese charm. He is survived by his wife, Suzanne, and two sons.
V L Telegdi.

John Gunn 1916 – 2002



John Gunn died on 26 July, aged 85. For many years he was a significant influence on British particle and nuclear physics, and its involvement in CERN.

From the age of 32, in 1949, Gunn held a professorial chair in theoretical physics at Glasgow University. During the early 1950s, three British universities were constructing particle accelerators in emulation of developments in the US; one of these was an electron synchroton in Glasgow. Late on the scene, these machines never quite fulfilled the hopes of their proponents. However, they led to the more timely construction in the early 1960s of higher-energy accelerators – a proton machine at the Rutherford Appleton Laboratory, and an electron synchroton at Daresbury in the north of England. Gunn took a notable part in the countrywide planning that led to these developments, and most significantly in that of the electron synchroton. The synchroton radiation from it later proved to have important applications in many other areas of science.

It was perhaps a second best for Gunn that the electron accelerator was sited in the north of England rather than in Scotland, but he and his experimental colleague Philip Dee (the initiator of the 1950s Glasgow synchroton) were successful in getting finance to build a linear electron accelerator for nuclear physics research sited near Glasgow. Initially led by George Bishop, this had a long and successful research life.

Gunn's influence continued with his appointment to the UK Science Research Council (SRC) from 1968 to 1972. At that time the question of building a much higher-energy European proton accelerator at CERN had arisen. The SRC Nuclear Physics Board oversaw both nuclear and particle physics in the UK, and advice to the government on CERN came largely from the chairman of that board and the SRC. Gunn was the chairman at the time the UK government decided that Britain should join the new CERN project.

From 1973 to 1981 Gunn was a member of the University Grants Committee (UGC), the main financier of UK universities. Here he was a forceful advocate of the so-called "dual support system", which meant that both the UGC and the SRC should directly support scientific research in the universities. Here he and others were responsible for beneficial reformation in scientific (and other) research grants from the UGC.

In the 1960s, no longer very active in hands-on physics research himself, Gunn was able to use his administrative position at Glasgow University to found three theoretical physics research groups – particle, nuclear and plasma – in the physics department.

Humorously communicative, and helpful through his wide experience, his company was much appreciated by his friends and acquaintances in many institutions.
Gordon Moorehouse.

RECRUITMENT

For advertising enquiries, contact *CERN Courier* recruitment/classified, Institute of Physics Publishing, Dirac House, Temple Back, Bristol BS1 6BE, UK.
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UNIVERSITY OF DELAWARE

TENURE TRACK FACULTY POSITION
THEORETICAL ATOMIC AND MOLECULAR PHYSICS

The Department of Physics and Astronomy at the University of Delaware (www.physics.udel.edu) invites applications for a tenure-track position in **Theoretical Atomic and Molecular Physics** at the rank of Assistant Professor to start September 1, 2003.

The Department has research programs in condensed matter and materials physics, atomic, molecular, and optical physics, particle theory, and astronomy and astrophysics that have been recently strengthened by a number of new hires. We seek candidates with broad interests and expertise in such areas as numerical simulations, Bose-Einstein condensation, high-precision electronic structure calculations, macro-molecules, cold atomic and molecular collisions, quantum dynamics of few-body systems, and clusters and nanostructures.

The successful candidate will be expected to demonstrate the potential for establishing a significant externally funded research program and to be a dedicated teacher of physics at the undergraduate and graduate levels. Significant start-up funds are available.

Applicants must send a curriculum vita, publication list, research plan, and a teaching statement, as well as arrange for three letters of reference to be sent directly to the

Atomic and Molecular Physics Search Committee, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716.

The curriculum vitae and letters of reference shall be shared with Departmental faculty.

For full consideration completed applications should be received no later than January 2, 2003.

The University of Delaware is an Equal Opportunity Employer, which encourages applications from qualified minority groups and women.

CORNELL

TWO PROFESSORIAL POSITIONS
EXPERIMENTAL ELEMENTARY PARTICLE PHYSICS

Cornell University is seeking outstanding individuals for two professorial positions in experimental elementary particle physics. One position is at the level of tenure-track Assistant Professor and the other is at the level of tenure/tenure-track Assistant, Associate or Full Professor. In addition to teaching undergraduate and graduate courses, responsibilities will include supervision of graduate students and participation in the research program of the Laboratory for Elementary Particle Physics, which is based on the CESR e^+e^- storage ring and the CLEO experiment, with future involvement in the international linear collider. CLEO provides a unique opportunity for high precision measurements in the Upsilon family, at the J/ψ, and near the DD and D_s D_s production thresholds. The Laboratory envisions a substantial role in both the particle physics and accelerator development of the linear collider. A PhD in Physics and experience in experimental elementary particle physics is required. Both positions will be available on or before August 1, 2003. Please send an application and at least three professional letters of recommendation to

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

Applications should include a curriculum vitae, a publication list, and a short summary of teaching and research experience. Applications received before January 15, 2003 will be given full consideration. Electronic submissions and mail inquiries may be addressed to **search@lns.cornell.edu**.

