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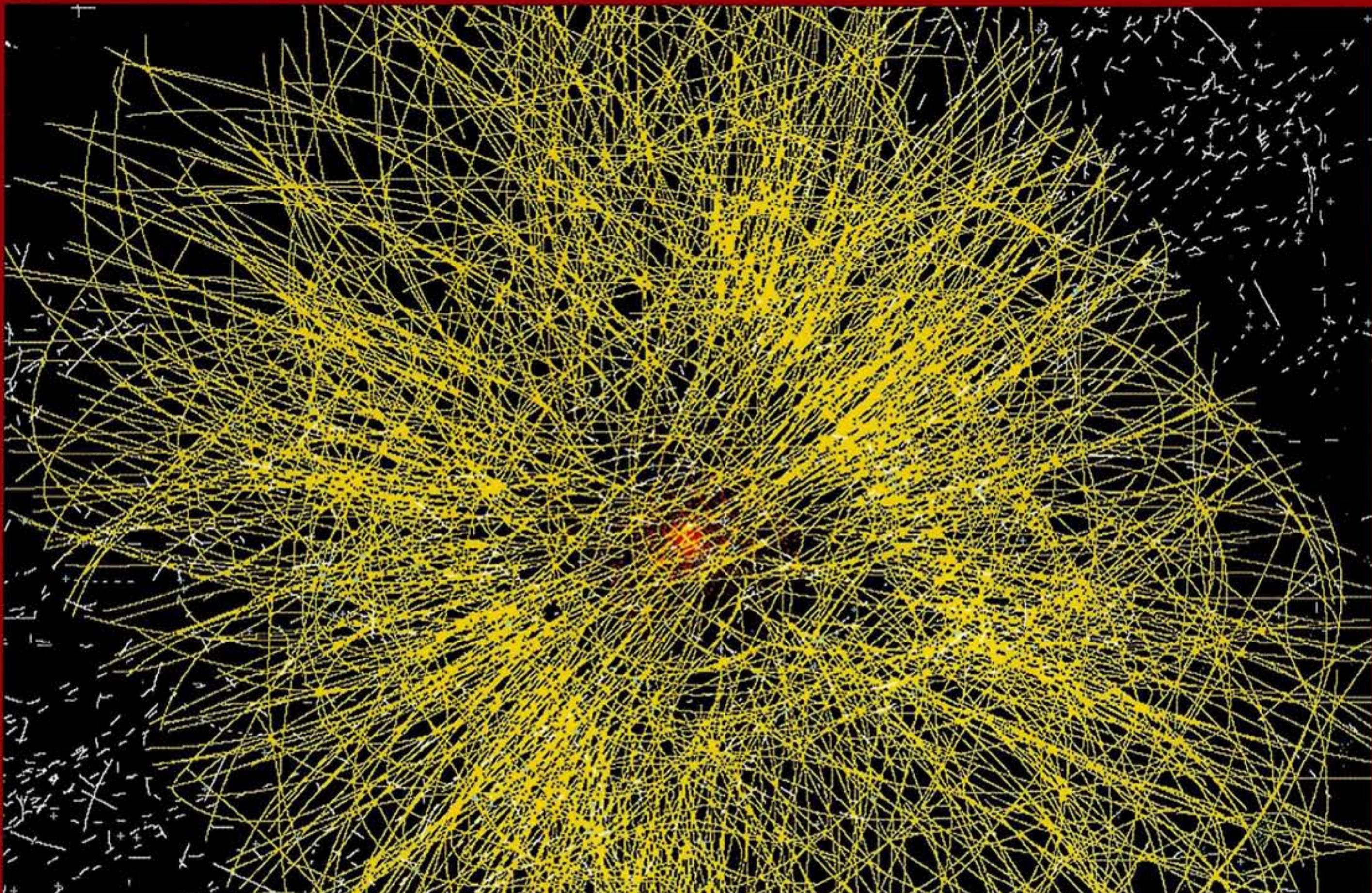

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Covering current developments in high-energy physics and related fields worldwide

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CERN COURIER

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Good news for Gran Sasso p6

Heavy ions at ALICE p20

New head of UK fusion p39

Cover: Events like this simulation of a lead–lead collision in the ALICE detector will allow the exploration of the dense quark–gluon plasma at CERN's Large Hadron Collider (p17).

