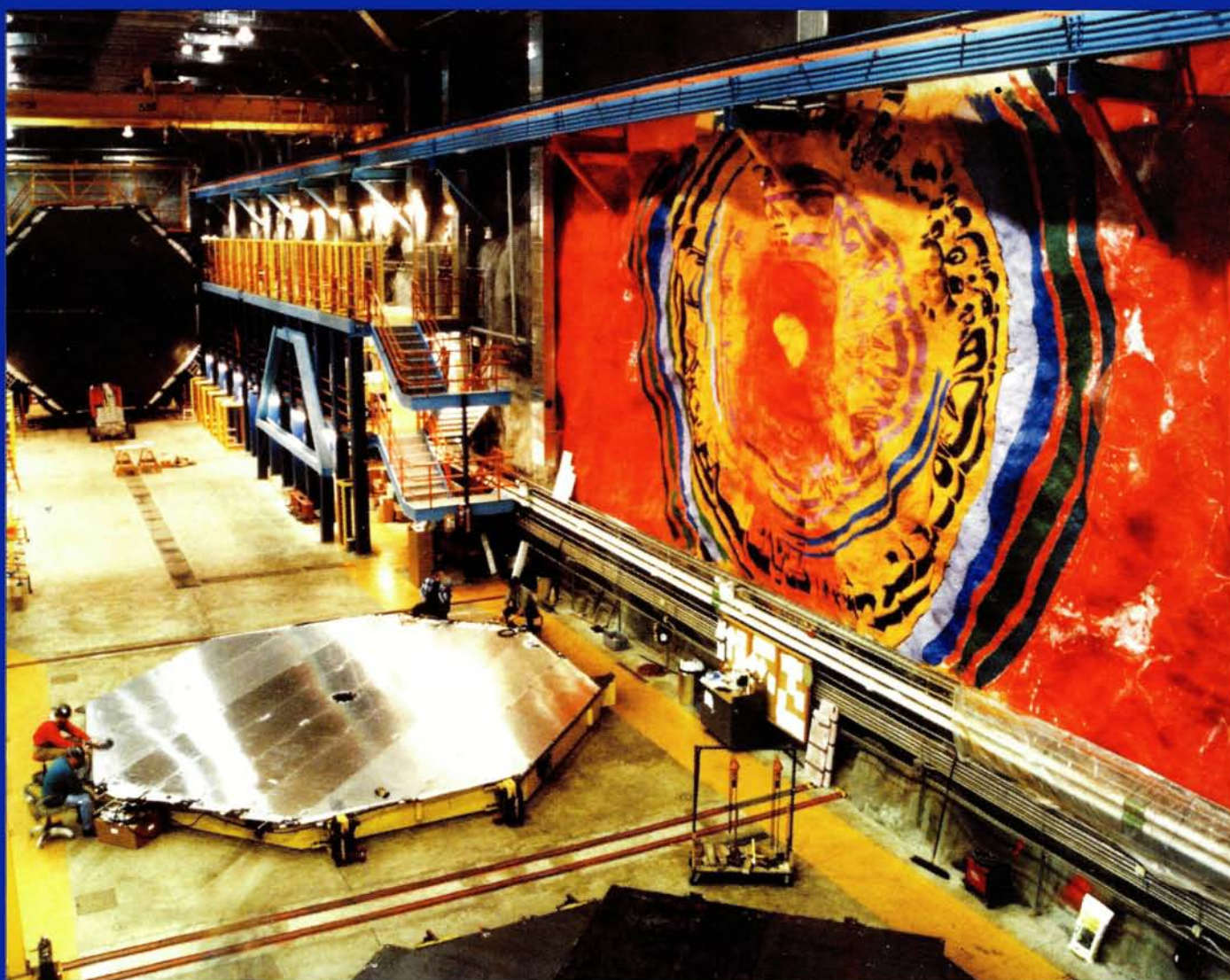


INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 42 NUMBER 3 APRIL 2002



Science meets art in Minnesota mine

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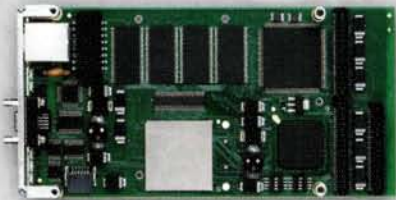
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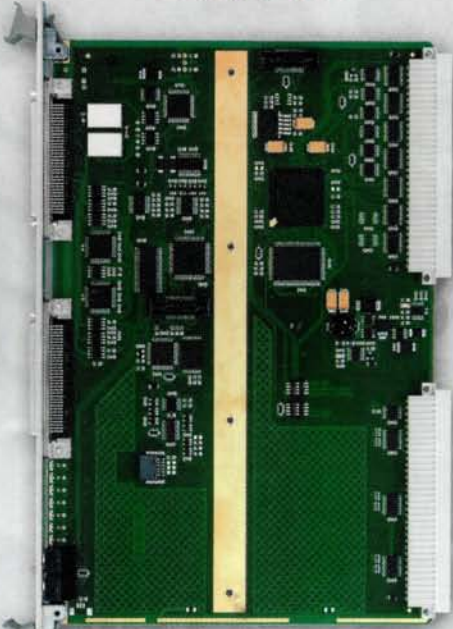
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Editor James Gillies
CERN, 1211 Geneva 23, Switzerland
Email cern.courier@cern.ch
Fax +41 (22) 782 1906
Web <http://www.cerncourier.com>

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Web <http://www.iop.org>

Publishing director Richard Roe

Publisher Jo Nicholas

Art director Andrew Giaquinto

Production Kerry Harding, Laura Churchill

Technical illustrator Alison Tovey

Advertising manager Chris Thomas

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Advertising Chris Thomas, Jayne Purdy,

Debra Willis or David Elsey

Tel. +44 117 930 1031

Email sales@cerncourier.com

Fax +44 117 930 1178

General distribution Jacques Dallemagne, CERN, 1211 Geneva 23,
Switzerland. Email jacques.dallemagne@cern.ch
In certain countries, to request copies or to make address changes,
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Germany Gabriela Heessel or Veronika Werschner, DESY, Notkestr.
85, 22603 Hamburg 52. Email desypr@desy.de

Italy Loredana Rum or Anna Pennacchietti, INFN, Casella Postale
56, 00044 Frascati, Roma

UK Su Lockley, Rutherford Appleton Laboratory, Chilton, Didcot,
Oxfordshire OX11 0QX. Email u.k.lockley@rl.ac.uk

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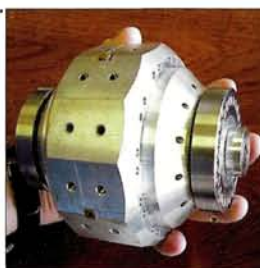
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Peter-Raymond Kettle reports on the new SLS at Switzerland's PSI

DESY workshop combines gravity and particle physics

Dieter Lüst reports on the DESY theory workshop in Hamburg

Space-time symmetry is put to the test

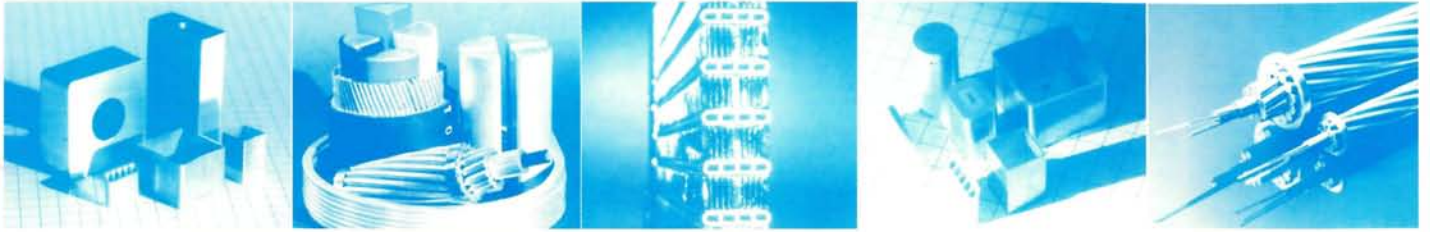
CPT and Lorentz symmetries under the microscope in Indiana

People

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Cover: The Soudan mine in Minnesota is being prepared to host the far detector of the MINOS neutrino oscillation experiment, which will view a neutrino beam sent from Fermilab. About 25% complete, the MINOS far detector shares its experimental hall with a visitors' gallery and a mural depicting artist Joseph Giannetti's impression of neutrino science (p7).



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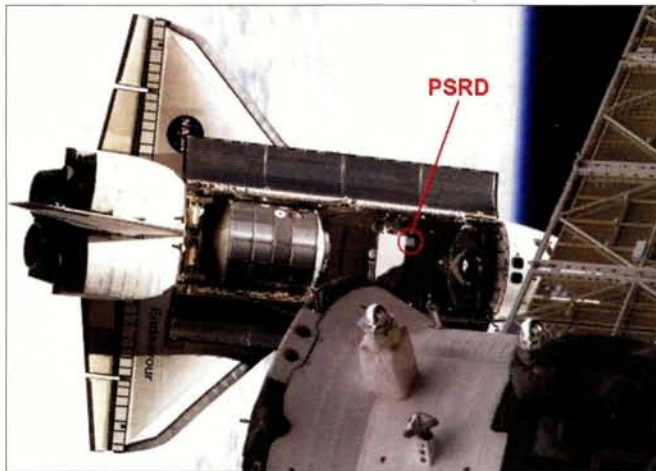
SPACE

Helping the AMS experiment to detect antiparticles in space

Particle physicists involved in the Alpha Magnetic Spectrometer (AMS) experiment are eagerly scanning data recorded during a December 2001 NASA space shuttle mission.

When the space shuttle Endeavour blasted off from Cape Kennedy on 5 December 2001, its main mission was to switch crew and transport supplies to the International Space Station, but it was also the focus of a range of scientific studies. As part of the AMS development programme, the Endeavour carried as a "hitch-hiker" a Prototype Synchrotron Radiation Detector (PSRD). On the shuttle's return to Earth on 17 December, the PSRD was shipped back to ETH Zurich. The data-storage disks were then read out and analysis of the results collected during the 110 h deployment window began.

The product of a major international collaboration masterminded by the 1976 Nobel prize winner Samuel C C Ting, many functions familiar from collider experiments will be incorporated into the AMS detector. It is the first major particle-physics detector to be sent into space; the prototype AMS-01 first flew on a shuttle in June 1998. Findings from last year's flight will have a vital bearing on the final configuration of the full detector, which is being prepared for a mission aboard the International Space Station. The 3 tonne



When the NASA space shuttle Endeavour blasted off from Cape Kennedy on 5 December 2001, its main mission was to transport fresh supplies to the International Space Station. However, it also carried equipment for a range of scientific studies, including the Prototype Synchrotron Radiation Detector.

prototype developed in 1998 was impressive enough, but the final configuration will weigh approximately 6 tonnes.

A fundamental goal of the AMS experiment is to look for antiparticles in the primary cosmic radiation of outer space. Other objectives include searching for otherwise invisible "dark matter" and carefully analysing details of the cosmic-ray spectrum. The detector will therefore be equipped with a powerful superconducting magnet and sophisticated tracking capability.

When high-energy charged particles are bent by a magnetic field, they emit a "screech" of electromagnetic synchrotron radiation. The

characteristic wavelength of this radiation can be used to identify the charged particles.

The Synchrotron Radiation Detector (SRD) will consist of an array of yttrium aluminium perovskite (YAP) crystals. Not available for 1998's prototype mission, the new SRD technology is seen as an integral part of the final AMS configuration, mounted as the outermost layer of the complete detector. The energy-resolving power of the array depends on its size, but it is hoped that ultimately the SRD will be able to detect multi-TeV (10^{12} eV) electrons and positrons.

As well as monitoring the constant flux of cosmic rays in deep space, the AMS detector will be

sensitive to special cosmic events such as the gamma-ray bursts now known to occur almost daily. These cataclysmic events are the largest explosions in the universe other than the Big Bang itself, but their origins are still a mystery. The extreme energies released in the bursts could provide new insights into the creation of matter and open up novel physics possibilities.

An imaginative theory proposed by John Ellis, Dimitri Nanopoulos and colleagues is the possibility that at this energy, the velocity of light could show a dispersion owing to quantum gravity effects. One objective of the SRD programme is to make careful measurements of the velocity of light under these conditions.

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POLARIZATION

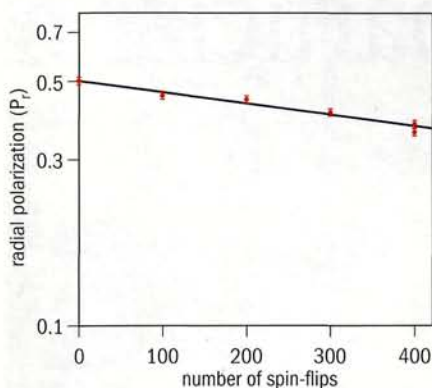
Snake charming induces spin-flip

As the venerable Cooler Ring at the Indiana University Cyclotron Facility in the US enters its final year, a Michigan-led team headed by Alan Krisch has notched up a polarized-beam milestone using the ring's unique accelerator-physics capabilities. The team, which includes physicists from Michigan and Indiana in the US, IHEP-Protvino in Russia and KEK in Japan, has charmed a string of magnets known as a Siberian snake to spin-flip stored protons some 400 times with very little polarization loss.

Siberian snakes were invented at Novosibirsk in the late 1970s. A Siberian snake is a chain of quadrupoles and solenoids that has the ability to overcome any other spin-changing device or random spin-changing effects in any storage ring.

To achieve this latest result, however, the spin-flip team used a small RF-dipole magnet to charm the snake into occasionally surrendering its dominance of all spin motion. This could be done because the RF-dipole used was even more closely matched to the spin motion's frequency than the Siberian snake.

The RF dipole's polarization loss is about 12% in 400 spin-flips, giving a spin-flip efficiency of more than 99.9%. This could allow many spin-flips of polarized proton or electron beams while they are stored for billions of turns, offering the promise of greatly reduced systematic errors in spin-asymmetry experiments. This capability could be important for scattering experiments in storage rings that already have Siberian snakes.



A team of researchers at the Indiana University Cyclotron Facility has achieved a spin-flip efficiency of 99.93% by beguiling a Siberian snake. Protons remained highly polarized after 400 spin-flips.

The same RF-dipole magnet could give a 99.9% spin-flip efficiency to the polarized protons accelerated at Brookhaven's RHIC (p8) and perhaps one day at CERN's LHC, DESY's HERA, or Fermilab's Tevatron. This is possible because an RF-dipole's transverse magnetic field is essentially invariant under the Lorentz transformation from its stationary rest frame to any highly relativistic proton or electron rest frame, in which each spin in the beam seems to receive the magnetic field's instructions.

The RF dipole was built by Michigan's Spin Physics Center in the late 1980s to serve as an injection-kicker to the Cooler Ring. Recycled in 1999, the dipole was connected to a small RF voltage supply, which gave it a

weak transverse RF magnetic field. This allowed some spin-flipping with the Siberian snake in the Cooler Ring, but efficiency was very low and most of the original polarization was lost after a few spin-flips.

The team then tried to improve the spin-flip efficiency by increasing the RF dipole's strength. The first step in this direction was taken by student Boris Blinov, who devised a way to increase the strength of the RF dipole to around 220 gauss cm while increasing its turn-on time from microseconds to milliseconds. This removed the high-frequency transient fields that had previously destroyed the beam and led to a spin-flip efficiency of $99.63 \pm 0.05\%$, measured in May 2001.

Then, in November and December 2001, the group used a much stronger voltage supply to increase the RF dipole's strength to about 560 gauss cm. This adjustment led to a $99.93 \pm 0.02\%$ spin-flip efficiency in a stored beam of 120 MeV protons.

The spin-flip team will spend its final year at the Cooler Ring on other experiments, since 99.93% seems sufficient. Possible projects include trying to spin-flip polarized deuterons and studying third- and fourth-order snake depolarizing resonances. These are hard to find at low-energy storage rings, but may be all too easy to find in proton rings such as Brookhaven's RHIC and DESY's HERA.

Further reading

B B Blinov *et al.* 2002 *Phys. Rev. Lett.* **88** 014801.

CERN

LEP collider comes to the end of the tunnel

A 14 month programme to dismantle CERN's Large Electron-Positron collider (LEP) reached its conclusion in February, when the last LEP half-dipole was removed from the collider tunnel. Some 30 000 tonnes of material have been brought back to the surface, clearing the way for the installation of CERN's next major facility, the Large Hadron Collider (LHC). Many components have been given to other scientific institutes around the world, where they



The last LEP half-dipole begins its journey to the surface on 12 February, marking the end of an era for CERN.

will be put to use in future research programmes. Quadrupoles, for example, were sent to the US, while current generators have gone to South Korea. Other items have been kept for possible future use at CERN and some have been donated to museums.

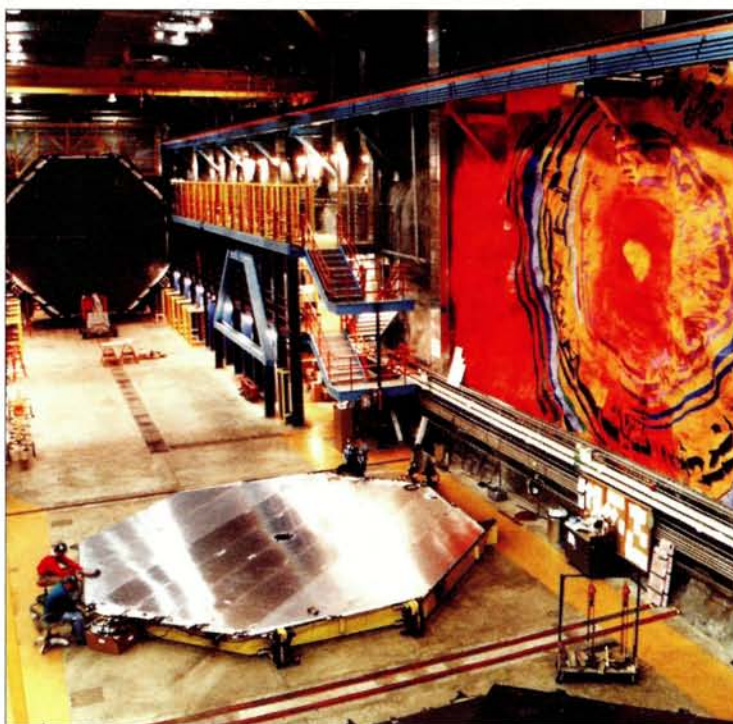
The tunnel will not be empty for long. Surveyors are already working on tracing out the positions of LHC components, and the installation of utilities has begun.

UNDERGROUND PHYSICS

Underground lab open for business

The expansion of the University of Minnesota's Soudan underground laboratory is now complete. Installation of the Main Injector Neutrino Oscillation Search (MINOS) far detector (*CERN Courier* October 1999 p6) began in summer 2001. The Soudan laboratory is located 710 m underground in north-east Minnesota and also houses the Soudan 2 proton-decay detector and the Cold Dark Matter Search experiment (CDMSII), which is searching for weakly interacting massive particle candidates for dark matter.

The new MINOS far detector experimental hall at Soudan includes an upper-level gallery for first-hand observation of physics research by the public. The laboratory is located in a state park, which offers tours of the historic mine workings.



Visitors to the MINOS far detector experimental hall in Minnesota's Soudan mine will be treated to a unique work of art. Currently about 50% complete, Joseph Giannetti's huge mural offers an artist's view of neutrino science. (Jerry Meier, University of Minnesota.)

Regularly scheduled public visits to the underground science facility will begin in summer 2002.

The MINOS far detector (to the rear of the photograph) is now about 25% complete. It is an octagonal magnetized-steel and plastic-scintillator cylinder 8 m in diameter, with a total design mass of 5400 tonnes. The assembly area for the far detector's 484 planes can be seen in the foreground of the image.

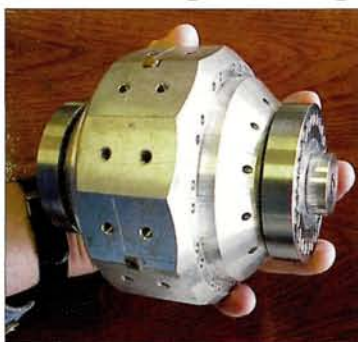
A unique element of the Soudan laboratory is the 18 m long by 9 m high mural that is mounted on the wall opposite the public gallery. The mural depicts the artist Joseph Giannetti's perception of neutrinos and neutrino science. The art work is now about half finished and completion is expected in time for the summer tours.

GRENOBLE

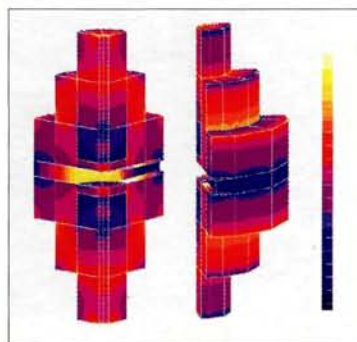
Record-breaking magnet has five-tesla field

A group of laboratories in Grenoble has built a permanent magnet that produces a world-record field of 5 T at room temperature. The magnet has already found an application at the Grenoble-based European Synchrotron Radiation Facility (ESRF).

The Grenoble magnet is the work of doctoral student Frederic Bloch, who built on the ideas of Berkeley's Klaus Halbach, a 1970s pioneer of using permanent magnet "wiguers" and "undulators" to produce synchrotron radiation from electron beams. In 1985, Halbach devised a configuration of permanent magnets



Left: the 5 T magnet sits comfortably in the palm of your hand. Right: in this field map, the yellow area indicates the region of strongest field.



that concentrates magnetic flux on one side of the array and cancels it on the other. His ideas have since been taken up by designers of magnetic levitation transport systems as well

The compact nature of the magnet meant that it could be inserted into an ESRF beamline in which the maximum field available using electromagnets had previously been 2.5 T.

as those with accelerator applications in mind (*CERN Courier* September 2001 p9).