Cornell is an equal opportunity/affirmative action employer.

http://www.lns.cornell.edu/public/eppprof.html

Duke University

Faculty Position in Experiment High Energy Physics

Duke University is seeking to fill a faculty position at the Junior (tenuretrack assistant professor) or Senior (tenured associate or full professor) level in the area of experimental high energy physics.

The Duke High Energy Physics group currently has a major research program in hadron collider physics through participation in the CDF and ATLAS experiments.

We are seeking candidates with outstanding records and exceptional promise for future growth in a new area such as neutrino physics. A strong commitment to excellence in teaching at both the undergraduate and graduate level is also expected. The position is available starting September 2003.

Applications received by January 15, 2003 will be guaranteed consideration.

Please send a resume and research statement to

High Energy Physics Search Committee, c/o Prof. Seog Oh,
Department of Physics, Box 90305, Duke University,
Durham, NC 27708, USA
(email: seog@phy.duke.edu).

Junior candidates should arrange to have three reference letters sent to the same address. Senior candidates should supply the names of up to three references.

Duke University is an affirmative action/equal opportunity educator and employer.

IOWA STATE UNIVERSITY

POSTDOCTORAL RESEARCH ASSOCIATE
EXPERIMENTAL HIGH ENERGY PHYSICS

The experimental high energy physics group at Iowa State University invites applications for a Postdoctoral Research Associate position. We seek a candidate to join our program in the BABAR experiment at the Stanford Linear Accelerator Laboratory (SLAC). BaBar is providing data for the study of B meson physics as well as charm and tau processes. The Iowa State group is involved in the study of B meson decays, especially CP violation and rare decay modes. The successful candidate will be stationed at SLAC as part of this program and is expected to participate in data analysis and detector operations. Experience with state-of-the-art detector systems and analysis of experimental high energy physics data are appreciated. Experience with C++ is desirable.

Candidates should have a Ph.D. in experimental elementary particle physics and have a strong interest in data analysis. Interested applicants should send their CV, a brief statement of research interest, and arrange to have at least three letters of reference sent to:

Professor Soeren Prell, Department of Physics and Astronomy,
Iowa State University, Ames, Iowa 50011-3160, U.S.A.
E-mail: prell@iastate.edu Phone: (515) 294-3853 Fax: (515) 294-3747

Applications will be accepted until the position is filled.

Iowa State University is an Affirmative Action/Equal OpportunityEmployer, and encourages applications from women and minority candidates.

Magnet Designer/ Beam Transport Physicist

Application forms can be obtained from: Operations Group, HR Division, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, OX11 0QX. Telephone (01235) 445435 (answerphone) or email recruit@rl.ac.uk quoting the reference VN2345. All applications must be returned by Monday 16th December 2002.

A Magnet Designer/Beam Transport Physicist is required to work within the ISIS Accelerator Division at the world-leading ISIS spallation neutron source at the Rutherford Appleton Laboratory (RAL) in Oxfordshire. The successful applicant will provide magnet design and beam transport expertise to facilitate upgrades to ISIS, particularly the new Second Target Station, to underpin the operation of ISIS, and to support RAL's role in international particle accelerator collaborations.

Candidates are expected to have a degree in physics, substantial theoretical and practical experience of designing, installing and commissioning magnets, and experience of charged particle beams. It would be advantageous for candidates to have proven ability to work efficiently on several tasks at the one time.

Starting salary will be either up to £25,790 on a pay range from £20,630 to £28,790 or up to £32,740 on a pay range from £26,190 to £36,010 according to experience. An index linked pension scheme, flexible working hours and a generous leave allowance are also offered.

More information about CCLRC is available from CCLRC's World Wide Web pages at http://www.cclrc.ac.uk

Further technical information about the post can be obtained from: D.J.S.Findlay@rl.ac.uk

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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
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FACULTY POSITION IN THEORETICAL HIGH ENERGY PHYSICS

The Department of Physics and Astronomy at Northwestern University is seeking outstanding candidates for a tenure-track Assistant Professor position in theoretical high energy physics. The appointment starts September 2003. Northwestern offers excellent opportunities for initiating and developing research programs in physics (for more information, see **http://www.physics.nwu.edu/**).