INTRODUCING

ORIGIN® 7.5

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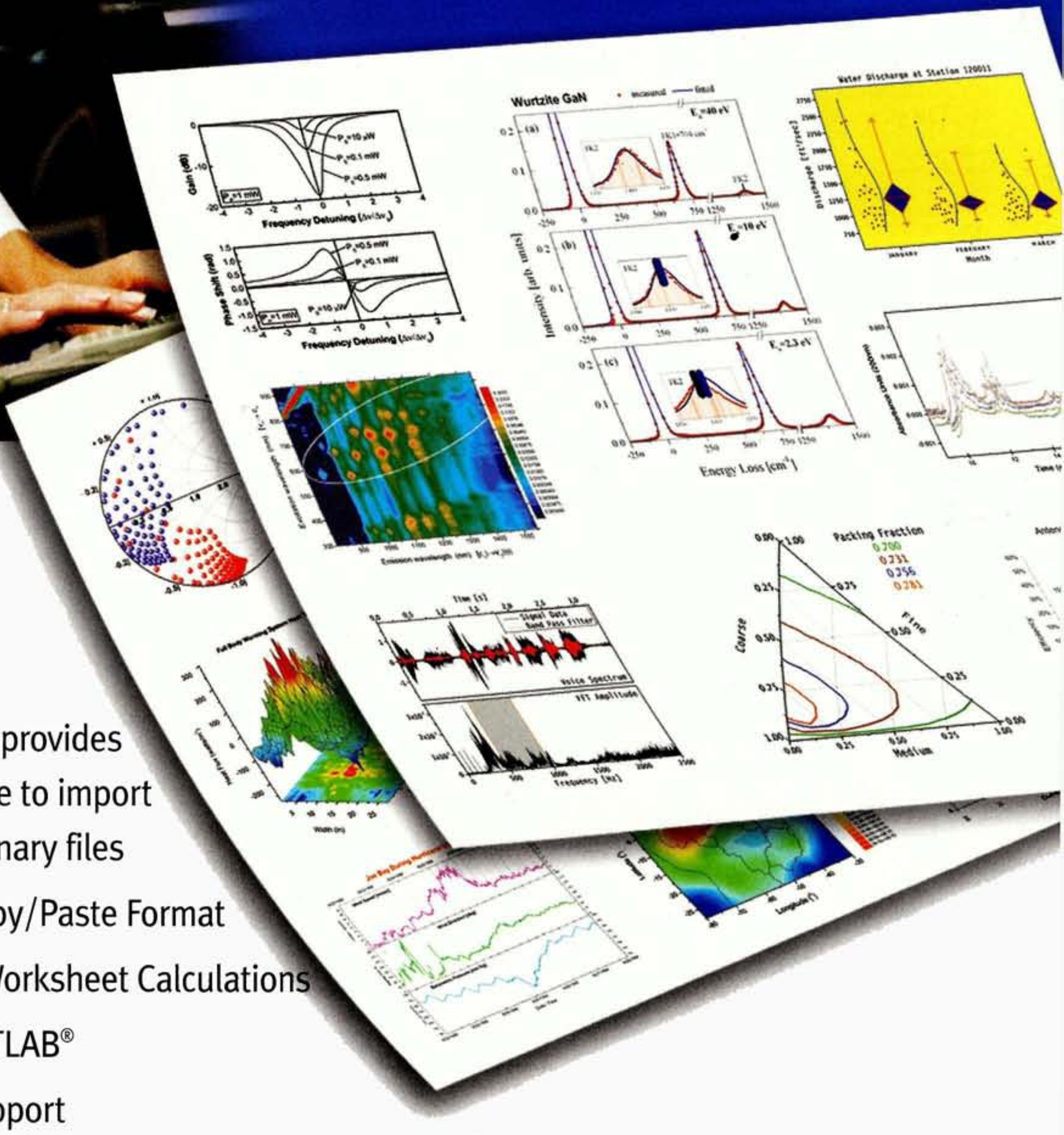

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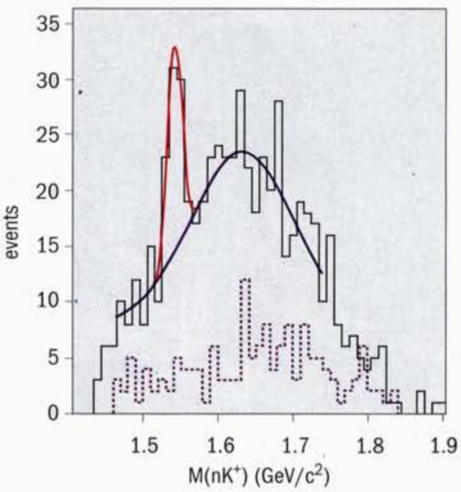
NEW PARTICLES

Four labs find five-quark particle

Four international collaborations have recently announced strong experimental evidence for a five-quark exotic baryon named the theta-plus (Θ^+), composed of two up quarks, two down quarks and a strange antiquark ($uudd\bar{s}$). Originally called the Z^+ by the Particle Data Group, but renamed the Θ^+ in April this year, as suggested by Russian theorist Dmitri Diakonov, the exact nature of the so-called "pentaquark" is not yet clear. Further experiments should reveal whether it is a tightly bound five-quark object or a molecular meson-baryon state, and will provide measurements of its spin, and the angular distribution and energy dependence of its production.

Physicists have searched for a five-quark state for more than 35 years. Recent experimental efforts were largely motivated by Diakonov and colleagues Victor Petrov and Maxim Polyakov. In 1997 they predicted an exotic isoscalar baryon having spin-parity $(1/2)^+$ and strangeness $S = +1$ (D Diakonov *et al.* 1997). In the antidecuplet of five-quark resonances that they predicted, the Θ^+ is the lowest mass member at about 1530 MeV, having a width of less than 15 MeV. The theorists suggested that the particle would be seen as a sharp peak in the nK^+ or pK^0 mass spectrum.

The first publicly announced experimental evidence emerged from the Laser Electron Photon Facility at SPring-8 (LEPS) collaboration in Osaka, Japan (T Nakano *et al.* 2003). The LEPS involvement began at a conference in 2000, when Diakonov convinced collaboration members to search for the exotic Θ^+ state. Using data from an unrelated experiment on ϕ-meson production, the SPring-8 team studied the inclusive reaction $\gamma n \rightarrow K^+K^-n$ on ^{12}C by measuring both K^+ and K^- at forward angles. They realized that they had a signal in August 2002, but kept their result quiet until the Particles and Nuclei International Conference (PANIC) in October 2002. After months of independent analyses to confirm the result, and after correcting for Fermi momentum, they reported a $4.6\,\sigma$ nK^+ peak at 1540 MeV, less than 25 MeV wide and consistent with the exotic baryon predicted by Diakonov *et al.*



Invariant mass of the (nK^+) system obtained from CLAS using the reaction $\gamma + d \rightarrow pK^-(nK^+)$. The sharp peak at the mass of 1.542 GeV/c^2 has the exotic quantum number $S = +1$. The fit to the peak and a smooth background gives a significance of $5.8\,\sigma$. The dotted histogram shows the spectrum associated with $\Lambda(1520)$ production.

Meanwhile, the DIANA collaboration from the Institute of Theoretical and Experimental Physics (ITEP) in Moscow, Russia, was examining a 1986 data set from low-energy K^+Xe collisions in a xenon bubble chamber. They analysed the effective mass of the pK^0 system in the charge-exchange reaction $K^+Xe \rightarrow K^0pXe'$, finding a baryon resonance with a mass of 1539 MeV and a width less than 9 MeV at an estimated statistical significance of $4.4\,\sigma$. Their findings will appear in *Physics of Atomic Nuclei* (V V Barmin *et al.* 2003).