Bloch's device is a 120 mm sphere of rare-earth permanent magnets. Its usable magnetic volume is an air gap with an adjustable diameter up to 6 mm. The magnet's peak field of 5 T was measured with a gap of 0.15 mm. Its first application was in an ESRF experiment making magnetic measurements on thin films.

BROOKHAVEN

Polarized protons collide in RHIC

The Brookhaven National Laboratory's Relativistic Heavy-Ion Collider (RHIC) collided its first polarized protons last November. Since its start-up in 2000, the RHIC research programme has concentrated on the physics of heavy-ion collisions (*CERN Courier* June 2001 p25). Polarized protons open up a new avenue of research into the spin structure of nucleons.

In 1988, CERN's European Muon Collaboration announced that quarks alone could not account for the spin of the nucleon. Since then, experiments at CERN, Hamburg's DESY laboratory and SLAC in California have progressively pinned down this phenomenon (*CERN Courier* November 2001 p25), attributing the missing spin partly to the gluons that bind quarks into nucleons and partly to the intrinsic angular momentum of nucleons. RHIC's polarized proton beams provide an ideal tool for studying the gluon contribution.

For RHIC's first proton run, which finished at the end of January, four Siberian snakes (p6), a spin-flipper and polarimeters were installed



In a spin: the corkscrew design of RHIC's Siberian snake magnets causes the magnetic field to spiral along the direction of the beam. (Brookhaven National Laboratory.)

into RHIC and a new high-intensity polarized proton source was commissioned.

The Siberian snakes were built at Brookhaven and funded by the Japanese Institute of Physical and Chemical Research (RIKEN) as part of the RIKEN-Brookhaven Research Center initiative. This is the first time that Siberian snakes have been used in a high-energy machine. They quickly proved their worth by maintaining beam polarization up to RHIC's full collision energy.

By the end of the run, 25% beam polarization was being maintained at a centre-of-mass collision energy of 200 GeV. Substantial improvements are expected when the Alternating Gradient Synchrotron's Siberian snake is upgraded. The big PHENIX and STAR detectors were also upgraded to make the most of polarized proton collisions. They, along with the smaller PP2PP proton elastic scattering experiment, have reported that useful data were recorded during RHIC's first polarized proton run.

MEETING

Mad about physics in Antananarivo

The Malagasy capital of Antananarivo welcomed HEP-MAD '01, Madagascar's first conference on high-energy physics, at the end of September last year. The conference was organized by the Montpellier branch of France's National Centre for Scientific Research (CNRS) and the town's Malagasy Cultural Association, along with the University of Antananarivo and Madagascar's National Institute of Nuclear Science and Technology.

Topics covered included introductory reviews of astrophysics, the status of electroweak theories, Higgs searches and precision tests of the Standard Model. Results on CP violation from CERN's NA48 experiment were discussed, along with the most recent results from



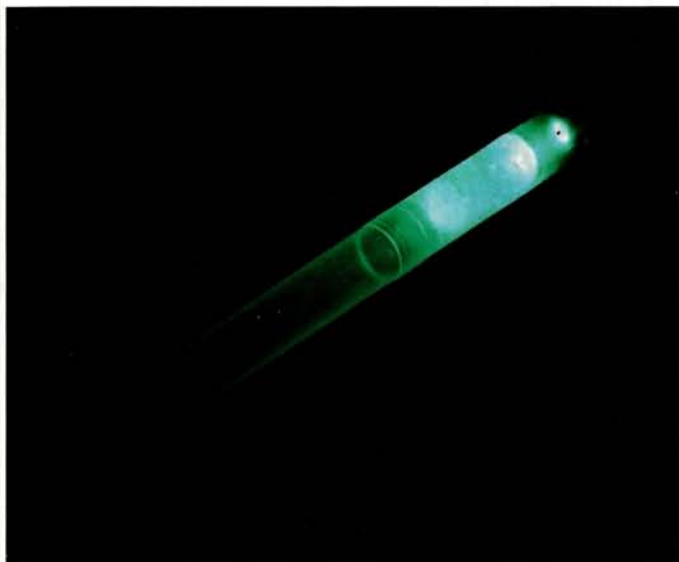
Inaugurating HEP-MAD '01 were (left to right): former Antananarivo University rector Emile Rakotomahanina Ralaisoa, representing the governor of the province of Antananarivo; CERN's John Ellis; conference organizer Stephan Narison, director-general of Madagascar's National Institute of Nuclear Science and Technology; Raelina Andriambololona, Antananarivo University rector; and Madagascar's Minister for Higher Education, Joseph Sydsen.

the BaBar and Belle experiments at the B-factories at SLAC in the US and KEK in Japan. These were followed by theoretical talks on heavy-quark decays and non-perturbative quantum chromodynamics (QCD). There were also discussions of QCD results from CERN's LEP and DESY's HERA colliders. Pre-conference presentations covered applications of the field in the environmental and medical domains.

The aim of the HEP-MAD conference was to stimulate the creation of a high-energy physics institute in Antananarivo, which was successfully achieved. HEP-MAD will now become a biannual event that will next be held in September 2003. The proceedings of the conference will be published by World Scientific.

Edited by Archana Sharma

Magnetism comes out of the blue



Future memory? A plastic light-tunable magnet developed by Ohio State University and the University of Utah is bathed in green laser light. Blue light induces magnetism while green light erases it. (Jo McCulty, Ohio State University.)



Arthur J Epstein (left) and Dusan Pejakovic of Ohio State University's Center for Materials Research demonstrate the use of laser light to tune the strength of their plastic magnet. (Jo McCulty, Ohio State University.)

A light-sensitive plastic magnet that works at record temperatures has been developed by Ohio State University and the University of Utah, offering new opportunities for light-controlled magnetic materials. The new plastic magnet becomes 1.5 times more magnetic when blue light shines on it. Green light partially reverses the effect. Such magnets have potential for new applications in electronic data storage.

A key factor in enabling commercial applications for this technology is that the magnet functions up to a temperature of 75 K. This temperature, which approaches that of today's high-temperature superconductors, represents an important first step towards future light-based forms of electronics.

The plastic magnet is made from a polymer comprised of tetracyanoethylene (TCNE)

combined with manganese (Mn) ions. The researchers deposited the Mn-TCNE powder into a thin film. After they "charged" the material with an initial 6 h dose of blue laser light, the magnet maintained a higher degree of magnetism – 150% of its normal level – even in the dark.

Green laser light reversed the effect somewhat, by decreasing the material's magnetism to 60% of its normal level. Why should light have this effect? The researchers think the different wavelengths of blue and green light cause the TCNE molecules to change shape in different ways. Once one molecule in the magnet locks into a different shape, its magnetism changes, and it encourages its neighbouring molecules to change shape too.

Scientists and engineers worldwide are working to develop computer data storage

based on light and magnetism. Such magneto-optical systems would theoretically work faster and much more efficiently than traditional electronics. A light-tunable magnet would be a critical component, because it would allow computers to write and erase data magnetically. In a future memory device, information could be encoded in the material as regions of stronger or weaker magnetism, which could be written and erased using tightly focused lasers. This could lead to information storage at very high densities. The organic magnet still has a long way to go, however, before it has the properties demanded of commercial devices.

Reference

D A Pejakovic, C Kitamura, J S Miller and A J Epstein 2002 *Phys. Rev. Lett.* **88** 057202.

Spin-logic gates point to smaller low-power electronic devices

Ever-smaller mobile devices demand progressively more highly integrated and lower-power implementations. A research team from Siemens in Germany and the University of Bielefeld has developed magnetic techniques for a new generation of low-power reconfigurable logic that could open the door to increasing miniaturization.

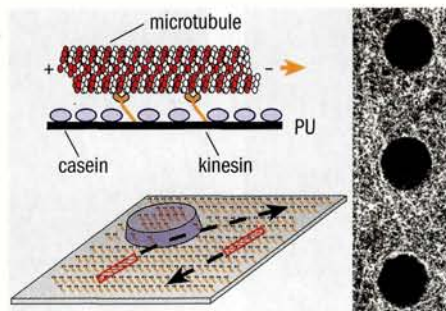
The team used spin-dependent tunnelling structures in which a thin

insulating layer separates two magnetic layers. The degree of quantum tunnelling through the insulator is influenced by the relative orientation of the magnetization in the two layers. These structures have been used to make non-volatile reconfigurable logic elements called spin-logic gates. The non-volatility of the gates allows logic operations to be performed with lower power consumption. *Electronic Engineering Times*

Nanobot explorers map out new terrain

Just like underground explorers finding their way with head torches, gangs of molecular robots can roam the surfaces of materials, avoiding obstacles and jumping crevices. These roaming nanobots are able to chart surface structure. Researchers at the University of Washington in Seattle have used such nanobots by stacking cylinders of the protein tubulin together to form molecular machines called microtubules. These normally act as scaffolding inside cells, providing a route along which materials are transported by proteins called kinesins.

The Washington team has turned this effect on its head, synthesizing self-propelled nanoscale robots by fixing kinesin molecules all over a surface. The microtubules then propel themselves randomly across the surface. A fluorescent dye added to the microtubules acts as their "head torches", permitting the researchers to track their paths



Left: kinesin "motors" adsorbed to a surface drive 24 nm microtubules around, allowing the surface to be mapped. Right: this array of 10 μm diameter posts has been imaged by recording the position of several hundred microtubules every 5 s for 2500 s and superimposing their paths.

as long as the surface being investigated is transparent to the light emitted.

Microtubule nanobots can probe holes,

cavities and pores that cannot be normally seen with a microscope. Their only limitation is steep walls, where they are too rigid for kinesin molecules to guide them. According to the Washington team, custom robots could be designed to study specific aspects of a surface, such as mapping out regions that are hygroscopic. This could help in understanding the structure of porous materials.

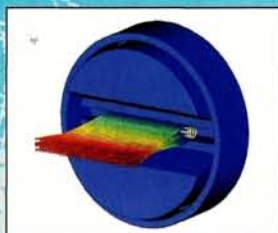
The resolution of the Washington nanobots is expected to be around 50 nm. The number and speed (typically 200–250 nm/s) of the robots determines the time taken to explore an accessible surface completely. Superposition of several hundred images enables mapping of the entire surface.

Reference

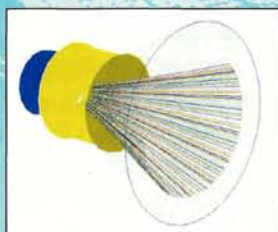
H Hess, J Clemmens, J Howard and V Vogel 2002 "Surface imaging by self-propelled nanoscale probes" *Nano Letters* **2** 113–116.

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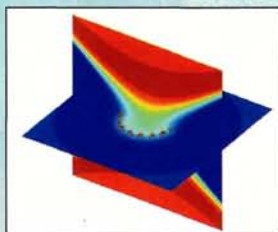
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ASTROWATCH

Guest editor Marc Türler

The end of the universe may be frozen in time

The long-term future of extragalactic astronomy could be dark and dreary, according to new theoretical research. Such a prediction might not have been taken so seriously, had it not originated from Abraham Loeb of the prestigious Harvard-Smithsonian Center for Astrophysics. Professor Loeb's assertion is based on a serious study of the evolution of how we will see the universe in the future.

According to the current cosmological model, some 70% of the universe could be composed of "dark energy" acting as a repulsive force opposing gravitation. If this were true, then rather than slowing down its expansion, the universe would actually be entering a phase of accelerated expansion similar to the inflation that lasted for a split second soon after the Big Bang. Consequently, over the next few billion years, the remotest galaxies would pass beyond our cosmic horizon. They would not suddenly disappear over the horizon, but their image would become frozen while gradually fading away. "This process is analogous to what you see if you watch a light source fall into a black hole," explains Loeb. "As an object crosses the black hole's event horizon, its



A photomontage of the only galaxies still visible in the distant future, seen from the edge of the Milky Way (bottom left). (Harvard-Smithsonian Center for Astrophysics.)

image seems to freeze and fade away because you can't see the light it emits after that point."

In some distant future, this will have ominous consequences for our study of the universe. Not only will the number of observable galaxies decrease, but we will also be

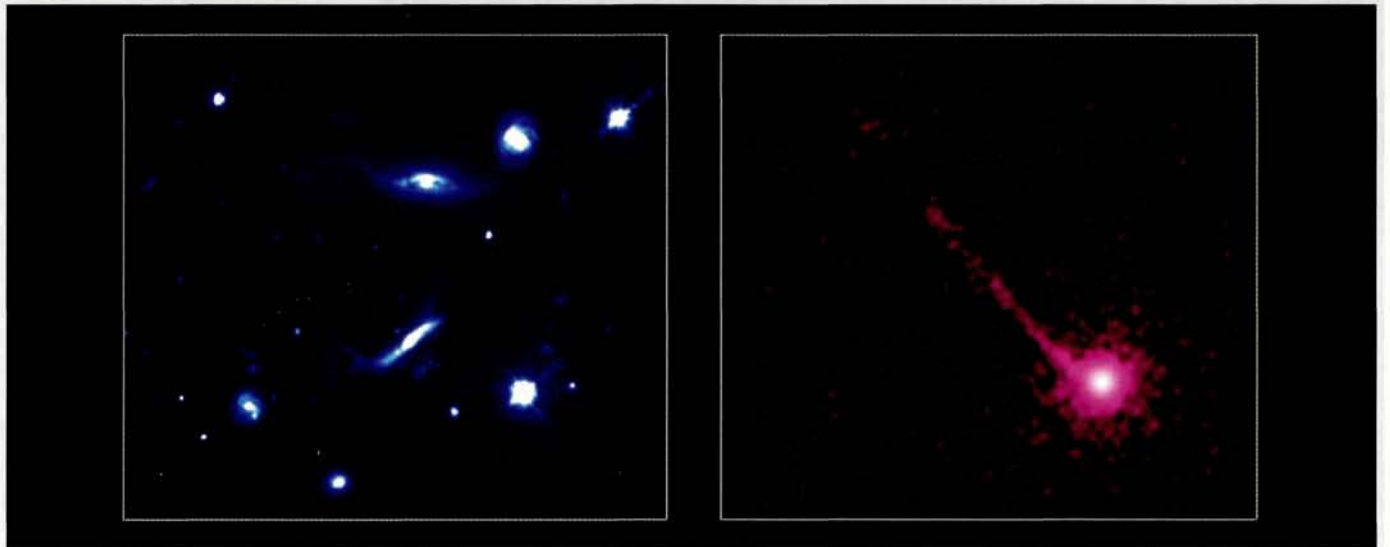
unable to observe their evolution beyond a certain time. Take the example of the most distant quasar observed to date. The light we receive from it left the quasar when the universe was only about a billion years old. If we observe this quasar over the next few billion years, we will see it solidifying and disappearing slowly at an age of only 6 billion years, which is less than half the universe's current estimated age of 14 billion years. So, even by observing distant sources over extremely long time scales, we will always have to rely on indirect arguments to connect the properties of such objects to those of nearby galaxies. Similarly, a light signal sent today from Earth will never be able to reach a galaxy currently observed with a spectral shift higher than $z = 2$.

In less than about 100 billion years, the only galaxies still visible will be those gravitationally linked to the local group of galaxies, including the Virgo cluster and perhaps part of the local supercluster. All other light sources will have frozen in time and faded to invisibility.

Reference

A Loeb 2002 *Phys. Rev. D* **65** 047301.

Picture of the month



An enormous jet of matter expelled from quasar PKS 1127-145 has been observed in the X-ray region by the Chandra satellite (right). This quasar is about 10 000 million light-years distant from the Earth ($z = 1.187$) and its jet extends over a distance of at least 1 million light-years, or about 10 times the diameter of our galaxy. The strong X-ray emission of the jet arises from interactions between relativistic electrons in the jet and photons of the cosmological microwave background. The image on the left, obtained using the Hubble Space Telescope in the visible region, shows the same field of view (40×32 arcsec). Distant galaxies appear, but the quasar is invisible. (X-ray: NASA/CXC/A Siemiginowska (CfA) and J Bechtold (U Arizona). Optical: NASA/HST/CfA/A Siemiginowska et al.)

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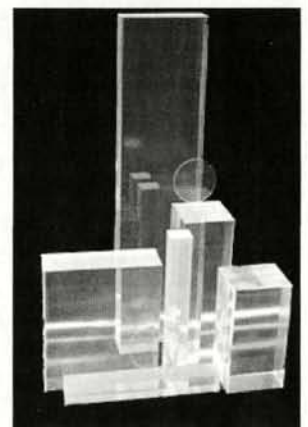
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How US physicists first came to work at CERN

After help from an eminent US figure, CERN was founded in the 1950s to provide a European stage for physics. Once the curtain was up, US physicists found the new laboratory increasingly attractive. In the first of two articles, **Gordon Fraser** traces the history of CERN-US collaboration from the post-war era to the advent of collider physics in the 1970s.

In the late 1940s, Europe was struggling to emerge from the ruins of the Second World War. The US had played a vital role in the conflict, but had been less affected materially, and a shining vision of life across the Atlantic was a beacon of hope for millions of Europeans living in austerity, if not misery.

In a speech at Harvard on 5 June 1947, US Secretary of State George C Marshall said that the US should help to “assist in the return of normal economic health in the world”. North American “Marshall aid” was a major factor in restoring European economic health and dignity.

During the global conflict, many eminent European scientists had been drawn into the Manhattan Project at Los Alamos. Post-war, US science remained pre-eminent. Anxious to stem a “brain drain” of talent, farsighted pioneers saw that Europe needed a comparable scientific focus. This was the seed of an idea for a European centre for atomic research.

UNESCO role

One of the organizations established in the wake of the Second World War to help promote world peace and co-operation was the United Nations Educational, Scientific and Cultural Organization (UNESCO). At the UNESCO General Conference in Florence, Italy, in June 1950, the idea for a European scientific laboratory still lay dormant. Among the US delegation at Florence was Isidor Rabi, who had won a 1944 Nobel prize for his work on the magnetic properties of nuclei. Rabi had played a key wartime role at the MIT Radiation Laboratory, and understood how pressing scientific needs could be transformed into major new projects. After the war Rabi played a



Playing a key role in the post-Second World War groundwork for what would become CERN was US physicist Isidor Rabi (right), who understood how pressing scientific needs could be transformed into major new projects. Also in this 1962 CERN photo are (left to right) Bernard Gregory, Giampetro Puppi and Cecil Powell.

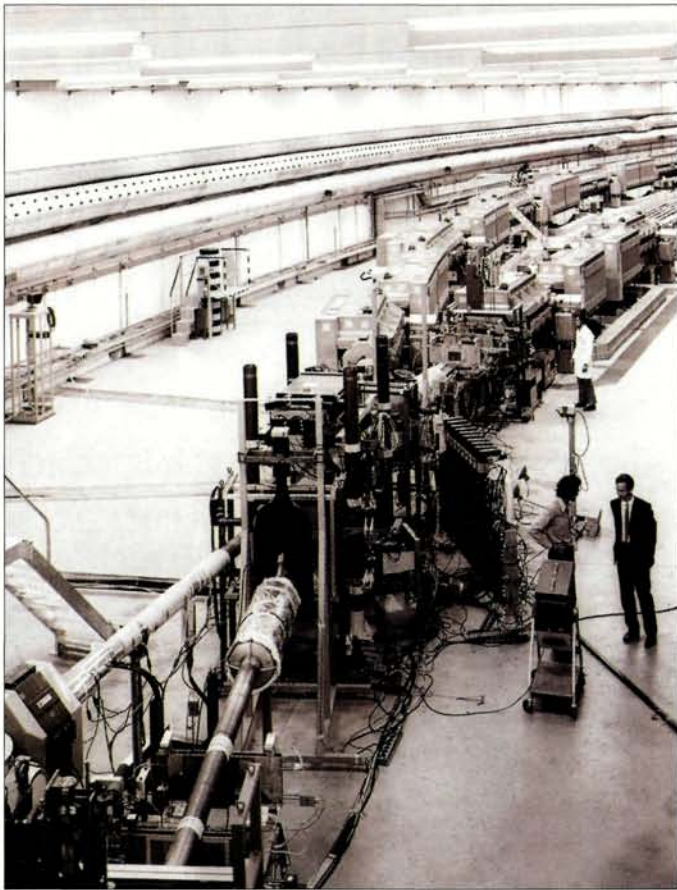
major role in establishing the US Brookhaven National Laboratory.

The establishment of an analogous European laboratory was to Rabi a natural and vital need. However, on arrival in Florence he was disturbed to find that there was no mention of this idea on the agenda. Two Europeans, Pierre Auger (then UNESCO’s director of exact and natural sciences) and Edoardo Amaldi, who was to be a constant driving force, helped Rabi through the intricacies of European committee formalities. So the European seed was fertilized and within a few years CERN was born.

Another major, and very different, US contribution to CERN came two years after the Florence meeting. In

1952 a group of European accelerator specialists – Odd Dahl of Norway, Frank Goward of the UK and Rolf Wideröe of Germany – visited Brookhaven. CERN’s initial goal was to build a scaled-up version of Brookhaven’s new synchrotron – the Cosmotron – and the CERN group were anxious to admire the highest-energy accelerator in the world at that time.

To prepare a welcome for the European visitors, Stanley Livingston at Brookhaven called together his accelerator specialists to see how they could help the Europeans. During one of these meetings Livingston pointed out that all of the machine’s C-shaped focusing magnets faced outwards. Why not make some of them face inwards? Quickly Ernest Courant and the rest of the Brookhaven team saw that arranging the magnets to face alternately inward and outward could increase the focusing power of the synchrotron. The European visitors arrived just as the implications of the “alternating gradient” idea were being appreciated. ▶



CERN's ISR, the world's first proton-proton colliding beam machine, came into operation in 1971. A unique physics machine, it soon attracted US physicists. Early modest experiments, such as that seen here, made valuable initial surveys of this new physics territory. Big detectors came later.