The successful candidate is expected to teach effectively at all levels.

Applicants should submit a curriculum vitae, statement of research interests and plans, and arrange for four letters of reference to be sent to:
Prof. Heidi Schellman, Chair,
Search Committee,
Department of Physics and Astronomy,
Northwestern University,
Evanston IL 60208-3112.

Applications should be received by February 3, 2003 to receive full consideration.

Members of minority groups and women are especially encouraged to apply. AA/EOE.

BOOKSHELF

Mathematics for the Imagination by Peter M Higgins, Oxford University Press, ISBN 0198604602, £7.99 (€13).

As a citizen of Antwerp, the place where the Renaissance produced some of its finest atlases, I was of course very pleased to read a book that for once properly explains the work of Gerardus Mercator.

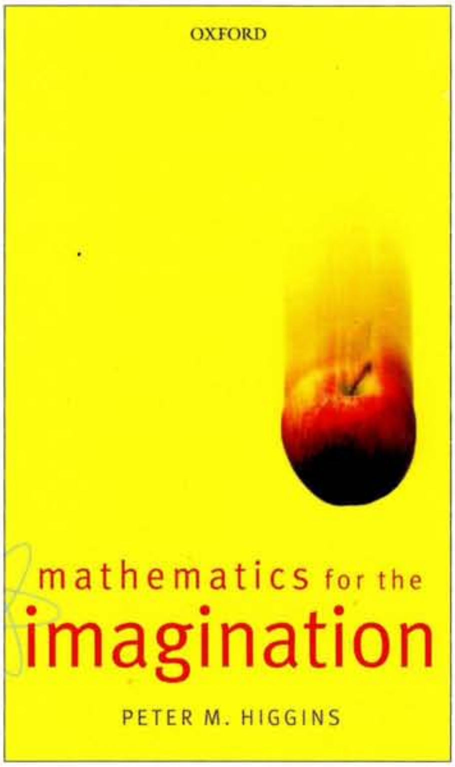
Fortunately (or perhaps unfortunately), I am not familiar with Peter Higgins' other books that popularize mathematics, so this is an impression of one work only. The author states that he wants to give something interesting to everyone. That is a very large audience, and I'm convinced that reality is somewhat more selective.

The book starts densely; each sentence has its weight, and speed-reading will not work. While I personally like that, it may lose some of the target audience now and then. I found the beginning of the trip rather bumpy; the first figure is a strange map of the world, and the second one has a confusing caption. The explanation of the date line is simply inadequate. A book on mathematics that still uses imperial units in a metric world is also annoying. Some concepts are introduced without any previous explanation. A few errors are merely funny; the inhabitants of the US state of Nevada will be pleased to learn that they share a border with Colorado, so maybe we do need five colours to paint the map!

However, after the rough road of the first 40 pages or so, the going gets good, and I found the reading most pleasing. A book of this type will inevitably talk about how certain parts of mathematics came to be discovered, and that means lots of history and people. Higgins' book has a number of interesting details that were new to me, including the fact that Abraham Lincoln took Euclid's elements with him on trips, as a source of mental relaxation.

There is a lot on classical plane geometry, mostly involving triangles. It is very pleasing to be able to refresh your school maths with these excellent chapters. There are some very good summaries of the properties of conical sections, though the accompanying drawings should have been made using proper tools; conical sections are too beautiful to be illustrated with the crude approximations the publishers have allowed. This made me cringe more than once!

The chapter on symmetries seems a bit out of place, especially considering that there is no treatment of groups, fractals, or the theorems of Gödel and Turing. A number of quite recent, but still "classical" developments that are familiar to everyone got no mention: Rubik's cube for example, and more on Penrose tilings. Today's computer graphics and printing are almost entirely based on Pierre Bézier's curve, and some entertaining exposition of its remarkable properties would have been a welcome addition to the geometry parts of the book.



However, the mere fact that I have a thirst for more means I have spent several hours of exciting reading.

Robert Cailliau, CERN.

JINR Information and Biographical Guide

For readers of Russian, the Joint Institute for Nuclear Research (JINR) in Dubna has just produced the second issue of its *Information and Biographical Guide*. Including 680 short biographical summaries of the scientists who created JINR and who have worked or are working there, the book profiles specialists in physics, mathematics, chemistry, radiobiology and engineering from more than 20 countries. It is a thorough compilation of JINR history, scientific discoveries, prizes and literature about the Institute and its scientists. Enquiries should be addressed to the editor, M G Shafranova, at shafran@sunse.jinr.ru; fax +7 09621 65767.