The CLAS collaboration at the US Department of Energy's Thomas Jefferson National Accelerator Facility (Jefferson Lab) revealed the most statistically significant result to date at the Conference on the Intersections of Particle and Nuclear Physics (CIPANP) in May. Their results have been submitted for publication in *Physical Review Letters* (S Stepanyan *et al.* 2003). Using data from August 1999, the CLAS team studied an exclusive measurement of the reaction $\gamma d \rightarrow K^+K^-pn$. Energy-tagged photons struck a liquid-deuterium target and the particles generated were detected in the CEBAF large-acceptance spectrometer. In the final state, the reaction produced a K^- meson and a proton, along with the five-quark object, which then decayed into a neutron (identified by missing mass) and a K^+ meson. The CLAS collaboration reports a $5.3\,\sigma$ Θ^+ peak in the nK^+ invariant mass spectrum at around 1542 MeV, with a measured width of 21 MeV. They have received approval for 30 days of beam time from the Program Advisory Committee, so as to characterize fully the exotic Θ^+ baryon, and the experiment could be conducted as soon as early 2004.

The most recent experimental evidence for the pentaquark comes from the SAPHIR collaboration at the Electron Stretcher Accelerator (ELSA) in Bonn, Germany. Again using older data, taken in 1997 and 1998, they measured the reaction $\gamma p \rightarrow nK^0_sK^+$ with the decay $K^0_s \rightarrow \pi^+\pi^-$ in the SAPHIR detector at ELSA. In an upcoming issue of *Physics Letters B* they report evidence for the Θ^+ in the invariant mass spectrum of the nK^+ system (J Barth *et al.* 2003). They observe a $4.8\,\sigma$ peak with a mass of 1540 MeV and a width of less than 25 MeV. After searching for a signal in the pK^+ invariant mass distribution in $\gamma p \rightarrow pK^+K^-$, they conclude that the Θ^+ must be isoscalar.

The details of the theory proposed by Diakonov *et al.* are hotly debated, as a brief scan of the pre-print servers will confirm. However, it is undeniable that the four collaborations that have announced convincing evidence of the Θ^+ baryon report consistent experimental results. This would seem to confirm the existence of the particle. If the groups' analyses are correct, this new exotic baryon could have profound implications for baryon spectroscopy and hadronic physics in general.

Further reading

V V Barmin *et al.* 2003 http://arxiv.org/abs/hep-ex/0304040.
J Barth *et al.* 2003 hep-ex/0307083.
D Diakonov *et al.* 1997 *Z. Phys. A* **359** 305.
T Nakano *et al.* 2003 *Phys. Rev. Lett.* **91** 012002.
S Stepanyan *et al.* 2003 hep-ex/0307018.

UNDERGROUND LABORATORIES

Gran Sasso puts its troubles in order

After a difficult year, it seems that an air of optimism is back in the INFN laboratories at Gran Sasso. On 17 June the competent court of the city of Teramo agreed to certain scientific activities starting up again in Hall C, as requested by INFN. In particular, the installation of the OPERA experiment in Hall C, which began in March 2003 but was suspended in early June, will be able to resume. This decision is a sign that the competent authorities recognize the importance of the research being done at the Gran Sasso Laboratories and on the CERN Neutrinos to Gran Sasso (CNGS) programme in particular.

The problems began on 16 August 2002 when, following a series of unfortunate errors in Hall C, the team from the BOREXINO experiment caused 50 litres of trimethylbenzene to be discharged into the environment. The accident occurred at the very moment when a local debate on a safety tunnel designed to provide the underground laboratory complex with access independent from the adjacent road tunnel – very necessary in case of a disaster in the road tunnel – was beginning to become acrimonious. In such a tense atmosphere, even though no damage was caused by the accident, the fact that it could have done was enough to trigger a judicial enquiry.

In October 2002, the BOREXINO detector was therefore placed under a sequestration order by the Teramo public prosecutor. Subsequently, as the release of information by the regional government cast serious doubts on the water-tightness of the Gran Sasso Laboratories' drainage system, INFN took the precautionary measure of suspending all activities requiring the handling of any kind of fluid throughout the underground laboratories on 5 June 2003. INFN then requested the immediate intervention of the competent government authorities, and at the same time, undoubtedly for the same reasons, the whole of Hall C was placed under a sequestration order.

Rapid and effective action from the Civil Defence Department is now awaited following the Italian government's decision on 27 June 2003 to declare a state of environmental emergency with regard to the entire Gran Sasso facility, that is, the laboratories, the road tunnels, the environment in general and the water system in particular. This intervention by the government should allow the laboratory's activities to return to normal and guarantee the complete safety of the citizens of the region of Abruzzo. These measures are fundamental to ensure that all of Gran Sasso's activities can begin again in an atmosphere of complete trust between the scientists and the local population.

The Gran Sasso Laboratories, now looking forward to a happier future.

FREE-ELECTRON LASERS

JLab's upgraded FEL produces first light

Researchers at the US Department of Energy's Thomas Jefferson National Accelerator Facility (JLab) have produced first light from their 10 kW free-electron laser (FEL). This device has been upgraded from the "1 kW infrared demonstration" FEL that broke power records by delivering 2.1 kW of infrared light in 1999 (*CERN Courier* Jan/Feb 2003 p6). Only one-and-a-half years after the 1 kW FEL was dismantled, the newly improved FEL, designed to produce 10 kW of infrared and 1 kW of ultraviolet light, is undergoing commissioning with the goal of producing 10 kW by the end of the summer.

As part of its mission to probe deep inside the atom's nucleus with electrons, JLab has developed superconducting technology for accelerating electrons, and this offers two commanding cost advantages for FELs. The laser can stay on for 100% of the time instead of only 1% or 2%, and more than 90% of the energy that is not converted to useful light in a single pass can be recycled.

The FEL upgrade project is funded by the US Department of Defense's Office of Naval Research (ONR), Air Force Research Laboratory and the Joint Technology Office. The navy's interest in this technology is the development of an electrically driven tunable laser that can operate at infrared wavelengths, where light is most efficiently transmitted in the atmosphere. This would have potential applications in shipboard defence.

During the two-and-a-half years that the 1 kW FEL operated, it broke all existing power records for tunable high-average power lasers. It was used by more than 30 different research groups representing the navy, NASA, universities and industry for a variety of applications. These ranged from the investigation of new cost-effective methods for producing carbon nanotubes and understanding the dynamics of hydrogen defects in silicon, to investigating how proteins transport energy.