The CERN team took the idea back to Europe and immediately incorporated it into their new synchrotron design. Two members of the Brookhaven team – John and Hildred Blewett – later went to CERN and played a major role in ensuring that the new CERN Proton Synchrotron (PS) delivered its first high-energy protons in November 1959, several months before Brookhaven's Alternating Gradient Synchrotron. This was the start of a long tradition of US-Europe collaboration in development work for major particle beam machines, which continues to this day.

Ernest Courant later made important contributions to CERN's Intersecting Storage Rings (ISR) project, helping to convince accelerator physicists that beams in a proton collider could remain stable for long periods. In the early 1970s, CERN specialists came to Fermilab to help build and commission the big new US synchrotron. A few years later, US machine physicists came to CERN when the comparable Super Proton Synchrotron was getting under way. In the mid-1970s, Burt Richter of SLAC, during a sabbatical sojourn at CERN, helped set the scale for CERN's LEP electron-positron collider, which had to be built as large as possible to minimize the losses caused by synchrotron radiation. The design eventually settled on a circumference of 27 km.

CERN officially came into being in 1954 when its convention

document was ratified by the founding member states. Three years later, its first particle accelerator, a 600 MeV synchrocyclotron (SC), began operations. SC experiments on pion decay soon began to make their mark on the world particle physics scene. Slower to get going at the SC was a major effort to precision measure the magnetic moment of the muon – the famous $g-2$ experiment.

Transatlantic figures

CERN experiments and major international physics conferences at CERN and in Geneva in the late 1950s introduced many US experimentalists to the attractions of Europe for a short visit or a longer sabbatical stay. One of these was Leon Lederman, newly tenured at Columbia, who made many useful contacts during his first stay at CERN and who left resolved to return. The SC $g-2$ experiment involved a lot of physicists by the standards of the day and attracted several other major US figures. Some also collaborated in bubble-chamber studies at CERN to determine particle properties vital for the emerging particle classification schemes based on internal symmetry.

As one of CERN's main aims was to stem the tide of scientific migration westwards across the Atlantic, it was natural for the laboratory to headhunt Europeans who had made the move to the US. So CERN's first director-general was the Swiss physicist Felix Bloch, who had left Europe in 1933 and went on to win a 1952 Nobel prize for measurements of nuclear magnetism. However, Bloch's move to CERN was not a success.

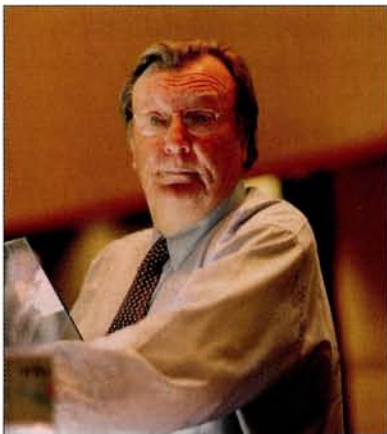
Another contemporary colossus straddling the Atlantic was Victor Weisskopf. Austrian by birth, Weisskopf had made pioneering contributions to quantum mechanics in Europe in the 1930s, and, like Bloch and many others, had fled to the US to escape Nazi persecution, eventually making his way to Rochester. During the Second World War Weisskopf had worked at Los Alamos as deputy to theory division leader Hans Bethe. At Los Alamos, Weisskopf developed a flair for 20th-century "big science".

When CERN was looking for a new director-general in the early 1960s, Weisskopf was a natural candidate, a distinguished European with experience in the management of big physics projects. Despite his protests that he knew little about administration, he was pushed into the job and CERN flourished. During Weisskopf's mandate CERN developed a strong sense of purpose, and ambitious new projects for the future were authorized.

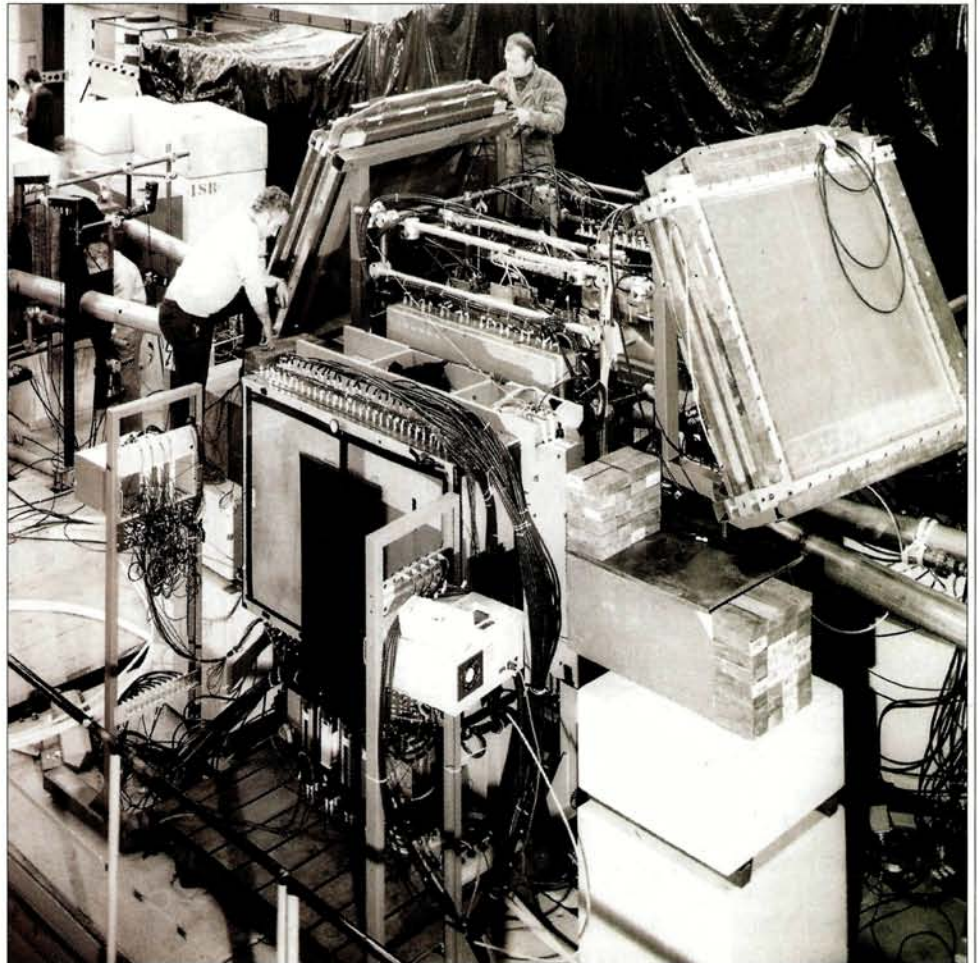
Younger Europeans who had been working in the US also chose CERN as their research base for a return to Europe in the early 1960s. Several were to go on to become very influential. Jack Steinberger emigrated to the US in 1934 and went on to make landmark contributions, mainly with bubble chambers, at the new generation of post-war accelerators at Berkeley, Columbia and Brookhaven. At CERN, Steinberger switched to electronic detectors.

After completing his degree at Pisa, Carlo Rubbia moved to Columbia for a taste of front-line research in weak interaction physics before moving to the SC at CERN. In their subsequent careers, Rubbia and Steinberger were highly visible from either side of the Atlantic. Both these physicists participated in the first studies at CERN of the phenomenon of CP violation, discovered at Brookhaven in 1964.

The Ford Foundation provided generous funding so that scientists from nations that were not signatories to the CERN Convention could



Transatlantic figures: Jack Steinberger (top) and Carlo Rubbia.



A CERN-Columbia-Rockefeller team at the ISR was among the first to see particles emerging at wide angles to the colliding beam direction.

participate in the laboratory's research programme. In this way, more young US researchers were able to visit. One was Sam Ting, who worked at the PS as a Ford Foundation fellow with Giuseppe Cocconi.

ISR testbed

Under Weisskopf, CERN's next major project was the innovative ISR, the world's first proton-proton colliding beam machine, which came into operation in 1971. It was unique. For the first time, Europe had a kind of front-line particle physics machine that the US didn't, attaining a totally new energy range, and many scientists were keen to see what it could do. Among the first to make the eastward pilgrimage to Geneva were Leon Lederman of Columbia and Rod Cool of Rockefeller.

Working at Brookhaven, Lederman had studied the production of muon pairs, initially hunting for the intermediate boson, the carrier of the weak nuclear interaction. This hunt was some 15 years premature, but on the other hand it convinced Lederman, and others, of the value of lepton pairs as a signature of basic interactions.

At the ISR, a Europe-Columbia-Rockefeller collaboration was among the first to see that under ISR conditions some high-energy particles emerged at wide angles to the direction of the colliding beams. This suggested that occasionally something violent happened when the proton beams clashed together. It was a few years

after the historic experiments at SLAC, which had used electrons to probe deep inside the proton and see that it contained hard scattering centres, but the ISR experiments saw the constituents deep inside protons colliding with each other.

Over the lifetime of the ISR (1971-84), US participation in experiments at CERN developed from small bands of intrepid pioneers to major groups. Other active collaborations involved researchers from Brookhaven, Harvard, MIT, Northwestern, Riverside, Stony Brook, Syracuse and UCLA.

A major US contribution at CERN was the 1979 discovery at the ISR of direct single photons from quark processes - the first sighting of electromagnetic radiation from quarks. Playing an important role here was Bob Palmer, a European migrant to the US who retained an attachment to CERN.

Over its first decade of operation the ISR made it clear that "keyhole physics", using just a small sample of the produced particles, was not the only way to go, and colliding beam machines needed big detectors to intercept as many as possible of the emerging particles. With their ISR apprenticeship, US physicists learned this lesson early.

The second half of this history will look at US involvement in modern collider physics at CERN.

Gordon Fraser, CERN.

Superluminal phenomena shed new light on time

Is it possible to travel faster than light? Can we travel back in time, or send signals into the past? These questions have intrigued physicists since the discovery of special relativity nearly a century ago highlighted the fundamental nature of the speed of light and revolutionized our concept of time. **Graham Shore** describes recent research that sheds new light on these old questions.

Quantum effects such as vacuum polarization in gravitational fields appear to permit "superluminal" photon propagation and give a fascinating new perspective on our understanding of time and causality in the microworld. To understand these new developments, we first need to question the origin of the received wisdom that superluminal motion necessarily leads to unacceptable causal paradoxes. In special relativity, the problem arises because while all observers agree about the time ordering of events linked by a subluminal signal, for a superluminal signal different observers disagree on whether the signal was received after or before it was emitted. In other words, viewed in a certain class of inertial frames, a superluminal signal travels backwards in time (figure 1). However, by itself this is not sufficient to establish the familiar causal paradoxes associated with time travel. A genuine causal paradox requires a signal to be sent from the emitter to a point in its own past light-cone –

a time-reversed return path must also be possible. In special relativity, such a return path is guaranteed by the existence of global inertial frames. Crucially, a causal paradox requires both of these conditions to be met.

This is the loophole that may allow the possibility of superluminal propagation in general relativity. Einstein's theory of gravity is based on the weak equivalence principle, which states that at each point in space-time there exists a local inertial frame – in other words a freely falling observer does not feel a gravitational force. This principle leads directly to the description of gravity by a curved space-time that is locally flat. In the conventional theory, however, this is supplemented by a further simplifying assumption, known as

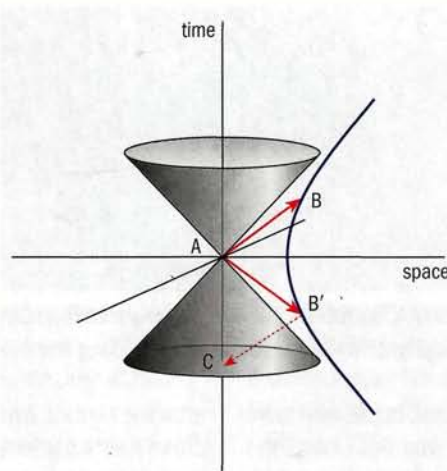


Fig. 1. A superluminal signal $A \rightarrow B$ that is forward in time in one inertial frame may be backward in time $A \rightarrow B'$ in another inertial frame related to the first by a Lorentz transformation. Difficulties with causality only arise if a return signal $B' \rightarrow C$ is possible, where C is in the past light-cone of A .

the strong equivalence principle (SEP), which requires that dynamical laws are the same in each of these local inertial frames.

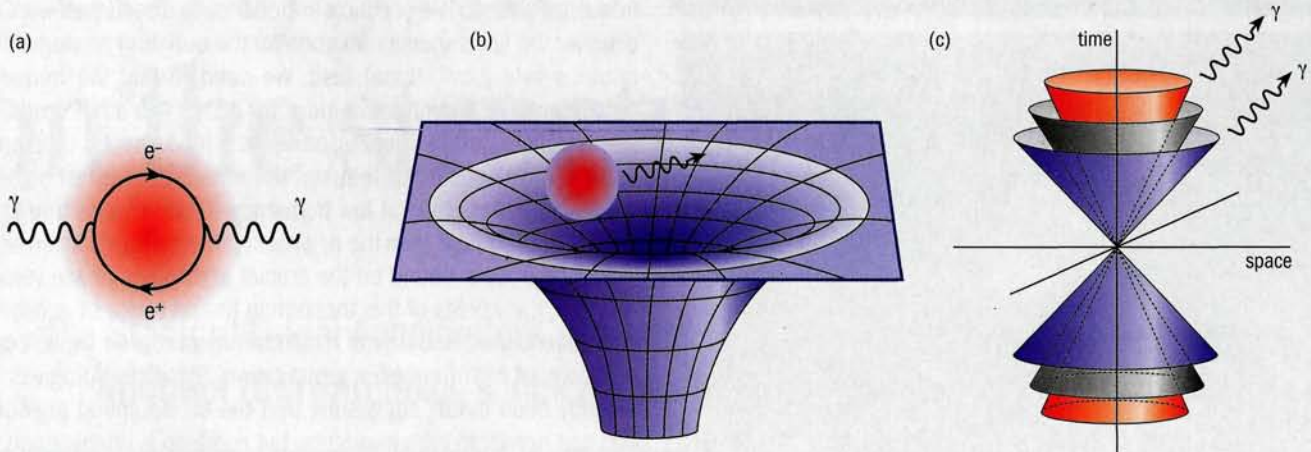
While the SEP may be consistently imposed in classical physics, somewhat surprisingly it is violated in quantum theory (see box 1). In quantum electrodynamics (QED), Feynman diagrams involving a virtual electron-positron pair influence the photon propagator. This gives the photon an effective size of the order of the Compton wavelength of the electron. If the space-time curvature has a comparable scale, then an effective photon-gravity interaction is induced. This depends explicitly on the curvature, in violation of the SEP. The photon velocity is changed and light no longer follows the shortest possible path. Moreover, if the space-time is anisotropic, this change can depend on the photon's polarization as well as direction. This is the quantum phenomenon of "gravitational birefringence".

The effective light-cones for the propagation of photons in gravitational fields no longer coincide with the geometrical light-cones fixed by the local Lorentz invariance of space-time, but depend explicitly on the local curvature.

Superluminal photons

Drummond and Hathrell first described this phenomenon in a seminal paper in 1980. But a further surprise was in store. When they computed the quantum modifications to the light-cones, they found that in many cases the photon velocity was superluminal. Indeed we now know that for propagation in vacuum space-times (solutions of Einstein's field equations in regions with no matter present, such as the neighbourhood of the event horizon of black holes),

Box 1



In QED, Feynman diagrams involving a virtual electron–positron pair effectively give the photon a “size” of the order of the Compton wavelength λ_c of the electron (a). This produces an interaction between the photon and gravity that distorts the photon’s trajectory through curved space–time so that it no longer follows the usual geodesic path (b). This effect changes the light-cones from $k^2 = 0$ to $k^2 = f_1 T_{\mu\nu} k^\mu k^\nu + f_2 C_{\mu\rho\nu\sigma} k^\mu k^\nu \epsilon^\rho \epsilon^\sigma$ where k and ϵ are the photon’s momentum and polarization. There are two distinct effects – one due to the energy momentum $T_{\mu\nu}$ of matter and a second, polarization-dependent, interaction depending on the Weyl curvature $C_{\mu\rho\nu\sigma}$ of the

space–time. The remarkable feature of this formula is that it permits both $k^2 > 0$ and $k^2 < 0$, implying superluminal motion (c).

In the low-frequency limit, f_1 and f_2 are constants of the order of $\alpha\lambda_c^2$, where α is the fine-structure constant. This determines the magnitude of the photon velocity shifts to be of the order of $\alpha\lambda_c^2/L^2$, where L is a typical curvature scale.

In general, f_1 and f_2 are functions depending on derivatives of the curvature. Determining their precise form is the subject of current research aimed at a complete determination of the dispersion relation for photon propagation in gravitational fields.

there is a general theorem showing that if one photon polarization has a conventional subluminal velocity, the other polarization is necessarily superluminal. In fact, gravity affects the photon velocity in two distinct ways: the first through the energy momentum of the gravitating matter; and the second through the component of the curvature of space–time that is not determined locally by matter, the so-called Weyl curvature. It is this that produces birefringence.

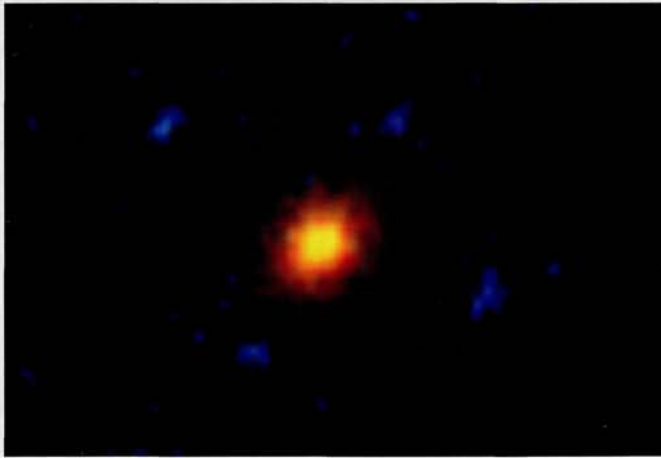
Can superluminal photon propagation really be compatible with the principle of causality, or does it necessarily imply the existence of time machines? After all, such motion is genuinely backwards in time as viewed locally by a class of inertial observers. The question remains controversial, but the key is the SEP. In special relativity, a causal paradox requires both outward and return signals to be backwards in time in a global inertial frame. In general relativity, however, global Lorentz invariance is lost and the existence of a sufficiently superluminal return signal is not guaranteed. The quantum violation of the SEP certainly permits superluminal motion, but with photon velocities predetermined by the local curvature. Consistency with causality is therefore a global question. If the original space–time admits a global causal structure with respect to the geometrical light-cones, then causality will be respected even in the presence of superluminal photons if this structure is preserved with respect to the new light-cones. This rapidly leads to sophisticated issues of global topology in general relativity, but at this stage superluminal photons appear to be both consistent with causality and predicted by QED.

Black holes and cosmology

Since the original Drummond–Hathrell discovery, superluminal photons have been studied in a variety of curved space–times, ranging from the Schwarzschild, Reissner–Nordström or Kerr metrics describing black holes to the Bondi–Sachs space–time describing gravitational radiation from an isolated source and the Friedmann–Robertson–Walker (FRW) space–time of Big Bang cosmology. One of the most fascinating results to emerge involves the status of the event horizon surrounding a black hole. At first sight, it seems that if we can exceed the usual speed of light, it may be possible to escape from within the black hole horizon. If so, the location of the effective horizon would become fuzzy on a microscopic scale, with potentially far-reaching consequences for the quantum theory of black holes. Remarkably, however, it turns out that this possibility is not realized – while the light-cones of physical photons may differ from the geometrical light-cones everywhere else, they coincide exactly on the event horizon. Once again, the superluminal phenomenon evades a potentially paradoxical clash with the causal properties of space–time.

Another fascinating result involves the propagation of photons in the very early universe. Investigations of superluminal photons in the FRW space–time show that photon velocity increases rapidly at early times, independently of polarization. Recent work on the rather different subject of cosmologies in which the fundamental constant c varies over cosmological time has shown that an increase in the speed of light in the early universe can resolve the so-called “horizon problem”, which motivates the popular inflationary ▷

Box 2



The bending of light by a massive object predicted by conventional general relativity gives rise to gravitational lensing, resulting in multiple images as seen here in the Hubble Space Telescope image of a quasar lensed by a foreground elliptical galaxy.

Gravitational birefringence produces a polarization-dependent shift $\Delta\phi = (f_2/R^2)\phi$ in the Einstein formula for the angle of deflection $\phi = 4M/R$ of light with closest approach distance R to a spherically-symmetric mass M . This would be seen if f_2 were characterized by an as yet unknown large scale rather than the quantum scale λ_c derived in Box 1, and would produce a polarization dependence in the apparent position of the lensed images. Observation of this effect would be direct evidence for gravitational birefringence and imply a violation of the strong equivalence principle on astronomical scales. (Photo: Kavan Ratnatunga, Johns Hopkins University.)

model of cosmology. Quantitative predictions of the size of quantum-induced superluminal photon velocities in the strong gravitational fields characterizing the inflationary epoch are currently beyond reach, but it is intriguing to reflect that quantum theory predicts that the physical speed of light increased sharply in the very early evolution of the universe.

Gravitational rainbow

The most recent research into superluminal photon propagation in QED has focused on the key issue of dispersion. In conventional optics, light passing through a refractive medium has a reduced phase velocity that depends on its frequency. This dispersive effect allows the group velocity of a wave pulse to differ from its phase velocity, and to be significantly greater or less than c . This is the origin of several striking recent experiments on the speed of light, notably those of Vestergaard Hau and colleagues at Harvard in which they reduce the group velocity of a light pulse almost to zero by shining tuned lasers on a cloud of ultracold sodium atoms.