Books received

Gauge Theories in Particle Physics Third Edition Volume 1: From Relativistic Quantum Mechanics to QED by I J R Aitchison and A J G Hey, Institute of Physics Publishing, ISBN 0750308648, £29.99 (€48).

For the third edition of this classic graduate textbook, first published in 1982, the authors have substantially enlarged the text to reflect developments both in university curricula and the field of particle physics. New introductory chapters have been added to give a historical account of the properties of quarks and leptons. Volume 2, covering the non-Abelian gauge theories of QCD and electroweak interactions, is scheduled for publication in 2003.

Introduction to Quantum Fields on a Lattice (Cambridge Lecture Notes in Physics) by Jan Smit, Cambridge University Press, ISBN 0521890519, £21.00 (€33).

This book is based on a series of lectures given by the author at an advanced undergraduate/beginning graduate level.

Finite Element and Boundary Element Applications in Quantum Mechanics (Oxford Texts in Applied and Engineering Mathematics) by L Ramadas Ram-Mohan, Oxford University Press. Paperback ISBN 0198525222 £24.95 (€39); hardback ISBN 0198525214 £49.95 (€79).

Mathematical Methods for Physics and Engineering (second edition) by K F Riley, M P Hobson and S J Bence, Cambridge University Press. Paperback ISBN 0521890675 £27.95 (€44); hardback ISBN 0521813727 £75.00 (€119).

Sketches of an Elephant – A Topos Theory Compendium by Peter T Johnstone, Oxford University Press. Volume 1 ISBN 0198534256 £100.00 (€158); volume 2 ISBN 0198515987 £100.00 (€158); both volumes ISBN 01982496X £175.00 (€277).

This comprehensive two volume set on the theory of topos – the abstract construction of algebraic geometry – owes its title to the Indian tale of four blind men asked to describe an elephant. Each of them inspects a different part of the animal by touch, and each comes up with a very different description. The same, says Johnstone, is true of topos – how you describe them depends on how you approach them.

VIEWPOINT

LHC and the Grid: the great challenge

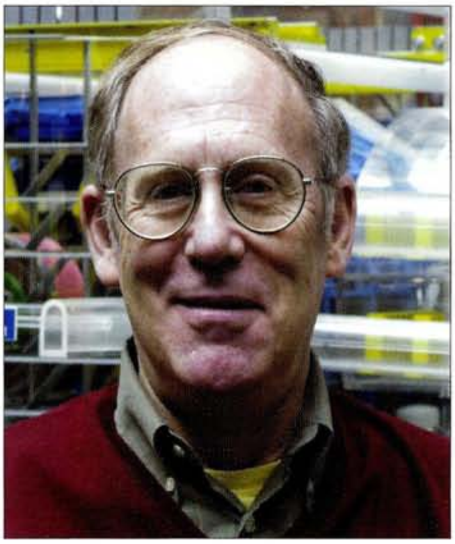
Ultra-high performance distributed computing software is vital for a successful LHC physics programme. This presents a challenge and an opportunity, says **Robert Eisenstein**.

"May you live in interesting times," says the old Chinese proverb, and we surely do. We are at a time in history when many fundamental notions about science are changing rapidly and profoundly. Natural curiosity is blurring the old boundaries between fields: astronomy and physics are now one indivisible whole; the biochemical roots of biology drive the entire field; and for all sciences the computational aspects, for both data collection and simulation, are now indispensable.

Cheap, readily available, powerful computational capacity and other new technologies allow us to make incredibly fine-grained measurements, revealing details never observable before. We can simulate our detectors and basic physical processes at a level of precision that was unimaginable just a few years ago. This has led to an enormous increase in the demand for processor speed, data storage and fast networks, and it is now impossible to find at one location all the computational resources necessary to keep up with the data output and processing demands of a major experiment. With LEP, or at Fermilab, each experiment could still take care of its own computing needs, but that modality is not viable at full LHC design luminosities. This is true not only for high-energy physics, but for many other branches of experimental and theoretical science.

Thus the idea of distributed computing was born. It is not a new concept, and there are quite a few examples already in existence. However, applied to the LHC, it means that the success of any single large experiment now depends on the implementation of a highly sophisticated international computational "Grid", capable of assembling and utilizing the necessary processing tools in a way that is intended to be transparent to the user.

Many issues then naturally arise. How will these various "Grids" share the hardware fabric that they necessarily cohabit? How can efficiencies be achieved that optimize its use? How can we avoid needless recreations of software? How will the Grid provide security



from wilful or accidental harm? How much will it cost to implement an initial Grid? What is a realistic timescale? How will all this be managed, and who is in charge?