POLARIZED TARGETS

Bochum breaks deuteron polarization records

Polarized solid targets have been used in nuclear and particle-physics experiments since the early 1960s, and with the development of superconducting magnets and $^3He/^4He$ dilution refrigerators in the early 1970s, proton-polarization values of 80–100% have been routinely achieved in various target materials at two standard magnetic field and temperature conditions (2.5 T; < 0.3 K and 5 T; 1 K). Due to the much lower magnetic moment of the deuteron compared with that of the proton, deuteron polarization values have been considerably lower, typically 30–50%. Now, however, research at the University of Bochum is yielding materials with deuteron polarizations as high as 80%.

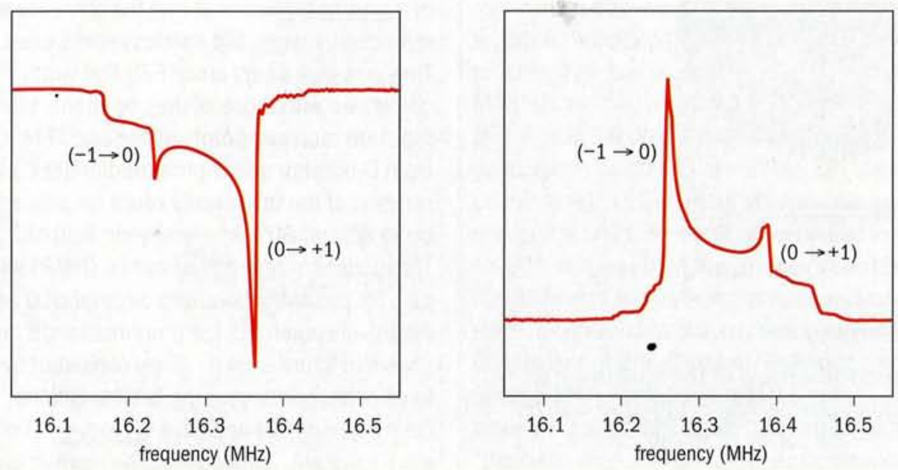


Fig. 1. NMR signals at a field of 2.5 T for positively polarized butanol-d10 (left) and negatively polarized 1,2-propanediol-d8, both doped with trityl radicals. Both signals show a 6:1 ratio of the strong to the weak transition intensity, corresponding to polarizations of about 80%.

During the past 10 years, polarized solid targets have been successfully used at CERN and SLAC to investigate the spin structure of the nucleon. For this purpose hydrogen- and deuterium-rich compounds such as butanol, deuterated butanol (D-butanol), ammonia (NH_3 and ND_3) and lithium deuteride (^6LiD) have served as proton and neutron target materials, respectively. The basic technique used to obtain a high polarization of the nuclear spins in the solid targets is to transfer the almost complete polarization of electrons at high magnetic fields and low temperatures to the nuclei via a microwave field with a frequency close to the electron Larmor frequency. This process – called dynamic nuclear polarization (DNP) – works for any nucleus with spin. Because all the target materials used are diamagnetic compounds, some amount of paramagnetic impurities (radicals or crystalline defects with unpaired electron spins) have to be implanted into the host material (doping). However, the efficiency of DNP in achieving high polarizations depends strongly on the nature of the paramagnetic centre and on the interactions to which the respective unpaired electron is exposed.

According to spin temperature theory, a narrow electron paramagnetic resonance (EPR) line enables the creation of high inverse spin temperatures – and thus of high nuclear polarizations. Guided by this prediction, a team at the University of Bochum has therefore been performing a systematic study of target-material doping for several years, using EPR spectroscopy to study the characteristics of the different paramagnetic dopants.

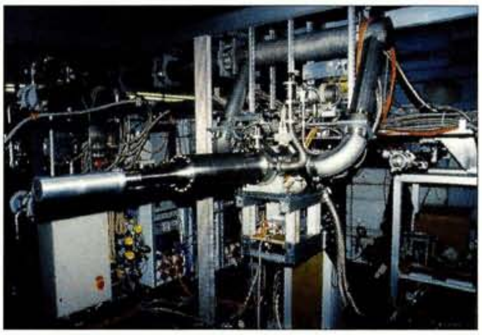


Fig. 2. The horizontal dilution refrigerator used for the Gerasimov–Drell–Hearn experiment at the Mainz microtron, MAMI. The target material, with a volume of about 6 cm^3, is located within the front end of the cryostat.

In the search for radicals with a small EPR line width, any effects that tend to broaden the line have to be minimized. The anisotropic g-factor of the unpaired electron is a particular danger, because its influence on the line width increases with increasing magnetic field. Hyperfine interactions of the electron also cause broadening. Radiation doping of deuterated materials therefore appears useful because the resulting paramagnetic centres combine a small g-factor anisotropy with weak deuteron hyperfine splitting.

A good example of the useful paramagnetic centres discovered so far is the so-called F-centre in ^6LiD, in which the EPR line width is almost entirely given by the magnetic interaction of the F-centre electron, with its six neighbouring ^6Li nuclei. A maximum deuteron polarization of 56% at 2.5 T is already being achieved with the target for the COMPASS experiment (NA58) at CERN, which was developed and produced at Bochum. Measurements at Saclay are also showing that even higher polarization values can be obtained in this material at higher magnetic fields.

The research at Bochum has also concentrated on the improvement of deuterated alcohol targets. These play an important role in experiments at intermediate beam energies because all the nuclei in these materials (apart from deuterium) are spinless – unlike ^6Li which has spin 1. The first breakthrough in this field came with the application of the radiation doping method to D-butanol. In this way, paramagnetic defects with characteristics very similar to those of the F-centres in ^6LiD could be created. Although a systematic investigation concerning the optimum irradiation dose has not yet been performed for this material, deuteron polarizations of 54% at 2.5 T and 71% at 5 T have already been reached.