For fundamental questions relating to causality, however, the relevant "speed of light" is not the group velocity, but the asymptotic value of the phase velocity at high frequency. The original analysis of

Drummond and Hathrell determined the phase velocity in the low-frequency limit, so it is of critical importance to extend their work and discover the full dispersion relation for the quantum propagation of photons in a gravitational field. We need to find the frequency dependence of the refractive index for gravity – in other words, the gravitational rainbow. There is, however, a fundamental theorem of conventional optics that requires the refractive index at high frequency to be less than at low frequency. If this remains true in the gravitational context, then the original superluminal prediction would in fact be a lower bound on the crucial asymptotic phase velocity. However, the validity of this theorem in the presence of gravity has been questioned and a final resolution must rely on explicit computations of high-frequency propagation. Significant progress has recently been made, suggesting that the superluminal phenomenon can persist to high frequency, but research is ongoing and further surprises cannot be ruled out.

Gravitational lensing

Theoretical evidence for superluminal phenomena is so far confined to the bizarre quantum microworld where virtual particles interact with a foamy, curved space-time. This is the regime where quantum field theory in curved space-time comes into its own and other phenomena arise that challenge our fundamental assumptions about the laws of nature, such as the famous prediction of Hawking radiation from microscopic black holes. But once the cat is out of the bag, it is hard to squeeze it back in. Once we have established that, in principle, superluminal light is possible and the SEP can be violated without compromising causality, it becomes an urgent question to ask whether nature has chosen to take advantage of this scenario on macroscopic, astrophysical scales. If so, how would we observe violations of the SEP in astronomy?

The clearest indication of a modified speed of light would be a change in the classic Einstein formula for the deflection of light by a massive object. This was the original prediction of general relativity that was triumphantly verified by Eddington's 1919 expedition to Brazil, when the deflection of light from a distant star by the Sun was observed during a solar eclipse. This effect is the origin of gravitational lensing (see box 2), which in recent years has been developed into a precise and sophisticated tool in astronomy and is used in searches for dark matter and protogalaxies. Gravitational birefringence on astrophysical scales would show up as polarization dependence in gravitational lensing, with the apparent positions of the lensed images changing with the polarization of the observed light. Polarization dependence in gravitational lensing would therefore be a smoking gun for interactions between light and gravity that violate the SEP, and its discovery would have profound implications for fundamental physics.

Further reading

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Graham Shore, *University of Wales Swansea.*

Forty years of research on the structure of matter

The Stanford Linear Accelerator Center celebrates its 40th anniversary this year.

Michael Riordan takes a look at its achievements and current research.



Left: SLAC director Jonathan Dorfman (top) and Pier Oddone, deputy director of the Lawrence Berkeley National Laboratory, celebrate the completion of the B-factory at SLAC. Dorfman was the B-factory project director; Oddone originated the idea of using an asymmetric electron-positron collider for B-meson experiments. Right: SLAC's klystron gallery is a particle-physics landmark that is easily visible in satellite photographs of the San Francisco Bay area.

Some 50 km south of San Francisco, a long, low structure stretches for 3 km through the rolling, oak-studded hills behind the Stanford University campus to the base of the Santa Cruz mountains. This curious feature is the klystron gallery of the Stanford Linear Accelerator Center (SLAC) – by far the world's largest electron microscope. It is one of the longest buildings on the surface of the Earth.

Ever since this powerful scientific instrument began operating in the mid-1960s, SLAC has been generating intense, high-energy beams of electrons and photons for research on the structure of matter. Physicists using its facilities have received three Nobel prizes for the discovery of the quark and the tau lepton, both recognized today as fundamental building blocks of matter. Led by Wolfgang Panofsky and Burton Richter, its first two directors, the centre has also played a leading role in developing electron-positron storage rings and large “ 4π ” detectors to observe subatomic debris spewing out from high-energy particle collisions.

Since the mid-1970s, other scientists have employed SLAC's ultra-bright X-ray beams to study the structure and behaviour of matter at

atomic and molecular scales in the Stanford Synchrotron Radiation Laboratory (SSRL), now a division of SLAC. Molecular biologists, for example, have used these X-ray beams to determine the detailed structures of important biological molecules such as HIV protease and RNA polymerase. Still others have examined the behaviour of catalysts, semiconductors, superconductors, and the endless variety of advanced materials that are becoming increasingly essential in today's high-tech industries.

SLAC is a national laboratory operated by Stanford University on behalf of the US Department of Energy (DOE), which supports its operations. The National Institutes of Health and the National Science Foundation provide additional funding for specific equipment and experiments. Use of SLAC's facilities is available to qualified researchers from around the world; about 3000 users come to the centre each year from more than 20 countries to perform research in groups ranging in size from a few to several hundred scientists. In addition, SLAC has a staff of about 1400, of whom more than 300 are scientists involved in ongoing research. The results ▷

LABORATORY PROFILE

of all research performed at the laboratory are published openly in scientific and technical journals; no classified research is carried out on the premises.

Three Nobel prizes

The principal focus of research at SLAC is elementary particle physics – the field in which the centre has earned its three Nobel prizes. The first of these went to Richter, who shared the 1976 prize with Sam Ting for the discovery of the famous J/ψ particle (which was eventually found to be made of charm quarks) two years earlier. In 1990, Jerome Friedman, Henry Kendall and Richard Taylor shared the prize for uncovering the quark substructure of protons and neutrons by studying deep-inelastic electron scattering from these targets in the late 1960s and early 1970s. SLAC's third Nobel prize was awarded to Martin Perl in 1995 for his discovery of the tau lepton in the mid-1970s.

Stanford and SLAC physicists have also spearheaded the development of linear electron accelerators since the late 1940s. In the past two decades they have pioneered the development of linear electron-positron colliders. This work began in the early 1980s when SLAC upgraded its linear accelerator and converted it into the Stanford Linear Collider (SLC). Whereas CERN's Large Electron-Positron (LEP) collider achieved higher energies, beam polarization proved to be the SLC's forte, allowing researchers to probe subtle phenomena in the dominant Standard Model of particle physics. During the late 1980s and early 1990s, experiments at the SLC and LEP studying the decays of massive Z particles pinned down the exact number of light neutrino species and measured many key parameters of the Standard Model – especially the weak mixing angle – to high levels of precision. Since the shutdown of LEP in 2000, SLAC has been generating the highest-energy electron and positron beams in the world.

Working with colleagues from other high-energy physics laboratories in Japan, Europe and the US, SLAC physicists have developed accelerator technology for a next-generation instrument called the Next Linear Collider, which will be 30 km long. In January 2002, the US High-Energy Physics Advisory Panel recommended that US physicists play a leading role in an international effort to design and build such a linear collider (*CERN Courier* January/February p5).

Current research programme

Today the SLAC high-energy physics programme pivots around the PEP-II B Factory. This facility was built during the mid-1990s under the leadership of SLAC's current director Jonathan Dorfan as an upgrade of the original PEP storage ring. The electron-positron collider resides in a roughly circular tunnel that courses for 2200 m under one end of the 450 acre site. Inside the sophisticated



At work on a double-crystal monochromator in the Stanford Synchrotron Radiation Laboratory at SLAC.

1200 ton BaBar particle detector, beams of electrons and positrons collide at unequal energies – 9.0 and 3.1 GeV – creating millions of pairs of B mesons per month. An international collaboration – involving about 550 physicists from more than 70 institutions in nine countries – is examining how these particles disintegrate and searching for subtle differences between matter and antimatter. During the summer of 2001, they uncovered conclusive evidence for such an asymmetry, known as CP violation, in certain specific decays of neutral B mesons (*CERN Courier* April 2001 p5; *CERN Courier* Sep-

tember 2001 p7). The BaBar collaboration is continuing to seek further examples of this rare phenomenon, which is widely believed to be responsible for the great preponderance of matter in the universe.

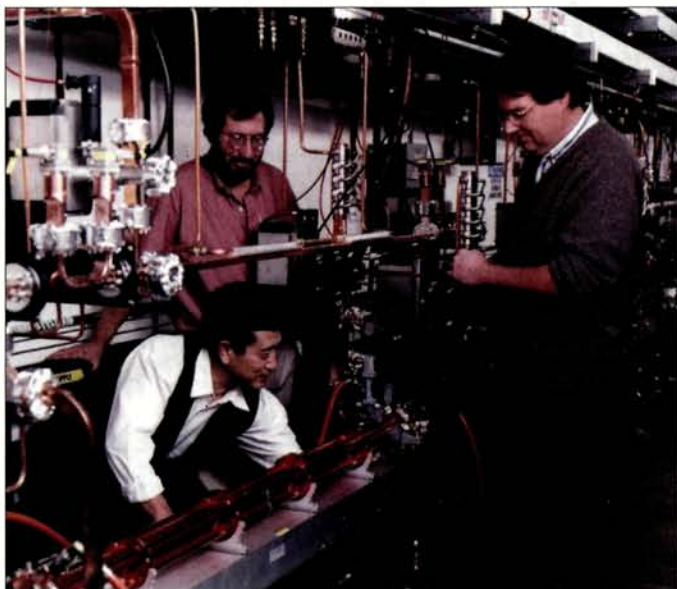
Physics research continues to thrive in SLAC's cavernous End Station A. Since the landmark discovery of quarks there, nuclear and high-energy physicists have used this fixed-target experimental facility to study the substructure of nuclear matter in great detail, most recently with polarized beams of 50 GeV electrons that became available after the construction of the SLC. They are now using these beams to make an exacting measurement of the weak mixing angle by scattering polarized electrons from atomic electrons and measuring the extremely slight asymmetries that are expected to occur. These physicists are also developing high-energy beams of polarized photons to continue their research on the quark-gluon substructure of protons and neutrons.

Looking to the long-term future of high-energy physics research, a group of SLAC physicists and engineers has been working for several years on advanced particle acceleration techniques. In collaboration with university researchers, for example, the group is developing laser-induced plasmas that can boost the energy of an

electron beam substantially over very short distances. This team has worked on "plasma lenses" to focus and accelerate particle beams.

SLAC has also been moving aggressively into the closely related fields of particle astrophysics and cosmology, using insights and techniques from particle physics to study the heavens. (In fact, the leading cosmological theory of inflation was conceived at SLAC in 1980 by Alan Guth, then a

SLAC physicists are currently designing the Gamma-ray Large Area Space Telescope, which will examine sudden outbursts of gamma rays from black holes and other exotic astrophysical sources



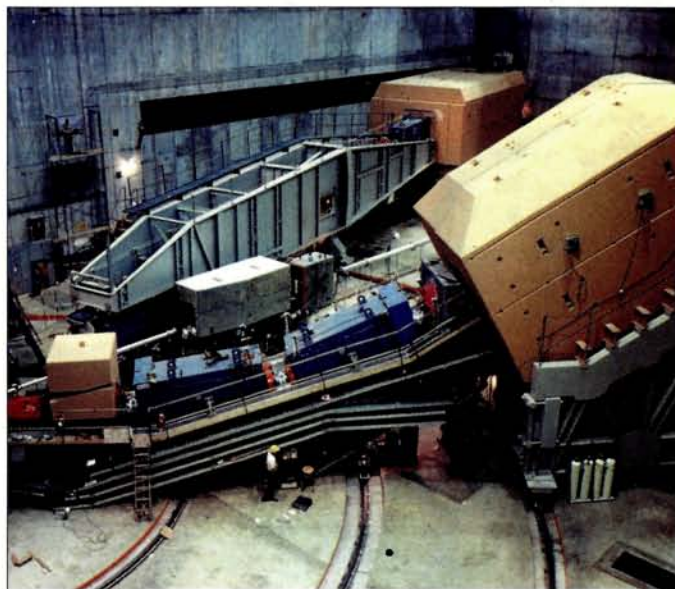
SLAC physicists examine a high-gradient accelerating structure in the laboratory's Next Linear Collider Test Accelerator.

postdoctoral researcher.) Aided by scientists from universities and laboratories in Europe, Japan and the US, SLAC physicists are designing and building the Gamma-ray Large Area Space Telescope (GLAST), a high-resolution detector of energetic (up to about 300 MeV) photons scheduled for launch into Earth orbit in 2005. GLAST will employ sophisticated particle-detection and data-acquisition techniques that were originally developed for ground-based particle-physics experiments. Jointly funded by the DOE, the National Aeronautics and Space Administration and foreign scientific agencies, this satellite will examine sudden outbursts of gamma rays from black holes and other exotic astrophysical sources.

Synchrotron radiation research

Cutting-edge research into the atomic and molecular structure of matter occurs at SSRL. Using the SPEAR storage ring, which was adapted to function as a dedicated synchrotron radiation source, scientists generate intense X-ray beams from a circulating 3 GeV electron beam. Each year, more than 1600 scientists from many different disciplines use this radiation for research in such areas as designing new drugs, developing advanced information technologies (for example flat-panel computer displays and high-density microchips) and remediation of environmental contamination. Since its inception in 1974, SSRL has pioneered this burgeoning field of synchrotron radiation research by developing equipment and experimental techniques commonly used today in nearly 50 such laboratories around the world. A major upgrade of the SPEAR facility that is currently under way will greatly increase the brightness of its X-ray beams and help to keep SSRL competitive with these other facilities.

Today, SLAC and SSRL are poised to begin building a next-generation facility, to be called the Linac Coherent Light Source, that will help to roll back the frontiers of X-ray research. Electrons accelerated in the final third of the linear accelerator will be compressed into tiny bunches that will then be directed through a special magnet array to produce laser-like X-ray beams of unparalleled



These two spectrometers in SLAC's End Station A were used to discover quarks in the late 1960s and early 1970s.

brilliance. This unique instrument should open up new avenues of scientific research on such topics as ultrafast chemical reactions.

SLAC is also the world's leader in developing high-power klystrons, which generate the microwaves used to accelerate electrons. Invented in 1937 at Stanford University, klystrons are also used to power radar arrays and for medical accelerators employed in cancer therapy. For decades, SLAC and the nearby Varian Corporation shared people, designs and ideas in a symbiotic relationship that has steadily advanced klystron technology. Medical accelerators are now a billion-dollar industry; they are used to give cancer treatments to more than 100 000 people every day. In addition, a software program called EGS (for Electron-Gamma Shower), developed by SLAC's Ralph Nelson to simulate showers of subatomic particles, is used by hundreds of hospitals throughout the world to plan radiation dosages for cancer therapy.

Computers and telecommunications are other areas where SLAC research has strongly affected both the US and world economies. In December 1991, Paul Kunz expanded the then-fledgling World Wide Web (invented at CERN by Tim Berners-Lee) to North America, establishing the first US website at SLAC and making its popular SPIRES database easily accessible. The following year, another SLAC physicist developed an influential graphical Web browser to help communicate the reams of data and publications that are produced in the field every year.

Scientific education is ultimately one of SLAC's most important goals. The thousands of students who have come to the laboratory to participate in advanced research have learned from working side by side with some of the best scientists on the planet, helping to push back the frontiers of their disciplines. They return to universities across the country and around the world – or take positions in industry or government – with a much better understanding of what it means to carry out scientific research.

Michael Riordan, SLAC.

QCD comes to the home of Goethe and Schiller

Weimar, a German town with strong European traditions, hosted the 4th European QCD network meeting on 12–15 September 2001.



Tischbein's painting of Goethe in Italy was chosen as the poster for the Weimar QCD network meeting. Goethe's strong European credentials make him a potent symbol for European networking in the modern age. (Städelsches Kunstinstitut, Frankfurt/Main.)

Financed by the European Union, the research network "Quantum Chromodynamics at High Energies and the Deep Structure of Elementary Particles" supports the collaboration of quantum chromodynamics (QCD) theorists from eight European countries interested in fundamental aspects of QCD and its applications in experiments at accelerator laboratories. Following meetings in Durham (the home institute of network spokesperson James Stirling), Florence and Paris, Germany hosted the meeting in 2001.

Around 70 participants from Europe, the US and Russia presented

and discussed recent results on QCD. A large number of presentations by young researchers showed how active the field is. Robert Klanner, research director of Hamburg's DESY laboratory, opened the meeting with an outline of prospects for DESY's upgraded HERA II collider, which started up in 2001. HERA II sees a factor of five increase in luminosity over the original collider. Klanner also reported on preparations for the future TESLA linear collider, which will lead to new challenges in QCD research.

HERA results on deep inelastic electron-proton scattering have

always been a focus of the network's interest. In particular, measurements of proton structure functions in the region of small momentum fraction (Bjorken- x) are crucial for the precise determination of parton densities, which will be necessary for understanding processes to be studied at CERN's forthcoming Large Hadron Collider (LHC). In the small-Bjorken- x region, unravelling the interplay of effects arising from Balitsky, Fadin, Kuraev and Lipatov (BFKL) theory for radiative corrections to parton scattering, and the QCD evolution equations of Dokshitzer, Gribov, Lipatov, Altarelli and Parisi (DGLAP), is a challenge to theorists. As Guido Altarelli pointed out, a resumption of large logarithmic corrections improves the accuracy and can extend the region of validity of the evolution equations.

Further developments

QCD also plays an important role in electron-positron scattering. One example is the search for the perturbative QCD pomeron that emerges from BFKL theory as being responsible for effects observed in small-angle collisions. Electron-positron scattering is the best environment to search for a BFKL pomeron, since photons radiated by the electron and positron provide the cleanest incoming states for hadronic processes. If both photons are highly virtual, perturbative QCD allows an absolute prediction for the total two-photon cross-section. Comparisons of leading-order BFKL calculations with data from CERN's LEP electron-positron collider have been made. These leave no doubt that a consistent next-to-leading-order calculation is needed, both for the BFKL pomeron and for the photon impact factor. Whereas the former has been completed, the latter is still under investigation, and two independent groups reported results.

For hadron colliders, researchers are working hard to develop reliable and efficient event-generator programs. As Bryan Webber of Cambridge University emphasized, the Monte Carlo simulation of multijet final states will be a vital tool in the search for new physics at the LHC. The development of these computer algorithms moves particle physicists back into the front line of modern computing.

Higher-order corrections

Another branch of contemporary QCD-related research is the calculation of higher-order corrections to hard processes. With HERA giving high statistics data on proton structure functions, theorists have started extending the accuracy of analytical QCD calculations up to three loops. These ambitious calculations require new techniques and tools to be designed to allow the calculation of higher-order Feynman diagrams to be computerized as completely as possible.

The most challenging question in QCD is the transition from perturbative QCD to nonperturbative high-energy scattering. In deep-inelastic scattering, HERA has measured the transition from QCD parton physics at large momentum transfer to photoproduction at zero momentum transfer, and theorists are trying to analyse the onset of nonperturbative effects. An intriguing possibility is the existence of a novel state of QCD - saturation - characterized by high gluon density. Phenomenological support for this comes from a model based on this idea that has been very successful in describing HERA data in the transition region. An alternative, more conservative approach starts from the nonperturbative side where the photoproduction cross-section is consistent with the hadronic pomeron, and intro-

duces a second "hard" pomeron to account for the observed stronger rise with energy at large momentum transfer. The investigation of the transition in QCD from perturbative to nonperturbative physics is likely to remain a point of interest for the next few years.

Weimar is a focal point for German and European history and culture; Germany's greatest poet and dramatist, Johann Wolfgang von Goethe lived there for more than 40 years. Friedrich von Schiller also settled there, and collaborated with Goethe to make the Weimar Theatre one of the most prestigious in the country. The composer Franz Liszt and the philosopher Friedrich Nietzsche are also among the town's celebrated residents. Weimar has witnessed more than its fair share of historic events, such as the battle of Jena and Auerstedt and the meeting of Napoleon and Tsar Alexander I in nearby Erfurt. It lent its name to the Weimar Republic from 1919 until 1933, and it gave birth to the world famous Bauhaus style of architecture. It is for this unique combination of reasons that meeting organizers, Jochen Bartels and Johannes Blümlein, chose Weimar for the European QCD network meeting. Following extensive renovations for Goethe's 250th anniversary in 1999, the town offered a pleasant and stimulating atmosphere for scientific discussions.

Further reading:

The QCDNET website is at: <http://www.cpt.dur.ac.uk/qcdnet/>.

Jochen Bartels, Hamburg University, and **Johannes Blümlein**, DESY.

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Swiss Light Source set to

October 2001 saw the inauguration of the Swiss Light Source at the Paul Scherrer Institute. As **Peter-Raymond Kettle** reports, the source gives Switzerland a world-class synchrotron radiation facility.

The Swiss Light Source (SLS) marks a milestone in Swiss science policy, as well as in the development of multidisciplinary and complementary research facilities at the Paul Scherrer Institute (PSI). The combination of the SLS with PSI's existing SINQ spallation neutron source and high-intensity muon beams from its proton cyclotron allows a diversity of probes to be used. It also makes a range of new applications available, from structural research in biology, physics, chemistry and materials sciences to nanotechnology and X-ray lithography.