It is clear that we have before us a task that requires significant advances in computer science, as well as a level of international co-operation that may be unprecedented in science. Substantial progress is needed over the next 5–7 years, or else there is a strong possibility that the use of full LHC luminosity will not be realized on the timescale foreseen. The event rates would simply be too high to be processed computationally.

Most of these things are known, at least in principle. In fact, there are national Grid efforts throughout Europe, North America and Asia, and there are small but significant "test grids" in high-energy physics already operating. The Global Grid Forum is an important medium for sharing what is known about this new computing modality. At CERN, the LHC Computing Grid Project working groups are hard at work with colleagues throughout the high-energy physics community, a principal task being to facilitate close collaboration between the LHC experiments to define common goals and solutions. The importance of doing this cannot be overstated.

As is often the case with high technology, it is hard to plan in detail because progress is so rapid. And creativity – long both a necessity and a source of pride in high-energy physics – must be preserved. Budgetary aspects and international complexities are also not simple. But these software systems must soon be operational at a level consistent with what the detectors will provide, in exactly in the same way as for other detector components. I believe it is time to depart from past practice and to begin treating software as a "deliverable" in the same way we do those other components. That means bringing to bear the concepts of modern project management: clear project definition and assignments; clear lines of responsibility; careful evaluations of resources needed; resource-loaded schedules with milestones; regular assessment and review; and detailed memoranda to establish who is doing what. Will things change en route? Absolutely. But as Eisenhower once put it: "Plans are useless, but planning is essential."

Several people in the software community are concerned that such efforts might be counter-productive. But good project management incorporates all of the essential intangible factors that make for successful outcomes: respect for the individuals and groups involved; proper sharing of both the resources available and the credit due; a degree of flexibility and tolerance for change; and encouragement of creative solutions.

As has happened often before, high-energy physics is at the "bleeding edge" of an important technological advance – indeed, software is but one among many. One crucial difference today is the high public visibility of the LHC project and the worldwide attention being paid to Grid developments. There may well be no other scientific community capable of pulling this off, but in fact we have no choice. It is a difficult challenge, but also a golden opportunity. We must make the most of it!

Robert A Eisenstein, CERN and US National Science Foundation.

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Quantum 315 **Quantum 210**

	Quantum 315	Quantum 210
Detector Type:	Array (3x3); Active area: 315mm x 315mm	Array (2x2); Active area: 210mm x 210mm
Number of Pixels:	6144x 6144; 37.75million	4096 x 4096; 16.8 million
Pixel Size at Detector Surfaces:	51 x 51 microns	51 x 51 microns
Phospher (optimized):	1 X-ray Angstrom	1 X-ray Angstrom
Spatial Resolution FWHM:	90 microns; 1.76 pixels	90 microns; 1.76 pixels
Taper Ratio:	3.7 to 1	3.7 to 1
Optical Coupling (CCD to Taper):	Direct bond	Direct bond
CCD Type:	Thomson THX 7899 (2Kx2K)	Thomson THX 7899 (2Kx2K)
CCD Pixel Size:	14 x 14 microns	14 x 14 microns
Operating Temperature:	-50 degrees Celcius	-50 degrees Celcius
Cooling Type:	Thermoelectric	Thermoelectric
Dark Current:	0.015 e/pixel/sec	0.015 e/pixel/sec
Controller Electronics:	ADSC Custom	ADSC Custom
Readout Times (Full Resolution): (2x2 binned):	1 second 330 milliseconds	1 second 330 milliseconds
Read Noise (Pixel Rate):	(1 MHz): 18 electrons estimated	(1 MHz): 18 electrons typical
Full Well Depth (Full Resolution):	270,000 electrons typical	270,000 electrons typical

Goniostat Two-Theta

Optional Accessory

Beam Height:
650 mm above base

Omega Axis:
Orientation: horizontal
Maximum slew rate: 600 degrees/minute
Angular accuracy: 0.005 degrees

Two-Theta Axis:
Orientation: horizontal
Maximum slew rate: 100 degrees/minute
Angular accuracy: 0.005 degree
Accessible range: 0 to 45.0 degrees

Shutter Assembly:
Reproducibility: 200 μ sec
Latency: 10 milliseconds.

Sample Viewing System:
High-sensitivity CCD camera with 7:1 zoom

Beam Stop:
Mounted on xyz alignment device
Diameter: 1-3 mm

Motorized Detector Mount:
Maximum slew speed: 300 mm/minute
Position accuracy: 0.1 mm
Minimum distance: 50 mm
Maximum distance: 800 mm

Optional:
Light curtain accessory
Motorized xyz goniometer head
Beam alignment device
Kappa/phi axes
Microkappa
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