A further substantial increase of the deuteron polarization has been achieved in both D-butanol and D-propanediol, chemically doped with radicals of the trityl family ▷

POLARIZED TARGETS

(which was developed and delivered by Amersham Health, Malmö). Basically, the paramagnetic part of these molecules consists of a methyl-type radical with the three H-atoms replaced by larger but spinless complexes. They possess a very small EPR line width compared with those of the commonly used nitroxide radicals, porphyrexide and TEMPO. Both D-butanol and D-propanediol doped with radicals of the trityl family could be polarized up to around 80% at a magnetic field of 2.5 T. The nuclear magnetic resonance (NMR) signals for positively polarized butanol-d10 and negatively polarized 1,2-propanediol-d8 are shown in figure 1 on p7. They consist of two lines corresponding to the two transitions ($m = +1 \rightarrow m = 0$) and ($m = 0 \rightarrow m = -1$) of a spin-1 system, respectively. The resonances are separated by the so-called quadrupole splitting, which is a consequence of the interaction of the deuteron quadrupole moment with the lattice electrical field gradient at the site of the deuteron. The measurement of the intensity ratio of the two transitions provides a very accurate method for determining the polarization.

These new developments will allow polarization experiments to be performed on the deuteron and neutron with a much higher precision than was previously possible. Doubling the maximum polarization means doubling the statistical accuracy for the same measuring time. Alternatively, for a given accuracy, the measuring time required is reduced by a factor of four. For these reasons, trityl-doped D-butanol was recently successfully used for the neutron part of an experiment to study the Gerasimov–Drell–Hearn sum rule at the Mainz microtron, MAMI, using a polarized tagged photon beam. Figure 2 shows the horizontal dilution refrigerator developed by the Bonn Polarized Target Group for this particular experiment. For the first time, after more than 40 years of polarized solid targets, it is now possible to perform these kinds of experiments with low-intensity beams to the same precision and over the same time span, no matter whether the proton or the neutron is the subject of investigation.

CERN

CERN offers grants to young Asian postgraduates

Within the framework of the CERN–Asia Fellows and Associates Programme, CERN offers three grants every year to young East, Southeast and South Asia postgraduates under the age of 33, enabling them to participate in its scientific programme in the areas of experimental and theoretical physics and accelerator technologies. The appointment will be for one year, which might, exceptionally, be extended to two years.

Applications will be considered by the CERN Associates and Fellows Committee at its meeting on 18 November 2003. An application must consist of a completed application form, on which "CERN–Asia Programme" should be written; three separate reference letters; and a curriculum vitae including a list of scientific publications and any other information regarding the quality of the candidate. Applications, references and any other information must be provided in English only.

Application forms can be obtained from: Recruitment Service, CERN, Human Resources Division, 1211 Geneva 23, Switzerland. E-mail: Recruitment.Service@cern.ch, or fax: +41 22 767 2750. Applications should reach the Recruitment Office at CERN by 17 October 2003 at the latest.

The CERN–Asia Fellows and Associates Programme also offers a few short-term associateship positions to scientists under 40 years of age who are on a leave of absence from their institute. These are open either to scientists who are nationals of the East, Southeast and South Asian countries who wish to spend a fraction of the year at CERN, or to researchers at CERN who are nationals of a CERN member state and who wish to spend part of the year at a Japanese laboratory.

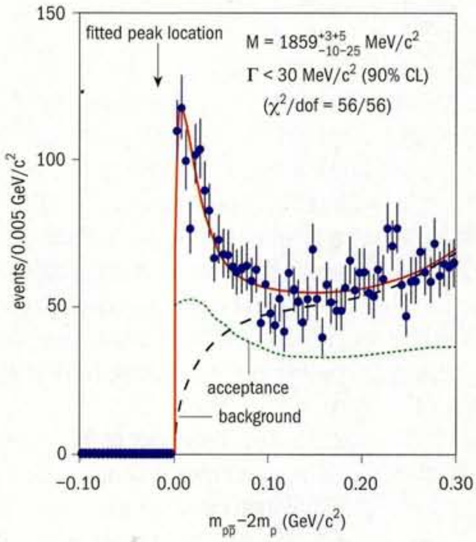
- The CERN–Asia Programme accepts candidates from: Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, China, India, Indonesia, Japan, Korea, the Laos Republic, Malaysia, the Maldives, Mongolia, Myanmar, Nepal, Pakistan, the Philippines, Singapore, Sri Lanka, Taiwan, Thailand and Vietnam.

NEW PARTICLES

BES collaboration observes new narrow state

The BES collaboration at the Beijing Electron Positron Collider (BEPC) has observed a clear signal for a narrow enhancement in the $p\bar{p}$ mass distribution near the $2m_p$ threshold in the process $J/\Psi \rightarrow \gamma p\bar{p}$. The peak, which has a statistical significance of more than 16σ, was found in the analysis of 58 million J/Ψ events. No corresponding enhancement has been seen in $J/\Psi \rightarrow p\bar{p}\pi^0$ decays.

The peak can be fit with either a S-wave (0^{-+}) or a P-wave (0^{++}) Breit–Wigner resonance function. For the S-wave fit, the mass is below $2m_p$ at 1859^{+3}_{-10} (stat)$^{+5}_{-25}$ (sys) MeV/c^2 and the width is less than 30 MeV/c^2 at 90% CL. For the P-wave fit, the mass is 1876.4±0.9 MeV/c^2 with a width of 4.6±1.8(stat) MeV/c^2. The acceptance-corrected photon angular distribution is consistent with that expected for a resonance with $J^{PC} = 0^{-+}$ or 0^{++}.



Graph showing the threshold region for the selected $J/\Psi \rightarrow \gamma p\bar{p}$ events.

Although there were indications of $p\bar{p}$ mass threshold enhancements in the $J/\Psi \rightarrow \gamma p\bar{p}$ process from earlier experiments, including MARK-III at SLAC and DM2 at Orsay, the limited statistics in the data samples meant no firm conclusions could be drawn. The high statistics acquired with BES-II, however, has excluded the interpretation of the effect as being due to known particles, such as the $\eta(1760)$. The high statistics also allow the mass and width of the state to be well determined, that is, below $2m_p$ (S-wave) or at $2m_p$ (P-wave). The mass and unexpectedly narrow width of the new resonance suggest it could be interpreted as a "deuteron-like" spin 0 proton–antiproton bound state (baryonium), with a zero baryon number.