Growing popularity

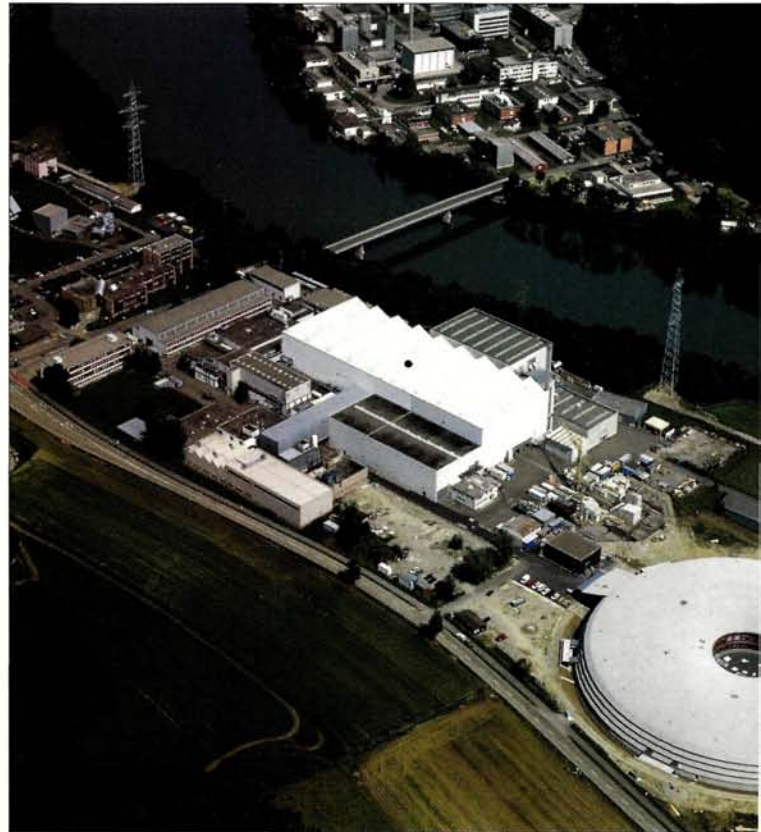
Synchrotron radiation, originally viewed by machine designers and experimentalists as a troublesome by-product of high-energy accelerators, has developed over the years into a powerful, multidisciplinary tool that is now fully exploited in modern synchrotron radiation light sources. The first dedicated source came into operation 35 years ago and there are now about 44 in operation worldwide. The demand for high-quality synchrotron radiation is still increasing, with an estimated 6000 users in Europe alone (*CERN Courier* October 2000 p26).

At present, third-generation light sources fall into two main categories according to machine energy. Both categories are typically based on storage rings optimized for magnetic insertion devices – wigglers and undulators – that enhance the brilliance (a simultaneous measure of the intensity and collimation) of the photon beams.

Facilities with electron energies below 3 GeV are particularly suited to the generation of radiation in the ultraviolet and soft X-ray region. Examples are national facilities such as the US's Advanced Light Source (*CERN Courier* March p28), France's SuperACO, Italy's ELETTRA and MAX-Lab in Sweden. Larger-scale international centres, based on machines with electron energies above 5 GeV, are optimized for the production of hard X-rays. There are now three such facilities in operation: the 6 GeV European Synchrotron Radiation Facility in France, the 7 GeV Advanced Photon Source in the US, and the 8 GeV SPring-8 in Japan.

The Swiss Light Source

The SLS was designed as an advanced third-generation light source capable of exceeding the performance of low-energy national sources and able to overlap with the hard X-ray spectral range of high-energy sources. Its performance is optimized for the production of light with a maximum brilliance in the vacuum ultraviolet to soft X-ray regions.

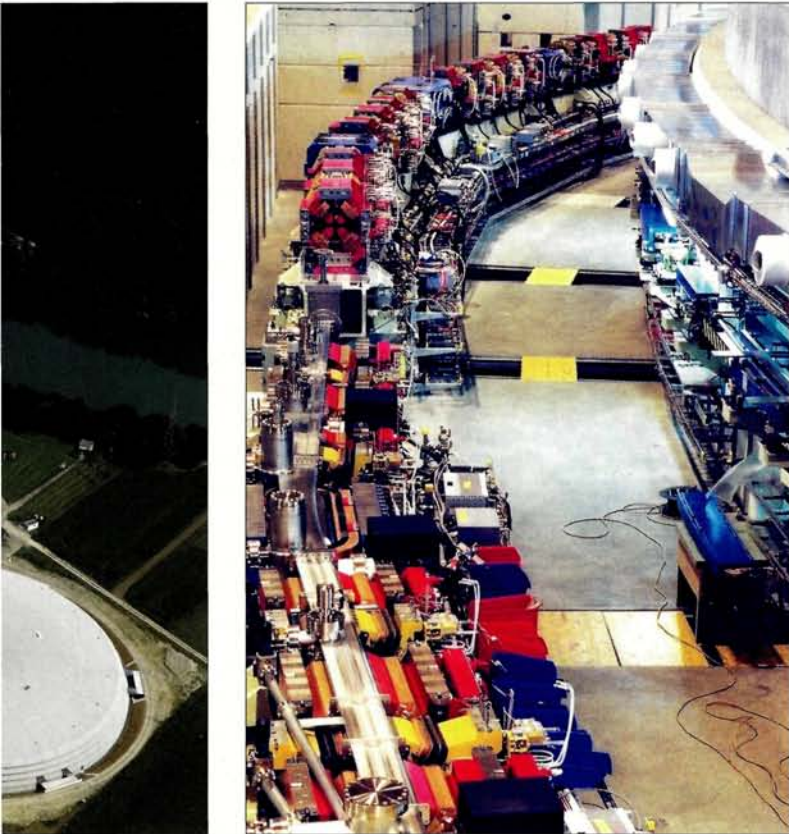


Left: the circular complex of PSI's new SLS is in the foreground. On the right: the neutron source. Right: the SLS storage ring runs outside the smaller-radius

The SLS machine complex has three main components. There is a two-stage acceleration phase comprising a 100 MeV electron linear accelerator followed by a booster synchrotron to accelerate the electrons to their final energy of 2.4 GeV, and the storage ring itself. It takes about 3 min to reach the design current of 400 mA in the 288 m circumference ring. The radius of each ring is similar, allowing them to be in the same shielding tunnel. The storage ring is a polygon with 12 straight sections where wigglers and undulators are installed. Together with the ring's bending magnets, these are the spectral sources of synchrotron radiation produced at the facility.

Wigglers and undulators consist of linear arrays of alternating magnetic poles placed above and below the beam axis. Depending on the strength of the magnetic field and the periodicity of the poles, the electrons either "wiggle" or "undulate" in the horizontal plane, greatly enhancing the emission of synchrotron radiation by multiple transverse acceleration. The higher magnetic fields and larger periodicity of the arrays in the case of wigglers leads to a wider spectral range of photons compared with undulators, where a much narrower cone of radiation is produced at each set of poles. This creates peak intensities at certain energies and high-brilliance beams that are tunable to experimental requirements.

be a world-class facility

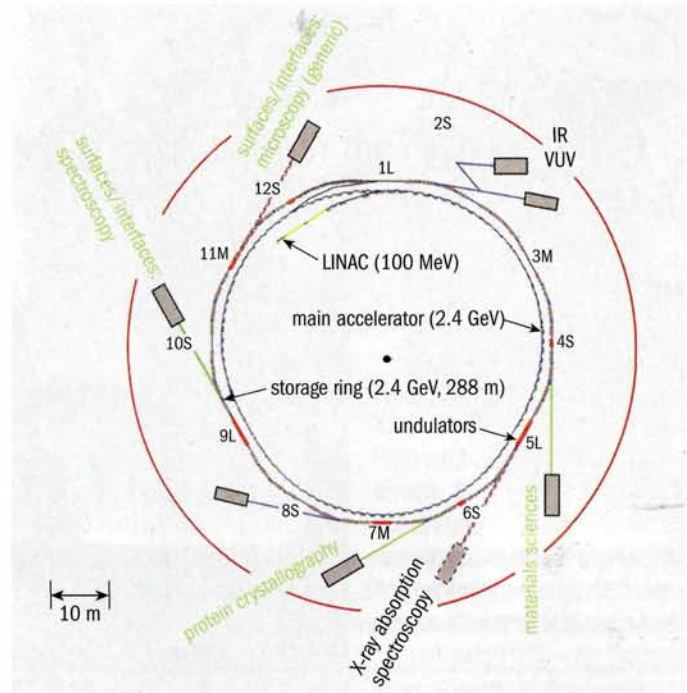


On the side of the river are the 590 MeV proton cyclotron and SINQ spallation neutron source. The booster ring, which follows the inner wall of the shielding tunnel.

Four beamlines are currently available to users at the SLS, spanning the spectral range of 10 eV – 40 keV. For the future, the facility has a projected capability of nine insertion devices and 24 bending magnet sources. Because of the high brilliance of the emitted radiation, several characteristics associated with this attribute, such as high flux density, a high degree of coherence, high energy resolution, good spatial resolution and good timing resolution can be simultaneously optimized in experiments. This opens up the possibility for novel imaging techniques such as holography to be exploited, or for time-dependent investigations of systems at the picosecond scale. The polarization of X-rays from linear to circular is also possible at the SLS, providing an important tool for investigating the magnetic properties of materials, for example, by imaging magnetic domains.

Exemplary commissioning

From initial ideas in 1990 to the start of the SLS project in 1997 was a process that involved around 30 votes and decisions. The project was first presented in 1993 and approved by the Swiss Government in 1996. Its budget of SwFr 159 m (€108 m) received near unanimous approval from both Houses of Parliament the following year, marking the official start of the project. The building and construction



The SLS facility comprises a 100 MeV electron linear accelerator, a 2.4 GeV booster ring and a storage ring with 12 straight sections housing insertion devices for producing synchrotron light. The four current beamlines are labelled in green.

phase, which began in summer 1998, was followed by the start of machine installation just a year later. Commissioning of the machines proceeded rapidly, starting with the LINAC in February 2000 and ending with a Christmas present in the form of the first stored beam in the storage ring on 15 December 2000. By the following June, the design current of 400 mA was reached, and with the measurement of the first sample diffraction pattern in the protein crystallography beamline one month later, an exemplary commissioning phase was complete, bringing the new light source on stream in time and on budget.

The construction of the beamlines and experimental facilities benefited greatly from co-operation with sister synchrotron sources around the world, and by August 2001, 70% of available beamtime could be given over to a few selected users. A test phase running to the end of 2001 ensued before the facilities were made available to the full SLS user community of around 80 groups.

The SLS was officially inaugurated on 19 October 2001 at an event celebrated by more than 200 prominent guests from the worlds of politics, science and industry. It was headed by Ruth Dreifuss, Swiss federal minister for internal affairs. Among the scientific guests at the inauguration were Nobel Laureates Heinrich Rohrer and K Alexander Müller, who had been involved in the assessment process of the project. ▶



Swiss federal minister for internal affairs, Ruth Dreifuss (right), and PSI director Meinrad K Eberle shake hands at the inauguration of the Swiss Light Source.

Festivities began with an official welcome by PSI director Meinrad K Eberle and were followed by speeches from minister Dreifuss, Stephan Bieri, vice-president of council of the Swiss Federal Institutes of Technology, and Heinrich Rohrer. All stressed the importance of the SLS in the context of international scientific co-operation. Director Eberle reviewed the project's history from conception to realization, while the technical aspects and the research prospects were covered in talks from project leader Albin Wrulich and research leader Frisco van der Veen.

The highlight of the inauguration festivities was a tour of the complex, the inside of the space-age building being bathed in a spectral extravaganza of light and sound. The inauguration was performed by Dreifuss and Eberle, who operated the power key to start up a symbolic "light source" that slowly appeared above the shielding wall, in the form of three chandeliers, and came to rest over a well decked buffet.

The whole event was, to the amusement of the guests, accompanied by film clips of historic scenes from previous ceremonies that were not executed quite so smoothly, while the musical ambience was provided by a modern jazz quartet. The festivities were rounded off with a series of congratulations from representatives of local government and sister laboratories, including Eberhard Jaeschke, technical director of the BESSY laboratory in Berlin, and Massimo Altarelli, scientific director of ELETTRA.

Peter-Raymond Kettle, Paul Scherrer Institute.

The Future of X-Ray Imaging is here

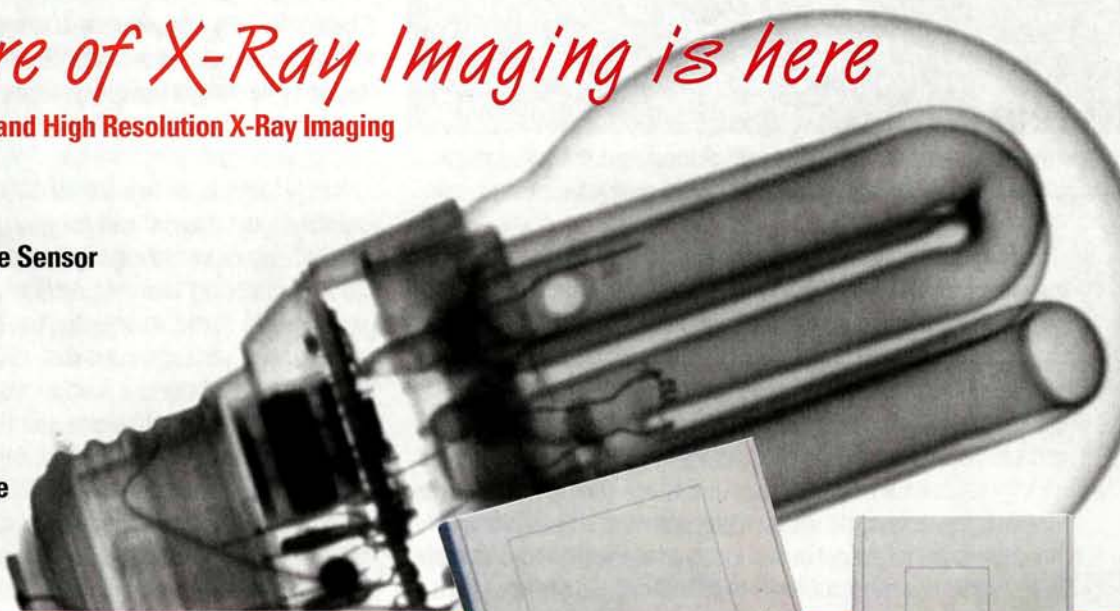
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DESY workshop combines gravity and particle physics

Gravity and particle physics took centre stage at last year's DESY theory workshop. As chairman of the organizing committee **Dieter Lüst** reports, there was plenty to talk about.

The relationship between astrophysics, cosmology and elementary particle physics is fruitful and has been constantly evolving for many years. Important puzzles in cosmology can find their natural explanation in microscopic particle physics, and a discovery in astrophysics can sometimes give new insights into the structure of fundamental interactions. The inflationary universe scenario offers a good example. Inflation is a beautiful way to understand the cosmological flatness and horizon problems (see box over-



Wilfried Buchmüller of DESY (left) in discussion with Hans-Peter Nilles of Bonn University at the DESY theory workshop.

leaf) and apparently induces large-scale density fluctuations consistent with experimental observations. Inflation also predicts the existence of dark matter elementary particles together with a certain amount of dark energy manifested as the cosmological constant Λ . This has recently become clear through fascinating new experimental results. However, some of the pieces essential for building a theory that combines the physics of the macrocosmos with all microscopic phenomena in a complete and satisfactory way are still missing.

Quantum gravity

On the theoretical and conceptual level, the quest for a theory of quantum gravity is the most prominent and important problem facing theoretical physics. Quantizing gravity will be necessary to describe the physics at regions of very large space-time curvature – near or inside black holes, for example, or at extremely short time scales after the Big Bang. Any new theory that goes beyond the established Standard Model of particle physics and of cosmology must explain known facts in a broader and more unified perspective. At the same time it should not introduce more – and perhaps hidden – assumptions than there are facts in need of explanation. Finally, it must pass experimental tests and be verifiable (or falsifiable), at least in principle. Superstrings offer, perhaps for the first time, a promising avenue for constructing a viable theory of quantum gravity, since they contain gravity with a spin 2 graviton field as well as all

the basic ingredients of the Standard Model.

The choice of topics – gravity and particle physics – for the 2001 DESY workshop (held in Hamburg) was largely influenced by impressive recent astrophysical observations showing that the overall mass and energy density of today's universe is extremely close to its critical value ($\Omega = 1$). Another main theme of the workshop was string theories, particularly the recently developed M-theory (often dubbed “the mother of all theories”) that underlies string

theories. In string and M-theory, multidimensional surfaces, rather than just strings, are also allowed. These higher-dimensional membranes (or branes) and one particular type, Dirichlet, or D-branes, subject to a particular set of boundary conditions, have proved important in understanding black holes in string theory.

At DESY theory workshops, introductory lectures covering the main topics of the workshop are traditionally given on the first day. On this occasion, Costas Bachas of the Ecole Normale Supérieure in Paris presented string theory, string dualities, D-branes and M-theory. Slava Mukhanov of the Ludwig-Maximilians University in Munich discussed inflation. Stefan Theisen of the Max-Planck Institute (MPI) in Potsdam covered the holographic principle, which asserts that information contained in some region of space can be represented as a “hologram” – a theory that lives on the boundary of that region. Finally, Orsay's Pierre Binétruy discussed the cosmological constant.

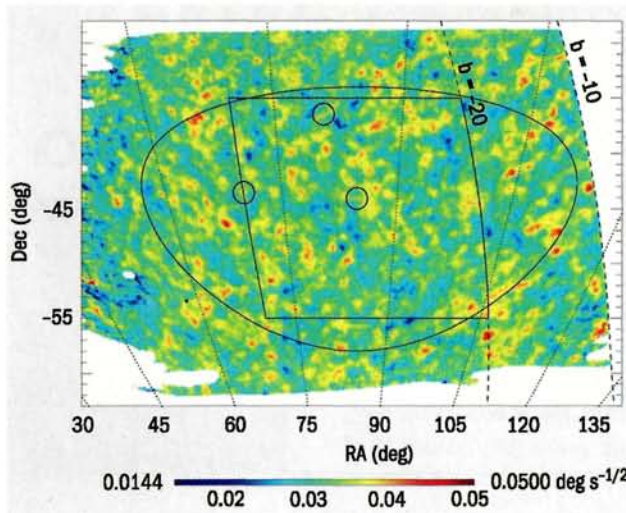
Cosmic inflation

Cosmic inflation in the early universe is one of the most appealing hypotheses in cosmology. Inflation stretches space to be flat, and leads naturally to the density of the universe, Ω , having its critical value of 1. It explains the large-scale smoothness of the cosmic microwave background (CMB) and inflates quantum fluctuations from microscopic scales to the cosmological scale, thereby creating density fluctuations. In the first talk of the workshop, Paolo ▷

de Bernardis of the University of Rome, La Sapienza, showed an impressive array of new experimental CMB data from the balloon experiment BOOMERanG. These are in complete agreement with the predictions of inflation. BOOMERanG and COBE show that the universe is indeed spatially flat. Moreover, the matter-energy density, Ω_M , is clearly dominated by a large dark matter component. Most excitingly, Ω_M is not enough to flatten the universe, but there is now convincing evidence for a non-vanishing contribution Ω_Λ from dark energy, arising from a cosmological constant Λ .

One of the most burning problems is explaining the microscopic origin of the cosmological constant Λ , while at the same time understanding why Λ is so small compared with the natural scale of gravity. In this context it is very important to determine whether Λ is a static quantity, totally unchanged through time, or whether it is dynamic. Quintessence – a “fifth force” that changes with time – offers a concrete realization of this idea. It was introduced by Slava Mukhanov and by Heidelberg’s Christof Wetterich, who discussed how the cosmic coincidence problem (why the cosmological constant only recently started to dominate the expansion of the universe) can be explained by some kind of attractor mechanism.

Agreement between the theoretical idea of inflation and experiment is convincing. However, model building is still difficult and seems to require several assumptions and fine-tuning of parameters. This leads to the question of whether there are serious competitors for inflation, for example, in M-theory. This would be desirable since some basic arguments state that de Sitter space-times, which describe an exponentially growing universe, are difficult to implement in supergravity and superstring theories. As Fernando Quevedo of Cambridge discussed, there is a nice way to build inflationary models into brane-world models in string theory in such a way as to trigger the graceful exit from inflation. This leads to a hybrid inflationary scenario being realized in brane-world models. A more radical approach to explaining the flatness and horizon problems – one that really competes with inflation – was introduced by



The latest results from the BOOMERanG experiment are improving our knowledge of the cosmic microwave background. (BOOMERanG collaboration.)

Burt Ovrut from the University of Pennsylvania. Taking its name from a Greek word meaning conflagration, the ekpyrotic universe theory explains the rapid expansion of the early universe as arising from the collision of branes. Through such a collision, a huge amount of energy is almost uniformly and homogeneously deposited on our universe. Despite offering a fascinating and challenging alternative to standard inflation, many aspects of the ekpyrotic universe need further investigation.

Challenging branes and strings

A particularly compelling picture of a 10-dimensional universe has been developed over recent years.

In this picture, observable gauge interactions are confined to a possibly three-dimensional domain wall, whereas the gravitational force is mediated over the entire 10-dimensional space-time. This scenario would account for the vast difference between the observed strength of the gravitational interaction and nature’s other fundamental interactions. It also offers the exciting possibility that the extra dimensions can be much larger than previously assumed – up to almost 1 mm. If the extra dimensions are compact, their sizes are constrained by high-precision experiments that measure deviations from Newtonian gravity below 1 mm, as Joshua Long of Colorado University pointed out. Depending on the coupling strength of gravity inside the extra dimensions, the present experimental upper bounds for their size vary between 1 mm and several microns. New techniques are expected to push these bounds below 1 μm . In addition, Bonn’s Hans-Peter Nilles and Valery Rubakov of Moscow’s Institute of Nuclear Research discussed more theoretical issues and exotic effects arising from extra dimensions.

One challenge in string theory is to construct brane-world models that come as close as possible to the Standard Model of elementary particles. Ralph Blumenhagen of Berlin’s Humboldt University suggested that intersecting brane worlds is a promising approach. Stable intersecting brane-world models reproducing the Standard Model can be constructed, but issues such as the correct pattern of Yukawa couplings and gauge coupling unification still need to be addressed.

Big Bang problems

Despite its success, there are three problems with the Big Bang model which were hotly debated at the DESY theory workshop.

- **The horizon problem** Remote regions of the universe that have been out of contact – or beyond each others’ horizon – are nevertheless similar.
- **The flatness problem** The universe appears to be largely “flat” – the mass-energy density Ω is close to its critical value of 1, which

would steer the universe to a fate between a big chill and a big crunch. Big Bang cosmology predicts that any deviation from flatness in the early universe should have increased as the universe expanded, which is difficult to reconcile with observation today.