Further reading

J Z Bai *et al.* 2003 *Phys. Rev. Lett.* **91** 022001.

TESLA

Test stand for RF couplers inaugurated at Orsay

A new test stand for radio-frequency (RF) couplers is operating at the French Laboratoire de l'Accélérateur Linéaire (LAL, CNRS/IN2P3) in Orsay. The facility, which was constructed and equipped within the framework of a co-operation agreement between the IN2P3 and DESY, was officially inaugurated on 7 July, in the presence of Michel Spiro, director of the IN2P3, and Albrecht Wagner, chairman of the DESY Directorate. It includes a class 10 cleanroom, a vacuum furnace, a system for the production of ultraclean water, and a 5 mW modulator/klystron ensemble. The test stand has been built for the preparation and conditioning of high-power RF couplers for the TESLA project.

Albrecht Wagner, left, and Michel Spiro cut the ribbon on the new test stand.

The international TESLA collaboration currently comprises 49 institutes from 12 countries, which are working together under the leadership of DESY to develop the technology for a superconducting linear accelerator. This accelerator technology will provide the basis for two major projects: a free-electron laser for X-ray radiation (XFEL) that is to be built through European collaboration, and an electron–positron linear collider (TESLA), which is under study as an international project. The superconducting linear collider would require around 20 000 of the RF couplers being tested at Orsay. The same couplers would also be used on the X-ray free-electron laser. The first high-power tests of prototype couplers in Orsay began in early spring this year.

FUNDAMENTAL CONSTANTS

Laser spectroscopy tests for inconstant constants

Recent astrophysical measurements of distant quasar spectra indicate that the fundamental constants may be changing with time. The dimensionless fine structure constant α, which scales the energy in electromagnetic interactions, might have been smaller at early times in the universe: the difference compared with today's value is a fraction of 10^{-5}. Assuming that the drift is linear, this would be a change of around 10^{-15} per year.

In general, such astrophysical measurements probe a drift of constants over extremely long time periods. Laboratory experiments on the other hand are limited to short timescales of some years. However, this can be compensated for by a higher accuracy. The recent dramatic evolution of techniques for measuring the frequency of light with a precision of a few parts in 10^{15} means that laser spectroscopy of atoms and ions has now reached a level of accuracy where a search for a drift of constants is feasible.

In particular, there is an effective magnification between a drift of α and the drift of an atomic transition frequency compared with the SI second provided by a caesium clock, leading to a frequency drift at an estimated level of 10^{-14} per year (*CERN Courier* March 2003 p15). A remeasurement of atomic transition frequencies previously measured some time ago is therefore of great interest, and earlier this year researchers at MPQ in Munich carried out such an experiment, measuring the 1S–2S transition in atomic hydrogen.

In 1999 the absolute frequency of this transition had been phase coherently compared with a caesium fountain clock, as a primary frequency standard, using a novel frequency comb technique. The second harmonic of laser light from an ultrastable continuous-wave dye laser emitting near 486 nm was used to excite cold hydrogen atoms, Doppler-free, from the ground state to the metastable 2S state. A selection of slow atoms by time-resolved spectroscopy allowed the reduction of systematic effects, mainly the second-order Doppler shift (A Huber *et al.* 1999). This measurement has demonstrated a precision of 1.9 parts in 10^{14} (M Niering *et al.* 2000).

Since then, the techniques used for frequency measurement, as well as the hydrogen spectrometer, have been improved, and data gathered in 12 days of measurement in February this year are now being evaluated. So far, eight days of data have been analysed, and the preliminary result for the difference of the two measurements is −48(60) Hz. Assuming that the measurements performed in 1999 and 2003 are equivalent, this implies a possible drift of the 1S–2S frequency of −5.4(6.8) × 10−15 Hz per year.

Further reading

A Huber *et al.* 1999 *Phys. Rev. A* **59** 1844.
M Niering *et al.* 2000 *Phys. Rev. Lett.* **84** 5496.

FRANCE AT CERN

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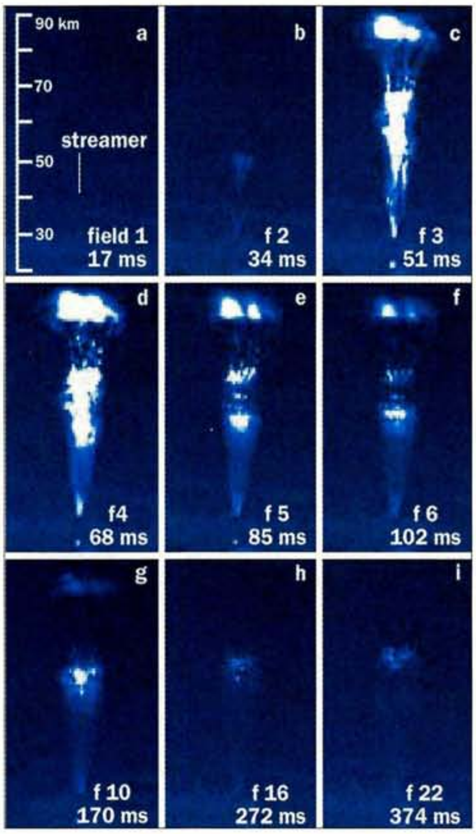
Compiled by Steve Reucroft and John Swain

Taiwanese team observes new kind of lightning

Gigantic electrical discharges between thunderclouds and the ionosphere, observed by a team in Taiwan, represent a previously unrecognized form of lightning. Su Han-tzong and Hsu Rue-ron of National Cheng Kung University, and colleagues, have directly observed five gigantic jets extending from clouds about 16 km above the ground to the ionosphere at 90 km.

Initially, the team believed that the jets they recorded at the southern tip of Taiwan in July 2002 were a form of the so-called "blue jets" discovered by researchers in the US in 2001. However, detailed analysis revealed that the gigantic jets are a new type of high-altitude lightning. While there was no evidence that these jets were triggered by cloud-to-ground lightning, extremely low-frequency (ELF) radiowaves associated with four of the jets were detected in Antarctica and Japan, indicating negative cloud to ionosphere discharges. These observations are now making atmospheric scientists think in new ways about the still poorly understood planetary electrical circuit.



Images of one of the giant discharges recorded in Taiwan show the evolution of the jet over a period of about 350 ms.

Further reading

H T Su *et al.* 2003 *Nature* **423** 974.

Fluorine and the environment

After the bad press that freon and chlorofluorocarbons (CFCs) have received over the years, it comes as something of a surprise to find that fluorine compounds are looking environmentally friendly. Dennis Curran of the University of Pittsburg in the US, and an increasing number of chemists, are realizing that fluorine-containing solvents can function well in place of dangerous chlorine-containing ones, but can also be very unreactive and hesitant to mix with other solvents. Acting almost like liquid teflon (another fluorine-containing compound), and easy to separate and recycle, they could greatly increase the cleanliness of industrial chemical processes.

Further reading

D Bradley 2003 *Science* **300** 2022.

Superconductor breaks high critical field record

Researchers at the University of Durham in the UK have set a new record in the strength of magnetic field that a superconductor can support before turning normal. H J Niu and Damian Hampshire found that a superconductor made from lead, molybdenum and sulphur, and fabricated out of nanocrystals, can reach a field of almost 100 Tesla. This is 10 times higher than can be achieved in the niobium-titanium alloys that are currently used in superconducting magnets for particle accelerators, and about five times higher than in the niobium-tin used in high-frequency NMR applications and high-field laboratories.

Theory shows that high critical fields, where the material turns normally conducting, can be achieved through increasing disorder in a material, either by increasing the resistivity in the normal state or by reducing the electron mean-free path. Chemical doping or alloying can produce such effects, but in this case the researchers used mechanical milling followed by hot isostatic pressing to make a disordered nanocrystalline form of the superconductor $PbMo_6S_8$. The milling produces a disordered nanocrystalline powder, which is then formed into bulk material in the pressing stage.

The superconductor made in this way has higher normal resistivity, but unlike materials produced by doping techniques, does not have a reduced superconducting transition temperature. The disorder reduces the electron mean-free path to 1 nm, which is less than a tenth the size of the grains, and together with the higher resistivity, ensures the high critical field. While conventionally produced $PbMo_6S_8$ has a critical field of around 50 T, the disordered nanocrystalline form reaches around 100 T.

Further reading

H J Niu and D Hampshire 2003 *Phys. Rev. Lett.* **91** 027002.

Complied by Marc Türler

Gamma-ray burst supports hypernova hypothesis

"He who seeks finds." After decades of speculation on the nature of gamma-ray bursts (GRBs), the very bright event known as GRB030329 is finally unveiling their origin. This burst is a "Rosetta stone" for scientists, revealing for the first time that a GRB and a supernova – the two most energetic explosions known in the universe – occur simultaneously. Thanks to this telling burst, a team of astronomers has pieced together the key elements of the so-called "collapsar" model of long-duration GRBs, from star death to the dramatic birth of a black hole.

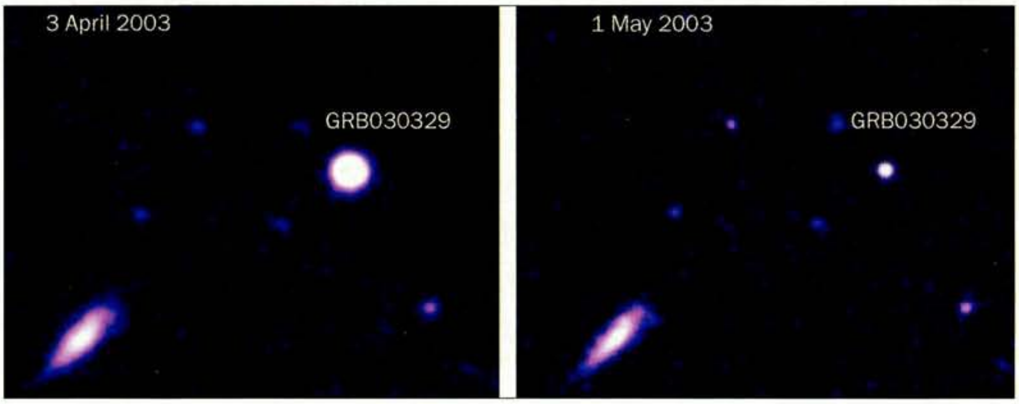
NASA's High-Energy Transient Explorer satellite (HETE-II) initially detected the burst on 29 March 2003 (at 11:37:14 UTC) in the constellation Leo. For more than 30 seconds the burst outshone the entire universe in gamma rays. Its unusual brightness triggered an unprecedented hunt for optical observations around the world (*CERN Courier* June 2003 p13). Within 24 hours a first, very detailed, spectrum of the burst's optical afterglow was obtained by the Very Large Telescope (VLT) of the European Southern Observatory (ESO) at the Paranal Observatory in Chile. The spectrum displays a redshift of 0.1685, corresponding to a distance of 2650 million light-years. This is near for a GRB and explains why this burst is among the 0.2% brightest bursts ever recorded. It provides the long-awaited opportunity to test the many hypotheses and models proposed since the discovery of the first GRBs in the late 1960s (*CERN Courier* June 2003 p5).

The afterglow of GRB030329 lingered for weeks in lower energy X-ray and visible light, allowing continued spectral observations with the VLT over a period of one month. The results were published in *Nature* (J Hjorth *et al.* 2003) by members of the Gamma-Ray Burst Afterglow Collaboration (GRACE) at ESO. According to the group of 27 researchers from 17 institutes, the spectral changes of the fading source give irrefutable evidence of a direct connection between the GRB and "hypernova" explosion of a very massive, highly evolved star. This is based on the gradual emergence of a supernova-type spectrum, revealing the extremely violent explosion of a star. With velocities well in excess of 30 000 km/sec (10% the velocity of light), the ejected material is moving at record speed, testifying to the enormous power of the explosion.