- **The monopole problem** Big Bang cosmology predicts that magnetic monopoles should be commonplace, yet so far not a single one has been seen.

D-branes have provided many important theoretical insights into the nature of gravity and gauge theory. One of the most prominent consequences of D-brane physics is that a string theory in a so-called anti-de Sitter space-time (one with constantly negative curvature) is equivalent to conformal field theories – in other words there is a deep connection between string theory and quantum field theory. This so-called AdS/CFT duality is one of the most prominent and basic consequences of D-brane physics. Further presentations on D-branes and supergravity were given by Jan Plefka of the MPI in Potsdam, Klaus Behrndt of Humboldt University, Matthias Gaberdiel and Dan Waldram of the University of London, and Thomas Mohaupt from Jena. Another important aspect of D-branes is the field of non-commutative geometry, since under general boundary conditions the world volume co-ordinates of D-branes become non-commutative. Non-commutative field theories have therefore recently received much attention, and were discussed by Luis Alvarez-Gaumé of CERN and Volker Schomerus from the MPI in Potsdam.

String theories have made great advances of late, but there remain many unsolved problems, as Hermann Nicolai of the MPI in Potsdam pointed out in his workshop summary. At a fundamental level, is there really a unified description of all string theories in terms of M-theory? It is still not clear what M-theory really is. Is it 11-dimensional supergravity together with membranes and five-branes? Or is it given by matrix theory? Or are the fundamental

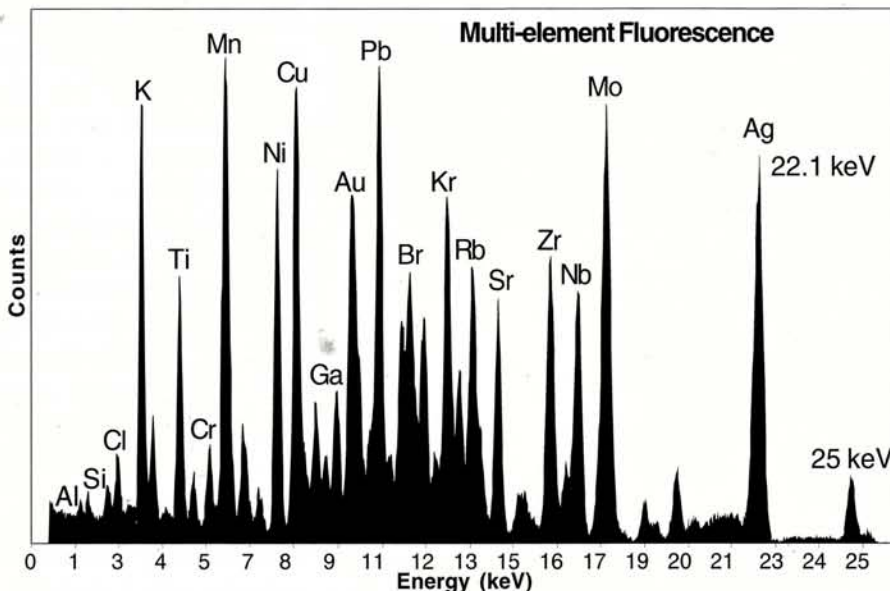
degrees of freedom of M-theory related to the supermembrane? The workshop could not provide the answers. Furthermore, there remains the fundamental question of how a small but positive cosmological constant Λ can be consistently built into superstring theory or supergravity theories. Data from future facilities will be essential in advancing our understanding of these issues.

The theoretical physics community looks forward to seeing these data, and several talks alluded to what we may expect. In astrophysics and cosmology, the study of supermassive black holes in galactic centres poses many questions on how the first black holes were formed, what masses they have, and what their final destiny is. Ralf Bender of Munich discussed these issues. Cosmology with gravitational waves could open up a new avenue for deepening our understanding of the early universe. Bernard Schutz of the MPI in Potsdam presented the status of the four ground-based interferometric gravitational wave detectors: GEO600 (Germany), VIRGO (Italy), LIGO (US) and TAMA300 (Japan). More ambitious is the LISA project, due to be launched in 2011, in which three spacecraft in orbit around the Sun will form the interferometer. LISA may even provide new information on string cosmology and brane-world scenarios. Albrecht Wagner, head of the DESY directorate, discussed future colliders, such as the LHC and TESLA, whose input is urgently needed for further theoretical progress in particle physics.

Dieter Lüst, Humboldt University, Berlin.

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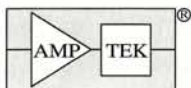
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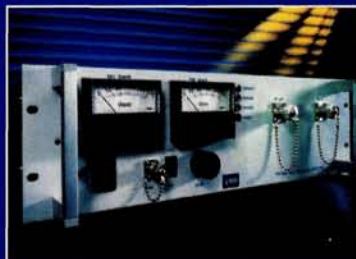
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Space–time symmetry is put to the test

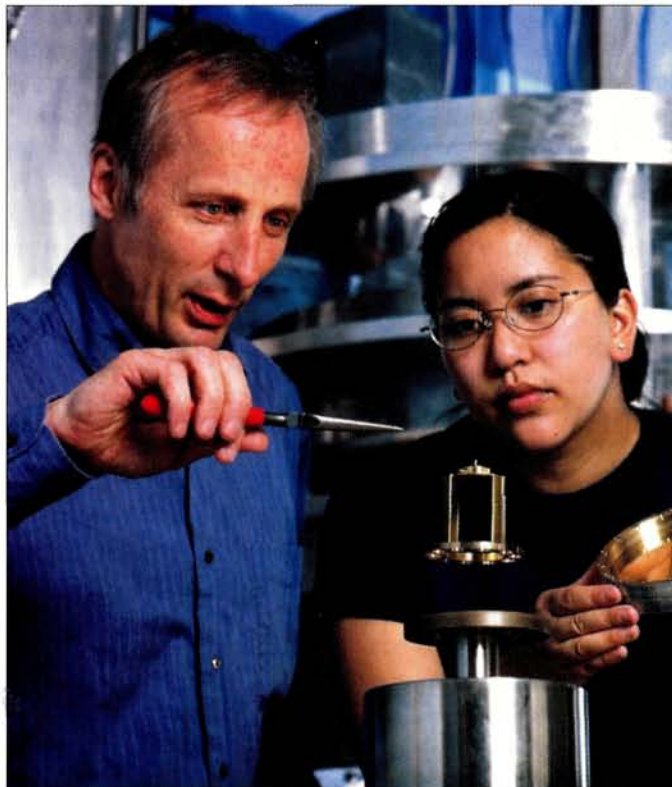
Symmetries underpin much of modern physics and, as a consequence, are sensitive probes for new phenomena. **Neil Russell** reports from a recent meeting held at Indiana University, where physicists discussed possible symmetry-violating mechanisms that could open the way to a deeper understanding of our universe.

The Bloomington campus of Indiana University, US, hosted its second meeting on CPT and Lorentz symmetry (CPT '01) on 13–15 August 2001.

The meeting, which was attended by physicists from the US, Japan and Europe, focused on experimental and theoretical developments in the study of space–time symmetries. The first meeting solely on this topic was held in Bloomington in 1998 (*CERN Courier* May 1999 p17).

Some of the most fundamental symmetries in physics are the space–time symmetries of Lorentz transformations – where the laws of physics are unchanged under boosts and rotations – and CPT – the combination of charge conjugation (C), parity inversion (P) and time reversal (T). Interest in these symmetries has flourished in recent years as attempts to find cracks in the Standard Model have intensified.

Lorentz symmetry, which states that reference frames are equivalent if either rotated or moved at a constant velocity with respect to each other, appears to be an exact symmetry in nature. So too does CPT symmetry. The 1954 CPT theorem of Bell, Lüders and Pauli states that any Lorentz-invariant field theory must be CPT-invariant. No experiment has detected any violation of either symmetry, but as experimental tests of CPT and Lorentz symmetry continue to improve, some intriguing opportunities to resolve asymmetry arise.



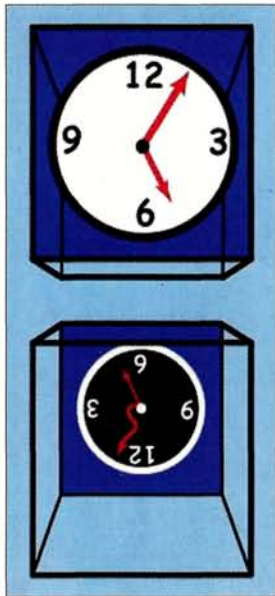
Blayne Heckel (left) from the University of Washington, US, demonstrates the Éot-wash experiment to a student. A torsion balance similar to this one has provided important bounds on Lorentz and CPT symmetry.

CPT '01 was opened by distinguished physicist Yoichiro Nambu of Chicago, US, who gave a historical perspective on the topic of CPT symmetry in physics.

For CPT symmetry to be broken in any theory, one of the preconditions of the CPT theorem must be removed. One possibility is to base the theory on extended objects – as in string theory, for example.

The Standard Model extension of Alan Kostelecky of Indiana University, US, uses this idea and spontaneous symmetry breaking as the context in which the Standard Model lagrangian is supplemented with general CPT- and Lorentz-violating terms. The extension has all of the usual features of the Standard Model of particle physics, except for the breaking of the two symmetries.

Since the first meeting on Lorentz and CPT symmetry in 1998, when only a handful of experimental bounds were known, a steady stream of new limits on CPT and Lorentz symmetry has been flowing. Kostelecky presented an overview of the theory – developed over a period of 10 years – and discussed the variety of experiments at the high-energy and high-precision frontiers that could be in a position to detect effects. The Standard Model extension is giving new impetus to Lorentz and CPT tests by isolating specific types of signals in an explicit framework. The ideas are intriguing, since many



The logo from CPT '01 encapsulates the meeting's theme. The two clock cubes are parity images of each other. The colour inversions represent the charge conjugation process; time reversal is indicated by the hands moving in opposite directions; and the bent hand represents a small violation of the combined symmetry.



Indiana University's Bloomington campus, which hosted the CPT '01 meeting, is home to some 39 000 students from more than 135 countries.

experiments have never probed effects with the characteristics that are predicted in this theory. One of these effects is sidereal variations in frequencies that were previously thought constant.

Sidereal variations occur because the theory challenges the traditional idea that empty space is isotropic and structureless, suggesting instead that special directions exist. In fact, most experiments point in a particular direction, given, for example, by the orientation of a linear accelerator, the plane of a cyclotron, or the magnetic field in an atomic clock. It is customary to ignore this orientation, because space is considered directionally inert.

However, if empty space has a faintly resolvable structure, including directional dependence, it may be possible to find variations in measurements repeated over time as the orientation of the experiment changes with the rotation of the Earth. Several speakers at CPT '01 reported attempts to isolate sidereal variations of this type. Impressive bounds on Lorentz and CPT violation have resulted.

Non-commutativity

An interesting theoretical development relating to the Standard Model extension is the realization that the model contains non-commutative field theory. Roman Jackiw of MIT, US, discussed Lorentz violation in non-commutative photodynamics. He also pointed out the relevance of non-commuting spatial variables in quantum mechanics. Other speakers discussed related issues, including a conservative bound on the non-commutativity parameter of $(10 \text{ TeV})^{-2}$. This has implications for Lorentz violation, since a non-commutative theory is recovered from the Standard Model extension by choosing suitable values for the parameters.

Robert Antonucci of the University of California at Santa Barbara, US, discussed implications for symmetry tests using polarization data from astronomical sources, such as quasars, and Indiana University's Matthew Mewes presented a new bound based on polarization-axis comparisons of light from such sources. The result is one of the most stringent bounds on Lorentz symmetry to date, of three parts in 10^{32} . This complements tests performed on systems within other sectors of the Standard Model extension.

Two CERN collaborations among several efforts worldwide to test fundamental symmetries are ATHENA and ATRAP, which plan to trap cooled antihydrogen for high-precision spectroscopy. ATRAP spokesperson Gerald Gabrielse of Harvard University, US, reported that his experiment is making good progress. The idea is to compare antihydrogen spectral frequencies with the corresponding frequencies that are known to a great precision for ordinary hydrogen. CPT symmetry requires that the comparison shows no differences. Since summer 2000, when the CERN antiproton decelerator began operation, steady progress has been made by CERN groups in the development of technology to create antihydrogen in a trapped form.

Continuing the search

A number of neutral-meson high-energy experiments continue to search for violations of Lorentz and CPT symmetry. For the K, D and B mesons, Lorentz-violating effects depend on the particle momentum. It is therefore of interest to search for speed- and orientation-dependent signals. Hogan Nguyen of the KTeV collaboration at Fermilab, US, reported a new result bounding parameters for CPT violation at 10^{-21} GeV in the neutral-kaon system.

Rob Gardner of the FOCUS collaboration at Fermilab presented the first result of a search for sidereal variations in the oscillations of neutral D mesons. The result implies sensitivity to effects in the charm sector, bounding parameters at 10^{-15} GeV. Yoshihide Sakai of the BELLE collaboration at KEK, Japan, reported a recent result bounding CPT symmetry in the B-meson system.

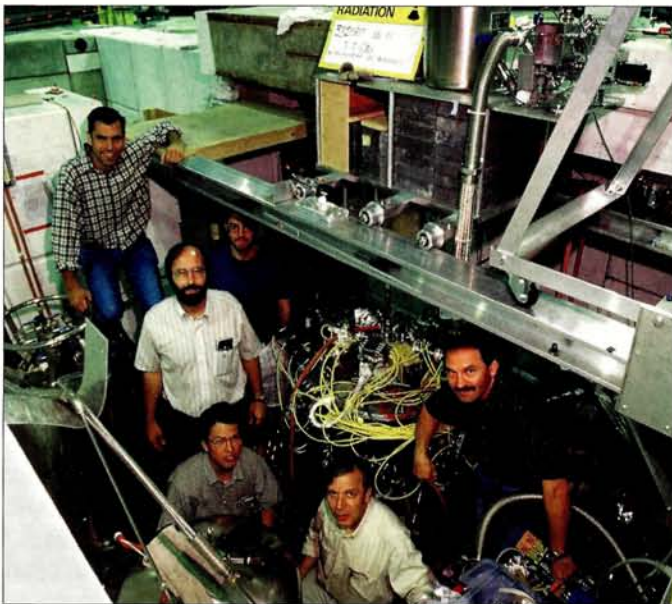
New bounds in the lepton sector have been contributed by recent muon and muonium experiments. David Kawall of Yale University, US, reported on the muonium experiment at Los Alamos National Laboratory in New Mexico, US. Using hydrogen-like muonium "atoms" composed of a positive muon and an electron, a collaboration led by Vernon Hughes, also of Yale, studied the ground-state hyperfine transitions in this system using data taken over a two-year period.

Analysis of the high-precision data reveals no sidereal variations in any of the transition frequencies, thereby bounding the relevant parameter combinations in the Standard Model extension at

Sidereal variations



The Standard Model extension discussed at the Indiana meeting predicts a background of minuscule directed quantities (tensors) that are fixed in space. The images above show these as red arrows filling the vacuum. Particles and antiparticles can interact differently with this background, so the combined symmetry CPT (the product of charge conjugation, parity and time reversal) can be violated. This is illustrated in the image on the left by different properties of a basketball and an antibasketball in a laboratory on Earth. The image on the right shows the situation 12 h later. The local direction of the arrows in the laboratory has changed because the Earth has rotated, so the CPT violation is different. Similarly, in real experiments, one way to observe CPT and Lorentz violation is to look for particle properties that vary with the Earth's sidereal period. Results from several such experiments were reported at the meeting.



Members of the ATRAP collaboration at CERN are putting fundamental symmetry to the test.

2×10^{-23} GeV. This first ever search for Lorentz violation in the muon sector provides a 10-fold improvement on the previous results. Mario Deile of Yale and David Hertzog of Illinois represented the Muon g-2 Collaboration at Brookhaven National Laboratory, US (CERN Courier April 2001 p4; CERN Courier January/February p7).

Plans to use data from this experiment to seek out possible Lorentz and CPT violation signals in the context of the Standard Model extension were discussed. The sensitivities are expected to be competitive with those of the Los Alamos group.

Several high-precision spectroscopic measurements are also proving invaluable in testing the Standard Model extension. Nobel Laureate Hans Dehmelt's Penning-trap group at the University of Washington, US, has placed several bounds on symmetry violation in the electron sector. These results were reviewed by Robert Bluhm of Colby College in Maine, US, who also described the theory behind other planned symmetry tests in atomic systems.

Some tests involve comparisons of particles and their antiparticles, which is possible with electrons and positrons for example, and also in muon experiments. Other tests involve monitoring atomic-clock and maser frequencies to identify Lorentz-violating variations. Ron Walsworth of the Harvard-Smithsonian Center for Astrophysics, US, discussed recent measurements and future possibilities with masers, and Mike Romalis of Princeton University, US, presented plans to build an innovative helium-potassium comagnetometer for future tests.

External influences

Resolving variations in frequencies is experimentally challenging because there are numerous environmental influences in a laboratory, such as temperature, that vary on a daily basis. Ensuring that an experiment is monitoring the right effect is critically important. New approaches towards these intricacies will be available in the near future when precision atomic clocks and masers are planned to fly on the International Space Station (ISS). It will be possible to exploit the short rotational period of about 90 min, and various other properties of the ISS platform.

Several scientists involved with ISS projects spoke at the Bloomington meeting, including Kurt Gibble of Penn State, US, who discussed the rubidium atomic-clock experiment (RACE), and Neil Ashby of Colorado, US, who presented the primary atomic reference clock in space (PARCS). Another experiment, SUMO, involves flying superconducting microwave oscillators on the ISS and was discussed by Joel Nissen of Stanford, US. It has the potential to test several aspects of fundamental symmetries. Also at the meeting was Lute Maleki, the Jet Propulsion Laboratory project manager for several ISS experiments. He outlined the novel SpaceTime experiment, which proposes to carry three oscillators on a high-speed sweep past the Sun.

One of the finest tests of CPT symmetry with electrons has been done by the Eöt-Wash group at the University of Washington, led by Eric Adelberger. The experimental apparatus, a torsion pendulum with an overall spin polarization, was described by Blayne Heckel. The results bound several CPT-violating parameters in the electron sector at about 10^{-29} GeV.

Further reading

CPT and Lorentz Symmetry: Proceedings of the Second Meeting World Scientific 2002 ISBN 9810248342.

Neil Russell, Northern Michigan University, US.

PEOPLE

EVENTS

CERN-inspired art exhibition opens in Geneva



CERN engineer Ian Sexton (left) and artist Ken McMullen contemplate their work.



Paola Pivi's "sculpture machine" of moving needles detects people as they approach.



Jerome Basserode's spinning tops are his reaction to the concept of time in motion.

"Signatures of the Invisible", the contemporary art exhibition inspired by particle physics, came home to Geneva in February. An initiative of the London Institute, the world's largest college of art and design, "Signatures of the Invisible" brought 11 of Europe's leading

artists together to create works based on research carried out at CERN. The resulting exhibition opened at London's Atlantis gallery in March 2001 (*CERN Courier* May 2001 p23) to critical acclaim, and has since visited Beijing and Rome. The exhibition remains at

Geneva's Centre d'Art Contemporain until May, when it will move on to Lisbon, New York, Paris, and a Japanese city (yet to be determined) are possible future venues.

For full details of the project, see <http://www.signatures.linst.ac.uk>.



Bruno Pontecorvo Prize laureate for 2001 **Nicholas Samios** (right) is seen here with **Nicolai Russakovich**, director of the Joint Institute for Nuclear Research's Dzhelapov Laboratory, and **Stepan Bunyatov**, secretary of the prize jury, in the Bruno Pontecorvo memorial study at the Laboratory of Nuclear Problems. Samios received the prize at the JINR Scientific Council meeting on 18 January 2002. (Yu Tumanov.)



Brian Foster takes over from Lorenzo Foà as chairman of the European Committee for Future Accelerators (ECFA) on 1 July. Currently spokesman of the ZEUS collaboration at Hamburg's DESY laboratory, Foster has served on numerous committees and worked on experiments at CERN, DESY and SLAC in California. He was a UK delegate to CERN Council in 1997, and has served on CERN's LEP and LHC committees. From 1992 until 1996 he was part of the UK delegation to ECFA's plenary sessions, and he was a member of the ECFA plenary panel on the future of European particle physics in 2000 and 2001. His mandate as ECFA chair runs until 2005.



John Iliopoulos, seen here with his son Alexander, has been awarded the Aristeio Bodossaki Prize for 2002. In 1970 Iliopoulos, currently director of the Theoretical Physics Laboratory at the Ecole Normale Supérieure in Paris, recognized the importance of a fourth kind of quark, along with Sheldon Glashow and Luciano Maiani, CERN's current director-general. This led to the famous GIM mechanism, which allows flavour-conserving Z-boson-mediated weak interactions within the Standard Model but no flavour-changing ones. The award is made by the Bodossaki Foundation, established in 1973 by Greek philanthropist Prodromos Athanassiadis, known as Bodossakis. The foundation promotes education, medical care and environmental concerns in Greece. Iliopoulos is the first recipient of the foundation's Aristeio prize, which has been instituted to recognize Greeks who have made significant contributions towards furthering their chosen fields of science. The award is accompanied by a sum of €150 000 and will be presented at a ceremony in Athens in June.

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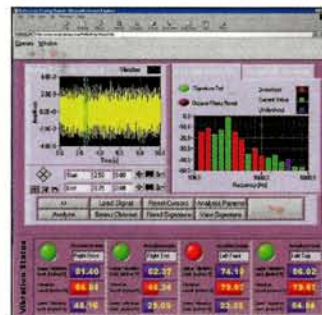
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Israel's ambassador to Switzerland, **Ygal Antebi** (left), is seen here with CERN research director **Roger Cashmore**.



Italy's deputy minister for productive activities, **Adolfo Urso** (centre), visited the string-2 test-bed for CERN's Large Hadron Collider in January. He is seen here with CERN's **Roberto Saban** (left) and director-general **Luciano Maiani**.

New title for IOPP

Institute of Physics Publishing (IOPP) has teamed up with the International Atomic Energy Agency (IAEA) in Vienna, Austria, to publish the journal *Nuclear Fusion*. All submissions and the peer review process will continue to be managed by the IAEA, while publication, distribution, subscription fulfilment and marketing of the journal in print and electronic form will now be the responsibility of IOPP.

Launched in 1960, *Nuclear Fusion* is a leading journal in the field. IOPP also publishes the *CERN Courier*.



Persis Drell of Cornell University has been appointed associate director of the Stanford Linear Accelerator Center's Research Division. She takes over from Steve Williams who has been acting associate director since September 2000.

Persis Drell is no newcomer to SLAC. She grew up on the Stanford campus where her father, Sid Drell, is a long-time member of the Stanford faculty and was deputy director at SLAC for many years. Following a PhD in atomic physics at Berkeley in 1983, Persis switched to particle physics and worked as a postdoc on the Mark II experiment. She served on the SLAC Program Advisory Committee from 1993 until 1995 and is currently chair of the SLAC Scientific Policy Committee.

The move back to California is a logical progression. At Cornell her research focused on studies of charm and bottom quarks at the pioneering Cornell Electron Storage Ring (*CERN Courier* January/February p13), a line of enquiry whose focus shifted eastwards with the start-up in 2000 of B-factories at SLAC and at KEK in Japan (*CERN Courier* October 2000 p6).

MEETINGS

The European Particle Accelerator Conference (EPAC '02) will take place at the Congress Centre of Paris's Cité des Sciences et de l'Industrie at la Villette on 3-7 June. Plenary sessions on the mornings of 3 June and 7 June will be complemented by parallel sessions on the intervening days. There will also be an industrial exhibition for the first three days of the conference, and a special session for industry is scheduled for the afternoon of 5 June. The European Physical Society Inter-Divisional Group on Accelerators prizes will be awarded at the conference. Full details are available at <http://epac2002.lal.in2p3.fr>.

Brookhaven National Laboratory will host the **10th Beam Instrumentation Workshop** on 6-9 May 2002. The workshop will address design principles and engineering issues of beam-diagnostic and control instrumentation for charged particle accelerators and beam

transport lines, and will offer a forum in which participants can exchange ideas and review instrumentation designs. It will also serve as an introduction to topics for engineers and scientists with the aid of tutorial sessions. The Faraday Cup Award for innovative achievement in instrument design (sponsored by Bergoz of France) will be presented by the organizing committee during the workshop. See <http://www.c-ad.bnl.gov/BIW02/>.

The 9th European Symposium on Semiconductor Detectors will take place on 23-27 June 2002 at Schloss Elmau in the Bavarian mountains. This meeting continues a successful series of conferences focusing on the physics, concepts and technology of radiation detectors and related electronics. Many ideas that are now well established were first presented in this conference series. See <http://www.hll.mpg.de/elmau>.

The 2002 Zuoz Summer School – "Exploring the Limits of the Standard

Model" will take place on 18-24 August in Zuoz (Engadine), Switzerland. To register contact the Secretary, Christine Kunz, CH-5232 Villigen-PSI, Switzerland. Tel. +41 56 310 4223; fax +41 56 310 3294; email christine.kunz@psi.ch before 1 June. No special form is required, but personal information should be complete. For more information or to register online see the website at <http://ltpth.web.psi.ch/zuoz2002/>.

The 2002 CERN School of Computing, organized by CERN in collaboration with the Institute of Composite Materials and Biomaterials, National Research Council, Naples, Italy, will be held on 15-28 September in Vico Equense, Italy. It is aimed at postgraduate students and research workers with a few years' experience in particle physics, computing or related fields. Special themes this year are: from detectors to physics papers; Grid computing; security and networks; tools and methods. More information is available at <http://www.cern.ch/CSC/>.

OBITUARIES

Theodore Kouyoumzelis 1906 – 2001

Theodore Kouyoumzelis passed away on 4 October 2001, aged 95. A tireless promoter of nuclear and particle physics in Greece, he graduated with a PhD from Athens University in 1932. Soon after, he moved to Munich where he worked as a postdoc under Arnold Sommerfeld and Walther Gerlach.

Professor Kouyoumzelis's long association with CERN predates the organization itself. He first represented Greece at the second meeting of the Council of the Interim Organization in June 1952. On that occasion, he was standing in for the original Greek delegate, Professor Hondros, from whom he formally took over two years later. He served as vice-president of the Council from 1972 until 1975, and attended his last CERN Council meeting in 1982 as its longest standing delegate. Thanks in large part to his efforts, Greece cast its vote in favour of all major machines at CERN during his mandate – the SC, the PS, the ISR, the SPS and LEP. In wishing Kouyoumzelis a fruitful retirement, director-general Herwig Schopper drew attention to the



Theodore Kouyoumzelis 1906 – 2001.

decisive contribution a small member state can make to an international organization such as CERN.

From 1945 until 1972, Kouyoumzelis taught physics at the University of Athens. He became a professor there in 1958, and held professorships at the army, navy and air force schools from 1940 until 1964. He was dean of the School of Chemical Engineers at the National Technical University of Athens from 1961 until 1970. At the University of Patras, he served on election committees from 1966 until 1967.

Kouyoumzelis was instrumental in the creation of Greece's national scientific research centre – Demokritos – and generations of Greek students in nuclear and particle physics have studied using his classic textbooks. From 1954 until 1960, he was general secretary of the Greek Atomic Energy Agency, and from 1968 until 1971 he was president of the country's Atomic Energy Committee.

Without a doubt, Theodore Kouyoumzelis has been the most influential person in nuclear and particle physics in Greece in the last 50 years. His legacy will continue to be felt by future generations of Greek physicists.
Emmanuel Floratos.

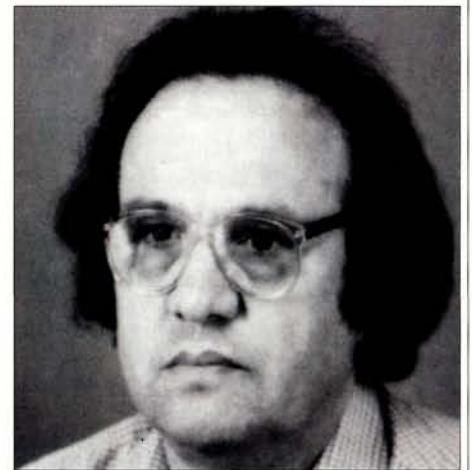
Dimiter Tsvetanov Stoyanov 1936 – 2002

Distinguished Bulgarian theoretical physicist Dimiter Tsvetanov Stoyanov died on 14 January 2002 at the age of 66. Stoyanov began his career in 1959 at the Institute of Physics of the Bulgarian Academy of Sciences. In 1963 he joined the Laboratory for Theoretical Physics at the Joint Institute for Nuclear Research in Dubna, Russia, where he became the head of a department in 1971. He had been an associate professor at the Institute for Nuclear Research and Nuclear Energy of the Bulgarian Academy of Sciences since 1973, and a full professor since 1982. In 1997 he was elected corresponding member of the Bulgarian Academy of Sciences.

Stoyanov will be remembered for pioneering

work on the relativistic 3-body problem in quantum field theory, and for work in the group-theoretic approach to dual-resonance models. His early work in the superconformal representation theory, and later studies of non-standard representations of the Lorentz and conformal group and their applications to conformal quantum electrodynamics, have also left their mark. Recently, he turned his attention to quaternionic analyticity, infinite-dimensional Lie algebras, and p-brane theory.

Dimiter Stoyanov left behind a generation of Bulgarian physicists inspired by his all-embracing devotion to science, his enthusiasm, and his profound vision. To all of them he was both a teacher and a dear friend.



Dimiter Tsvetanov Stoyanov 1936–2002.



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ACCEL

ACCEL Instruments GmbH is a world wide operating advanced technology engineering and manufacturing company. We are specialised in custom designed equipment for research and industry in the fields of particle accelerators, synchrotron radiation instrumentation, and medical applications, with specific emphasis in radiofrequency, magnet, vacuum, and cryogenic systems. We are dedicated to excellence in performance and trustful collaboration with our customers. For our expanding business we are looking for creative and innovative specialists as members of our project teams (see also www.accel.de)

Accelerator Physicists

We offer two positions, one with focus on circular accelerators one with focus on linear accelerators.

You will be in charge of optics design/beam dynamics calculation and layout of complete accelerators or subsystems like pre-accelerators or beam transfer lines and coordinate the specification of respective components like power supplies, magnets, etc.. The applicant should have a physics degree and experience with beam optics design programs like MAD or similar. Additional experience with e.g. beam diagnostics would be beneficial.

You will be in charge of scientific and engineering specification, conceptual and detailed design, coordination of manufacturing and procurement, assembly, testing and installation of components and complete linear accelerators. Applicants should have a physics degree and experience in accelerator development and operation. Experience in accelerator related RF technology, cryogenics, beam diagnostics or particle sources is helpful.

Physicist / RF-Engineer

You will be working on rf installations for superconducting and room temperature accelerator projects and have responsibility for the design, fabrication and operation of RF components such as cavities, HOM and high power couplers. Accelerator installation and test is part of this position. Applicants should have a degree in electrotechnical engineering or physics. Experience in the application of FEM codes like MAFlA, MWS or HFSS for the design of rf components is welcome.

Beamline Scientist and Beamline Engineer

You will be working on beamline projects for synchrotron radiation facilities taking responsibility for scientific respectively engineering specification, conceptual and detailed design, organisation of the manufacturing process, assembly, testing and installation of beamline components and complete beamlines. The positions require a degree in experimental or applied physics and corresponding engineering disciplines respectively and/or experience in vacuum technology/high precision mechanics.

You will be located at our premises near Cologne in Germany. English language skills are required, German language is beneficial but not mandatory. Please send your CV together with a covering letter to:

ACCEL Instruments GmbH, Friedrich Ebert Strasse 1,
D-51429 Bergisch Gladbach; accel@accel.de,
www.accel.de

Deutsches Elektronen-Synchrotron Diagnosis and Instrumentation



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

At DESY there are several accelerators in operation for the production of Synchrotron Radiation and for High Energy physics experiments. Starting 07/01/2002 our group, which is responsible for the beam instrumentalization of these facilities is looking for a

Physicist (m/f)

BAT Ib

Your tasks will comprise development, construction and commissioning of beam diagnosis monitors, mainly using synchrotron radiation. This includes transversal and longitudinal profile monitors with very high resolution. A team of committed technicians and engineers will be available for support.

You should have a degree in physics or a comparable qualification as well as experience in operating accelerators and in beam diagnosis and instrumentalization in combination with profound knowledge of accelerator physics, technology and instrumentalization. For this position you should like teamwork and you should also be able to work as a team leader. Furthermore your work would partly consist of shift work. Your health should also permit the use of a breath protection mask. If you fulfil all these requirements, please send your letter of application and three names of referees to our personnel department.

Please note: This is a replacement for a position becoming vacant due to part time retirement. At first this position will have limited responsibility and pay BAT IIa. After 12/31/2004 you will be given full responsibility.

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

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

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

Deutsches Elektronen-Synchrotron DESY

code: 06/2002 • Notkestrasse 85 • 22603 Hamburg • Germany
Telefon +49 (0)40/8998-3956 • www.desy.de
email: personal.abteilung@desy.de

Deadline for applications: 30.04.2002

PhysicsJobs @physicsweb.org



VETENSKAPSRÅDET

THE SWEDISH RESEARCH COUNCIL

The Swedish Research Council has a national responsibility for the development of Swedish basic research and information about research. The Council prioritises and finances basic research of the highest scientific quality in all fields of science. The goal is to ensure that Sweden holds a leading position as a nation engaged in research.

The Swedish Research Council is a public agency under the auspices of the Ministry of Education and Science. The secretariat contains about 130 persons.

THE SWEDISH RESEARCH COUNCIL

Natural and Engineering Sciences invites applications for

A Senior Research Position in Superstring Theory (Ref: 629-2001-6205)

The Council's intention in creating these positions is to contribute to the recruitment of researchers and to the renewal of research in Sweden. The programme is aimed primarily at scientists with a doctorate who recently have established themselves as independent researchers and have started and established an active research career. The positions are held for three plus three years and are placed at appropriate university departments in Sweden to be chosen by the candidate in consultation with the Council and the suggested university. The applicant is kindly requested to state at which university he/she wants the position. The universities decide on tenure. Duties can commence from July 1, 2002. The salary range will correspond to that of an assistant/ associate professor. A curriculum vitae including a list of publications, a short research plan plus a description (maximum six pages) of scientific achievements and pedagogical skills, and a maximum of ten reprints of scientific papers should be appended. Other documents which the applicant wants to refer to could also be included. Four copies of the application and all appendixes and reprints should be submitted.

Applications, quoting Ref, should reach the Swedish Research Council, NT, S-103 78 Stockholm, Sweden, by April 2, 2002.

Further information can be obtained from Ms Natalie Lunin at the Secretariat of The Swedish Research Council, phone no +46 8 546 44 232, e-mail-address Natalie.Lunin@vr.se, fax no +46 8 546 44 180.



NUI MAYNOOTH

Ollscoil na hÉireann Má Nuad

PROFESSORSHIP OF EXPERIMENTAL PHYSICS

The Irish Government's National Development Plan (2000-2006) has transformed the landscape for basic research in Ireland through initiatives such as the Programme for Research in Third Level Institutions and Science Foundation Ireland. There now exists in Ireland the potential to assemble research teams and to develop programmes which are globally competitive. NUI Maynooth has participated successfully in each of the above initiatives. Applicants for the positions below are encouraged to consider the opportunities currently presented by Science Foundation Ireland (www.sfi.ie).

Professor of Experimental Physics

National University of Ireland, Maynooth invites applications for appointment to the post of Professor of Experimental Physics. The position is full-time and permanent and carries also the responsibilities of Head of Department for at least a five year period. Established in 1795 under the auspices of a Chair of Natural Philosophy, the Department has a well established tradition of excellence in teaching and research. The Department is accommodated in a purpose-built facility which was constructed in 1998. Applicants should have a proven background of excellence in research, including a substantial record of scholarly publications. They should also have experience of providing leadership in teaching, and in academic administration.

Salary Scale (new entrants): €81,803 - €105,476 (6 points)

Prior to application, further details of the post should be obtained by writing to the **Personnel Officer, National University of Ireland, Maynooth, Maynooth, Co. Kildare, Ireland. Confidential Fax No. +353-1-7083940; Email: personnel@may.ie**

Applications, which should include a full Curriculum Vitae, a statement of research interests and future research plans, together with details of three referees (including postal and email addresses, telephone and fax numbers) should be forwarded to the **Personnel Officer** so as to arrive no later than **Friday, 5 April, 2002**. Applicants should also submit a concise statement on their vision of the future development of the Department.

Further information on the Department of Experimental Physics is available on the web at <http://www.may.ie/academic>. Inquiries may be made to Professor D.M. Heffernan, Secretary of the Search Committee for Professor of Experimental Physics, Telephone: +353-1-7083775; Email: dmh@thphys.may.ie



UNIVERSITY OF FLORIDA

Technology Scientist Needed for Global Grid Laboratory

The Physics Department of the University of Florida invites applications for a new position at the Assistant or Associate Scientist level (non-tenure accruing), to begin May 1, 2002 and continuing for the lifetime of the project, contingent on Federal funding. We are looking for an outstanding individual to act as a technology scientist for the International Virtual Data Grid Laboratory, (<http://www.ivdgl.org/>), an exciting five-year technology deployment initiative funded by the National Science Foundation. The iVDGL will deploy a global Grid laboratory, together with US and international partners, that will be utilized by advanced scientific experiments, including those in high energy physics, nuclear physics, gravitational wave searches (LIGO), virtual astronomical observatories (NVO) and other disciplines. The Laboratory will be based on the Globus and Condor Toolkits and draw on Grid technologies from GriPhyN, Particle Physics Data Grid (PPDG) and the European Union DataGrid projects. It is expected that the iVDGL will encompass dozens of sites in the U.S., Europe, Asia, Australia and South America.

Candidates should have completed a Ph.D or have equivalent experience in the physical or computational sciences. The successful candidate will take part in a wide variety of iVDGL testbed activities, including developing and deploying Laboratory infrastructure and applications, conducting testbed experiments, integrating Grid toolkits and coordinating with US and international partners.

Applicants should submit a letter outlining their qualifications and interests and a curriculum vitae, including a list of publications and brief summaries of research interests and accomplishments. Send applications to, and arrange to have at least three letters of reference sent directly to,

**Prof. Paul Avery P.O. Box 118440 Department of Physics
University of Florida Gainesville, FL 32611-8440 USA**

Questions by e-mail to avery@phys.ufl.edu or phone to 352-392-9264.

To ensure full consideration, applications must be received before April 1, 2002.

The University of Florida is an Equal Opportunity, Affirmative Action Institution

Im Rahmen der Neustrukturierung der Physik und der Zusammenarbeit mit den Ingenieurwissenschaften und den anderen Naturwissenschaften sind im Fachbereich Physik folgende Universitätsprofessuren neu zu besetzen:



1. Universitätsprofessur (Bes.-Gr. C 4)

für Theoretische Physik (Nachfolge Prof. Dr. H.D. Dahmen)

Die Bewerberin/der Bewerber muss in einem der Fachgebiete der Theoretischen Elementarteilchenphysik wissenschaftlich ausgewiesen sein.

Der Fachbereich Physik verfügt über einen Schwerpunkt „Methoden und Geräte der Hochenergiephysik und deren Anwendungen“, an dem auch die Theoretische Physik beteiligt ist. Dieser Schwerpunkt und der neuingerichtete Emmy-Noether-Campus für den Physik-Bereich stellen ein ideales Umfeld für die/den zu berufende/n Bewerberin/Bewerber dar. In der Lehre muss die Bewerberin/der Bewerber das Gebiet der Theoretischen Physik vertreten.

Voraussetzung ist die Habilitation oder eine gleichwertige wissenschaftliche Qualifikation. Ferner wird die Bereitschaft zur aktiven und konstruktiven Mitarbeit in Selbstverwaltungsgremien der Universität vorausgesetzt.

2. Universitätsprofessur (Bes.-Gr. C 4)

für Experimentalphysik (Nachfolge Prof. Dr. M. Holder)

Die Bewerberin/der Bewerber muss in einem der Fachgebiete der Quantenoptik wissenschaftlich ausgewiesen sein.

In der Lehre wird die Bewerberin/der Bewerber das Gebiet der Experimentalphysik vertreten müssen.

Voraussetzung ist die Habilitation oder eine gleichwertige wissenschaftliche Qualifikation. Die Bereitschaft zur Zusammenarbeit mit den Ingenieurwissenschaften und den anderen Naturwissenschaften wird vorausgesetzt; ferner die Bereitschaft zur aktiven und konstruktiven Mitarbeit in Selbstverwaltungsgremien der Universität.

Die Universität Siegen strebt eine Erhöhung des Anteils von Frauen in Forschung und Lehre an. Entsprechend qualifizierte Wissenschaftlerinnen werden um ihre Bewerbung gebeten.

Die Bewerbung geeigneter Schwerbehinderter ist erwünscht.

Bewerbungen zu 1. und 2. richten Sie bitte mit den üblichen Unterlagen (Lebenslauf, Lichtbild, Zeugniskopien, Schriftenverzeichnis) **innerhalb von sechs Wochen** nach Erscheinen dieser Anzeige **an den Dekan des Fachbereichs 7 - Physik - der Universität Siegen**, Walter-Flex-Straße 3, D-57068 Siegen.

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ACCELERATOR PHYSICIST

Applications are invited for a re-advertised post, based at the Rutherford Appleton Laboratory, in the newly created Accelerator Science and Technology Centre (ASTeC), to lead a programme of development of future accelerators for particle physics.

An accelerator physicist is required to lead the research and development for a neutrino factory. Possible areas of work include high current proton accelerators, high power targets and muon collection and acceleration, but there will be considerable scope to contribute in all relevant areas. The work will involve close collaboration with staff in CLRC's Particle Physics Department, university teams and other international accelerator laboratories. There may also be the possibility to work on electron-positron linear colliders at the Daresbury Laboratory. More details can be found on <http://www.astec.ac.uk/jobs>

Suitable candidates would be expected to have at least 5 years relevant experience and to demonstrate their leadership capabilities. The initial salary would be up to £32,380.

Candidates should have a first degree in physics or a closely related subject, and a Ph.D or equivalent would be beneficial.

Application forms can be obtained from HR Operations, HR Division, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, OX11 0QX. Telephone (01235) 445435 (answerphone) or email recruit@rl.ac.uk quoting reference VN2189R. For an informal discussion about the post please contact Ken Peach on (01235) 445782 or e-mail Ken.Peach@rl.ac.uk Those who responded to the original advertisement need not re-apply.

Applications must be returned by 30th April 2002. Interviews will be held during May 2002.



COUNCIL FOR THE CENTRAL LABORATORY
OF THE RESEARCH COUNCILS

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www.cclrc.ac.uk

Associate Scientists

The Beams Division of Fermi National Accelerator Laboratory (Fermilab) currently has excellent opportunities for Associate Scientists.

The first individual will work in a systems department (Tevatron, Main Injector, Antiproton Source, Proton Source), and contribute to machine operation, improvements, and diagnostics. Additional duties will include writing application programs in C, performing shift work during machine commissioning periods and conducting beam studies, coupled with advanced accelerator calculations aimed at improving machine performance and versatility. This role will also entail making accesses into beam enclosures and working in radiation and ODH areas. Some shift work is required during commissioning.

The other position is in the Beams Physics Department performing advanced calculations and modeling of accelerator systems and particle beam motion, including experiments in particle beam physics. This work supports both existing Fermilab accelerators as well as studies of future accelerator facilities and advanced acceleration techniques. As a member of this group, the Associate Scientist would be directly involved in one or more of these activities and would be expected to make significant contributions toward the advancement of the field of accelerator physics.

Qualified candidates for both positions will possess a Ph.D. in Physics, with a minimum of three years of postdoctoral work and prior experience in experimental beam, accelerator and/or high-energy physics. Exact titles and levels will depend on the qualifications of the selected candidates.

Located 40 miles west of downtown Chicago, Fermilab offers a competitive salary and excellent benefits package. For consideration, please forward a curriculum vitae, publication list and the names of at least three references to: **Dr. John Marriner, Head Beams Division, Fermi National Accelerator Laboratory, P.O. Box 500, M.S. 306, Batavia, IL 60510-0500. U.S.A.** Fermilab is an EOE/AA Employer M/F/D/V



Fermilab

CORNELL UNIVERSITY

RESEARCH ASSOCIATE EXPERIMENTAL ELEMENTARY PARTICLE PHYSICS

The experimental high energy physics group at Cornell University has an opening for a Research Associate to work on the CLEO-c experiment at the Cornell Electron Storage Ring. This experiment provides a unique opportunity for high precision measurements in the Upsilon family, at the J/Psi, and near the DD and DsDs production thresholds.

These measurements will play a significant role in future unitarity constraints through both direct contributions and through precision calibration and testing of QCD calculation techniques. The high statistics radiative J/Psi sample will provide a powerful laboratory for the search of exotic QCD resonances, such as glueballs and hybrids. The successful respondent will also play a lead role in the development of a Linear Collider Detector R&D program at Cornell.

Appointments are nominally for three years with the possibility for renewal beyond that, subject to mutual satisfaction and the availability of funds under our NSF contract. A Ph.D. in experimental elementary particle physics is required.

Please send an application including curriculum vitae and a publications list to

**Lawrence Gibbons, Newman Laboratory,
Cornell University, Ithaca, NY 14853,**

and arrange for at least two letters of recommendation to be sent.

Email correspondence may be directed to search@lns.cornell.edu.

*Cornell is an equal opportunity/affirmative action employer.
Women and minorities are encouraged to apply.*

Deutsches Elektronen-Synchrotron PARTICLE PHYSICS



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

For the experimental particle physics programme at HERA - experiments H1 and ZEUS, HERMES and HERA-B - and the preparation of experimentation at TESLA several

DESY Fellowships

are announced. The place of work is Hamburg or Zeuthen. Young scientists who have completed their Ph.D. and are younger than 32 years are invited to send their application including a resume and the usual documents (curriculum vitae, list of publications and copies of university degrees) and should arrange for three letters of recommendation to be sent to DESY.

The DESY fellowships are awarded for a duration of two years with the possibility for prolongation by one additional year.

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

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

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

Deutsches Elektronen-Synchrotron DESY

code: 35/2002 • Notkestrasse 85 • 22603 Hamburg • Germany
Telefon +49 (0)40/8998-3877 • www.desy.de
email: personal.abteilung@desy.de

Deadline for applications: 30.04.2002

Research Position in Experimental High Energy Physics University of Colorado at Boulder

The experimental high-energy physics group at the University of Colorado has openings for a person with a strong computing background and with a strong interest in experimental High Energy research. The persons are to participate in the BaBar experimental program at the Stanford Linear Accelerator Center and may participate in NLC detector simulation studies. In particular these persons will participate in every aspect of the BaBar data analysis. They will work with

Colorado graduate students in BaBar and may help guide a group of undergraduates working on NLC detector simulation, particularly in design of calorimetry based on the energy flow concept. The applicant should have a Ph.D. degree and is expected to have a strong C++ software language background.

Applicants should send a Curriculum Vitae and arrange to have three letters of recommendation sent to

Prof. Uriel Nauenberg, Department of Physics, Campus Box 390, University of Colorado, Boulder, CO 80309-0390

You can also communicate via e-mail, uriel@cahep.colorado.edu.

All applications should be received by June 30 2002.

The University of Colorado at Boulder is committed to diversity and equality in education and employment.





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

In the framework of an international collaboration, DESY is coordinating the development of the superconducting electron-positron linear collider project, TESLA, with integrated free electron laser facility. The Laboratory in Zeuthen (near Berlin) invites applications for a

Research Associate (m/f)

for R&D work associated with the installation, operation and further development of a test facility for RF photo-injectors.

For the operation of free electron lasers and e^+e^- linear colliders; electron sources with very challenging beam properties are required. In order to do research and development in this field, a new photo-injector test facility is at present being commissioned at DESY Zeuthen. The successful candidate should play an important role in this project and should contribute significantly to the development, operation and optimization of the RF photo-injector for using at the TESLA test facility free electron laser as well as at TESLA. The work will include detailed measurements as well as further development of simulation tools.

Applicants should have a PhD in physics. Substantial knowledge in accelerator physics and particle beam dynamics is required as well as several years' relevant professional experience. Candidates will be expected to take responsibility for sub-projects. The capability to work with physicists and technicians in a motivated team is necessary.

In the framework of the position shift work may be necessary at times.

The position is permanent. The salary will be according to the German civil services BAT-O 1b salary scale. The deadline for applications is April 30th, 2002.

DESY is an equal opportunity employer and welcomes the application of qualified women. Handicapped applicants will be given preference in case of equal qualification.

Research group contact: Dr. Frank Stephan, Tel.: +49 / 33762-77 338, see also: <http://desyntwww.desy.de/pitz/>

Interested scientists should send their complete application as well as the names of three referees and their addresses to:

**DESY Zeuthen, Personalabteilung
Platanenallee 6, 15738 Zeuthen, Germany**

EUROPEAN SYNCHROTRON RADIATION FACILITY



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We also offer PhD positions.

Have a look at our website for a full description of our vacancies and activities: <http://www.esrf.fr>, and contact us at recruitm@esrf.fr or fax #: +33 (0)4 76 88 24 60

ESRF, Personnel Service, BP220, F-38043, Grenoble cedex 9, FRANCE.

PhysicsJobs @physicsweb.org

CORNELL
UNIVERSITY

SENIOR RESEARCH ASSOCIATE IN ACCELERATOR PHYSICS

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

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

Applications containing a curriculum vitae and three letters of reference should be sent to

**Prof. Maury Tigner at search@lns.cornell.edu or to
SRF Search Committee, Floyd Newman Laboratory,
Cornell University, Ithaca, NY 14853**

Cornell University is an equal opportunity, affirmative action employer.

PHYSICIST

The Physics Department at Brookhaven National Laboratory presently has an opportunity for an experimental physicist in the PHENIX Group. The PHENIX Group has a major responsibility for the design, construction, operation and exploitation of the PHENIX detector, one of the two large experiments at RHIC Collider. The position requires a Ph.D.; a distinguished record; initiative and accomplishment in relativistic heavy ion physics research; and excellent credentials in hardware, software and physics analysis. In addition, the applicant must have demonstrated the ability to work well in a diverse group setting and be capable of taking a lead role in helping to define the physics goals of the group, as well as to provide hands-on contributions achieving them. The person filling this position will be expected to devote 100% of their effort to RHIC physics, divided equally between detector operation and physics research.

Interested candidates should submit a CV and three letters of reference, indicating position number MK2263, to: M. Kipperman, Brookhaven National Laboratory, Bldg. 185, PO Box 5000, Upton, New York 11973-5000. BNL is an equal opportunity employer committed to workforce diversity.

BROOKHAVEN
NATIONAL LABORATORY

www.bnl.gov

The Experimental Physics Division invites applications for a long term position of a

PHYSICIST

in experimental particle physics research.

Candidates are expected to have a PhD in particle physics and an excellent record of successful work with typically 5-10 years of post-doctoral experience in this field. Further requirements include: a high capacity for innovation and leadership; competence in detection techniques and in the use of on-line and off-line software; potential for making a significant medium to long-term contribution to the scientific programme of the Organization. Very good communication skills and an aptitude for team work.

The position is of a long-term nature and offers a competitive remuneration package and excellent career prospects.

The selected candidate will take a leading role in all aspects of particle physics experiments, involving the conception and design of experiments, the development and operation of detectors and the analysis of data. He/she will also coordinate or make important contributions to studies, projects or committee work and represent the Organization at conferences, workshops, or in other research laboratories and institutions.

Interested candidates are asked to send an application letter, a CV including the names of three referees and a brief description of research interests as well as a list of publications to Dr. D. Schlatter, EP Division Leader, CERN, CH 1211 Geneva 23, e-mail: Dieter.Schlatter@cern.ch, by 17 May 2002.

Preference will be given to nationals of CERN Member States*.

This position is also published under reference EP-DI-2002-13-FT, which can be consulted at www.cern.ch/jobs/.

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

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

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CORNELL UNIVERSITY

TENURE/TENURE-TRACK PROFESSORIAL POSITION IN

Experimental Elementary Particle Physics

We are seeking an outstanding individual for a professorial position in experimental elementary particle physics at the assistant, associate or full professor level. In addition to teaching undergraduate and graduate courses, responsibilities will include supervision of graduate students and participation in the research program of the Laboratory of Nuclear Studies, 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 Υ 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. The position will be available in September 2002.

Please send an application and at least three letters of recommendation to

**Prof. Ritchie Patterson, Search Committee Chair, Newman Laboratory,
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Applications should include a curriculum vitae, a publication list, and a short summary of teaching and research experience.

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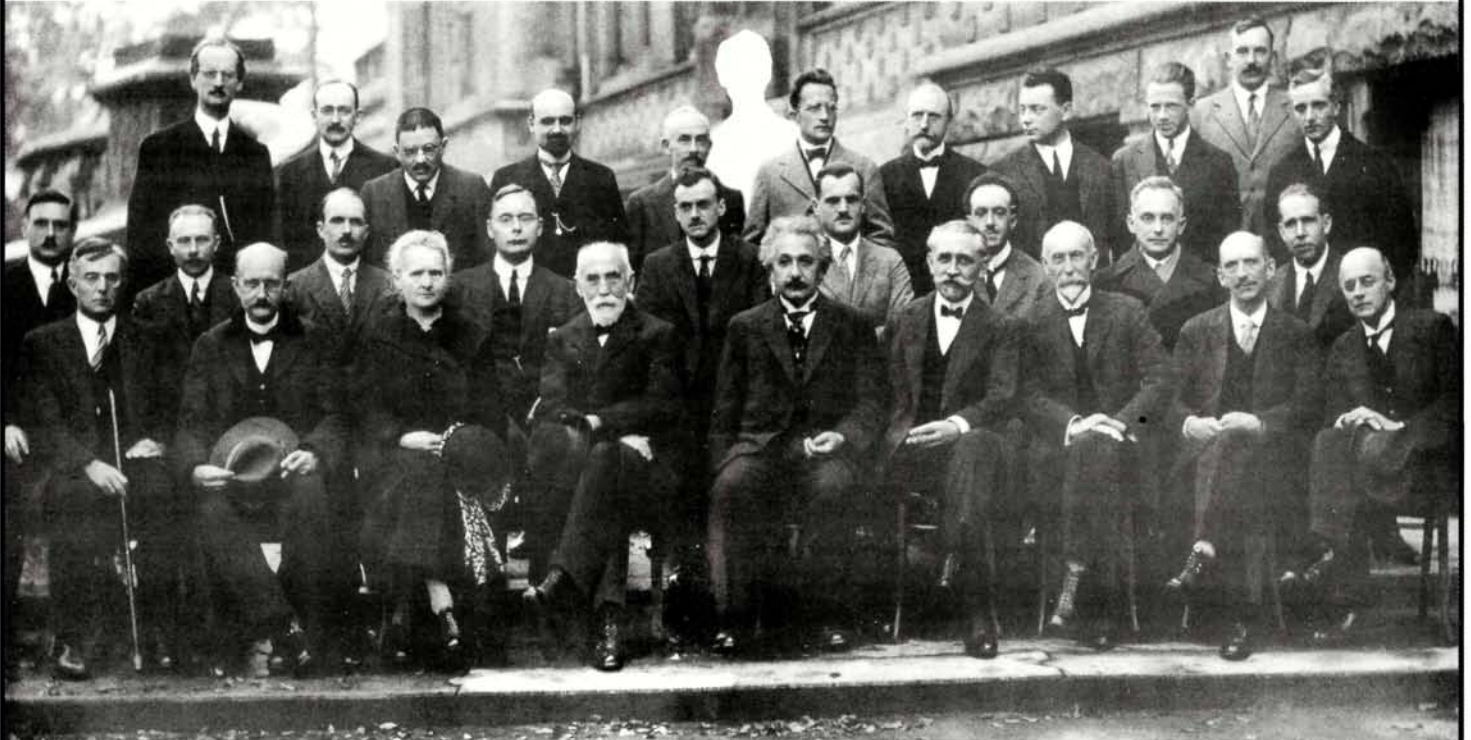
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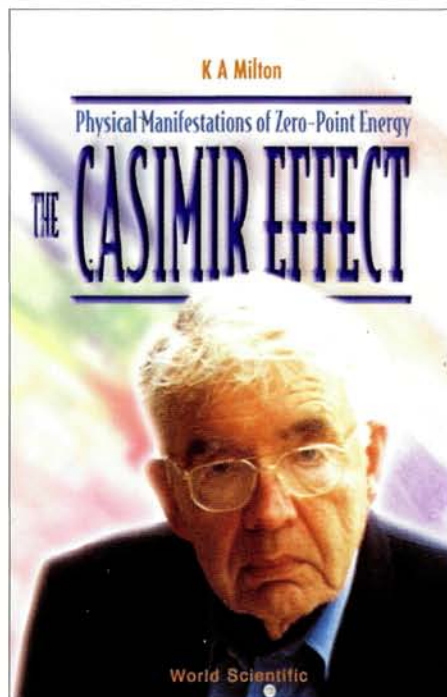
The Casimir Effect: Physical Manifestation of Zero-Point Energy by K A Milton, World Scientific, ISBN 9810243979 \$87/£58.

In 1948 Hendrik Casimir showed that, according to quantum electrodynamics (QED), two parallel conducting plates should exert a force on each other – an effect that now bears his name. This force, according to one of several possible interpretations, is a direct result of the existence of zero-point vacuum fluctuations of the electromagnetic field. In simple terms, as the plates are placed closer and closer together, more and more modes of the electromagnetic field are excluded, with a corresponding reduction in the (admittedly infinite) amount of zero-point energy between them and an associated (and, amazingly, finite) attractive force. Similar effects occur whenever boundaries are placed in the vacuum, and all are collectively considered to be manifestations of the Casimir effect.

Milton's book reviews this remarkable phenomenon from a theoretical viewpoint. Starting with parallel conducting plates, he goes on to extensions to different geometries; partially conductive and dielectric materials in place of conductors; the relation to van der Waals forces; dimensions more and less than the usual 3+1; contributions due to fermion fields; finite temperature effects; radiative corrections; and implications for hadronic physics and even cosmology.

With all these calculations and applications one might imagine that the Casimir effect would be well understood, but hardly anything could be further from the truth. For example, Casimir forces can be repulsive; they tend to expand a spherical shell, which is by no means intuitively obvious and in fact is a bit of a pity. Anticipating a force of the opposite sign, Casimir had hoped that they might supply the Poincaré stresses needed to stabilize a model of an electron as a tiny spherical shell of charge, and even lead to a calculation of the numerical value of the fine structure constant.

If the sign of the Casimir effect for a spherical shell is somewhat surprising, what happens in other cases can be even stranger. Change a spherical shell to a cubical box and it still tries to expand, but make it a long thin rectangular box and it tends to collapse. Go to an even number of space dimensions and the force on a hyperspherical shell becomes infinite. It's all wonderfully bewildering.



Casimir – a formidable force in QED.

Perhaps the most interesting recently recognized manifestation of the Casimir effect – if indeed that's what it is – is the phenomenon of sonoluminescence, in which an acoustically tickled bubble of air in water releases visible light in 100 picosecond bursts. While the jury is still out on what exactly is going on, there are calculations suggesting that this could be due to a dynamical version of the Casimir effect in which vibrations of the bubble excite the QED vacuum. Here, however, the theory is much more difficult to work out, and different approximations lead to wildly differing estimates of how big the effect ought to be.

The Casimir effect is about a lot more than a force between two metal plates, and Milton's book offers a great opportunity to read about it and learn the techniques by which it can be calculated. My one criticism of the book, which is probably not really fair given that the author is a theorist, is that it would be beneficial to have a discussion of the techniques by which the effect is observed in the laboratory. That said, the book is very comprehensive, clearly written and filled with wonderful physics.

John Swain, Northeastern University.

Quantum Electrodynamics by V Gribov and J Nyiri, 2001 Cambridge University Press (Cambridge monographs on particle physics, nuclear physics and cosmology no. 13),

ISBN 0521662281, £55/\$80.

This short book is based on the lectures of Vladimir Gribov that were given in Leningrad in 1974. It was completed, after his death in 1997, by his collaborator Julia Nyiri and it provides a pleasant introduction to the basics of field theory and quantum electrodynamics (QED). One of the book's strengths is its intuitive and relatively leisurely introduction to quantum field theory (QFT) via the Feynman propagator and diagram approach that is particularly suited to students on their first approach to the forbidding machinery of modern QFT. Indeed, in its treatment of elementary but fundamental topics – such as the construction of the scattering amplitude; the relation between causality, unitarity and analyticity in the Mandelstam plane; and tree-level processes such as the Compton effect or soft electron bremsstrahlung – it can be compared to two of the best older texts on quantum electrodynamics – Feynman's own book of this title and the volume on QED of the Landau and Lifshitz series. Unfortunately it also inherits deficiencies from its origins in the early 1970s.

Though the last two chapters discuss radiative corrections in QED and some aspects of renormalization theory, such as Ward identities, no mention is made of the central topic of the renormalization group, either in its older Gell-Mann-Low form or in the more modern Wilsonian guise within the effective field theory picture. Thus there are no anomalous dimensions of operators or running couplings as encapsulated in beta-functions – apart from what the student may find rather confusing remarks on the “zero charge problem”. Without these crucial tools a student is ill-prepared to explore the deeper properties of quantum field theory.

In addition there is no discussion of spontaneous symmetry breaking, the Higgs mechanism, Yang-Mills theory, ghosts, dimensional regularization, anomalies, or the operator product expansion. Therefore none of the physics of the theory of the strong or weak interactions can be discussed. So sadly, despite its pleasing and pedagogical introduction to the basics of QED, it can't compete with modern quantum field theory texts, such as Peskin's “Introduction to Quantum Field Theory”, as a full introductory course. However, I can recommend it as an enjoyable basic supplement to more complete texts.

John March-Russell, CERN.

A Century of Physics by D Allan Bromley, Springer-Verlag New York, ISBN 0387952470, \$59.95.

Senior statesman of US physics, Allan Bromley, has chosen the centenary of the American Physical Society to offer an illustrated review of the last 100 years of physics. At various times in his career, Professor Bromley has been president of the American Physical Society, the American Association for the Advancement of Science and the International Union of Pure and Applied Physics. He was also founder of Yale's nuclear structure laboratory, and is Sterling professor of the sciences and dean of engineering at Yale. All of these achievements make him very well qualified to present a successful and accessible overview of 20th-century physics.

Pictures are the stars of this book, bringing the highly readable narrative to life. The reader's eyes are spoiled by images such as that of J Robert Oppenheimer and Edward Teller shaking hands, despite their well publicized differences. The great advances in

accelerators are brought home by the picture of the original Cockcroft-Walton machine, and the hilarious photo of Isidor Rabi cooking hot dogs on the coil head of the Columbia cyclotron demonstrates not only that cooling technology has improved over the years, but that physicists can have a delicious sense of humour.

What *A Century of Physics* necessarily lacks in depth, it more than makes up for in breadth. After covering events from the early part of the century, such as the Annus Mirabilis of 1932 and the Manhattan project, Bromley moves on to discuss post-war physics. He covers subjects as diverse as superconductivity and the evolution of computers, and he explains the Standard Model and covers the research activity of laboratories all around the world.

At the end of the book, Bromley draws connections between particle physics research and cosmology. In the book's final breath, he goes back to the start of it all. Ten unanswered questions conclude his report, opening the door to a new century of physics. *Montserrat Capellas Espuny, CERN.*

Books received

Quantum Chaos Y2K proceedings of Nobel Symposium 116 Bäckaskog Castle, Sweden, 13-17 June 2000, eds K-F Berggren and S Åberg. ISSN Royal Swedish Academy of Sciences 00318949 (02811847), ISBN Royal Swedish Academy of Sciences 9187308932, ISBN World Scientific 9810247117, £56.

Strings, Branes and Gravity lecture notes from the Theoretical Advanced Study Institute in Elementary Particle Physics 1999 (TASI 99) edited by Jeffrey Harvey, Shamit Kachru and Eva Silverstein, World Scientific, ISBN 9810247745, £91.

Symposium of North Eastern Accelerator Personnel, Oak Ridge National Laboratory, US, 25-28 October 1999, edited by D K Hensley *et al.* World Scientific, ISBN 9810244665, £58.

Lectures on Quantum Chromodynamics by Andrei Smilga, World Scientific, ISBN 9810243316, £22.

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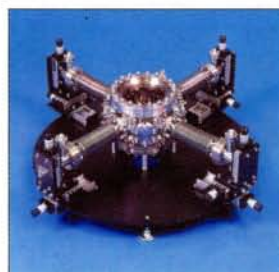


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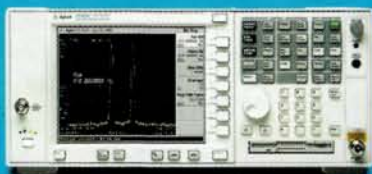
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