Hypernovae are rare events and probably caused by the explosion of stars of the "Wolf-Rayet" type. These WR-stars were originally formed with a mass greater than 25 solar masses and consisted mostly of hydrogen. During their WR-phase, having stripped themselves of their outer layers, they consist almost purely of helium, oxygen and heavier elements, produced by intense nuclear burning during the preceding phase of their short life. Such a dense star of about 10 solar masses will rapidly deplete its fuel, triggering a Type Ic supernova/GRB event. The core collapses, without the star's outer part "knowing". A black hole forms inside, surrounded by a disc of accreting matter, and within a few seconds launches a jet of matter away from the black hole that ultimately makes the GRB. The jet passes through the outer shell of the star and, in conjunction with vigorous winds of newly forged radioactive nickel-56 blowing off the disc inside, shatters the star. The GRACE team say this "collapsar" model, introduced by Stan Woosley of the University of California in 1993, best explains the observation of GRB030329.

"We've been waiting for this for a long, long time," said lead author Jens Hjorth. "This GRB gave us the missing information. From these detailed spectra we can now confirm that this burst, and probably other long GRBs, are created through the core collapse of massive stars. Most other leading theories are now unlikely."

As Stan Woosley, one of the co-authors, points out, this does not mean the GRB mystery is completely solved because, "we cannot reach any conclusion yet on what causes short GRBs." Many astronomers think these bursts, lasting less than two seconds, might be caused by neutron star mergers, but they are still waiting for their "Rosetta stone" burst.



Images obtained at the 8.2 m VLT telescopes show the fading image of the optical afterglow of GRB030329, as seen on 3 April (four days after the GRB event) and 1 May 2003. (ESO.)

Picture of the month

The delicate filaments in this image from NASA's Hubble Space Telescope are sheets of debris from a stellar explosion in our neighbouring galaxy the Large Magellanic Cloud (LMC). This small companion galaxy to the Milky Way is only visible from the southern hemisphere. The filamentary material of this supernova remnant, denoted LMC N 49, will eventually be recycled into building new generations of stars in the LMC. The Sun and planets are constructed from similar debris of supernovae that exploded in the Milky Way billions of years ago. (NASA, The Hubble Heritage Team, STScI/AURA.)

Further reading

J Hjorth *et al.* 2003 *Nature* **423** 847.

ADSC Quantum

CCD X-Ray Detectors

	Quantum 315	Quantum 210
		
Detector Type:	Array (3x3); 315mm x 315mm	Array (2x2); 210mm x 210mm
Number of Pixels:	6144 x 6144; 37.75 million	4096 x 4096; 16.8 million
Pixel Size at Detector Surfaces:	51 x 51 microns	51 x 51 microns
Phospher (optimized):	1 X-ray Angstrom	1 X-ray Angstrom
Spatial Resolution FWHM:	90 microns; 1.76 pixels	90 microns; 1.76 pixels
Taper Ratio:	3.7 to 1	3.7 to 1
Optical Coupling (CCD to Taper):	Direct bond	Direct bond
CCD Type:	Thomson THX 7899	Thomson THX 7899
CCD Pixel Size:	14 x 14 microns	14 x 14 microns
Operating Temperature:	-50 degrees Celcius	-45 degrees Celcius
Cooling Type:	Thermoelectric	Thermoelectric
Dark Current:	0.015 e/pixel/sec	0.015 e/pixel/sec
Controller Electronics:	ADSC Custom	ADSC Custom
Readout Times (Full Resolution):	1 second	1 second
Read Noise (Pixel Rate):	(1 MHz): 18 electrons estimated	(1 MHz): 18 electrons typical
Full Well Depth (Full Resolution):	270,000 electrons typical	270,000 electrons typical
Dimensions:	34.7 in. L x 17.7 in. W x 18.1 in. H (880.6 mm x 450.0 mm x 460.0 mm)	31.7 in. L x 13.7 in. W x 12.4 in. H (804.5 mm x 346.8 mm x 315.6 mm)
Weight:	294 lbs. (133.0 kg)	128.0 lbs. (58.0 kg)

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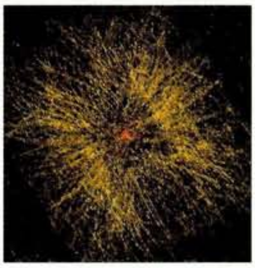
The net closes in on quark–gluon plasma



The search for quark–gluon plasma – the state of deconfined strongly interacting matter – received a big boost in the 1990s with the acceleration of heavy ions in the Super Proton Synchrotron (SPS) at CERN. Measurements from several experiments, when taken together, implied that matter with unusual properties appeared to be formed in the early stage of the collisions. Now results at different energies from experiments at CERN and RHIC have provided further evidence for the long-sought quark–gluon plasma and encouraged the study of its properties at the Large Hadron Collider.

Has the deconfinement phase transition been seen?

New results from the NA49 experiment at CERN suggest that the onset of the transition to deconfined quarks and gluons has been observed at the lower end of the SPS energy region.

In the mid-1990s a study of results from experiments at CERN (with a collision energy in the centre of mass of the nucleon pair of $\sqrt{s_{NN}} = 20$ GeV) and the Alternating Gradient Synchrotron (AGS) at Brookhaven ($\sqrt{s_{NN}} \leq 5.5$ GeV) indicated some intriguing changes in the energy dependence of hadron production between top AGS and SPS energies (M Gaździcki and D Röhrich 1996). Within a statistical model of the early stage of the collision process, these changes could be attributed to the onset of the deconfinement phase transition, where quarks and gluons are no longer confined within hadrons (M Gaździcki and M Gorenstein 1999). The model predicted a sharp maximum in the multiplicity ratio of strange hadrons (hadrons that contain strange and anti-strange quarks) to pions (the lightest hadron) at the beginning of the transition region, at about $\sqrt{s_{NN}} \approx 7.5$ GeV. This prediction triggered a new experimental programme at the SPS – the energy scan programme – in which the NA49 experiment recorded head-on (central) collisions of two lead nuclei (Pb+Pb) at several energies, $\sqrt{s_{NN}} = 6.3$, 7.6, 8.7 and 12.3 GeV. Other heavy-ion experiments at the SPS (NA45, NA50, NA57 and NA60) participated in selected runs of the programme.

Recently published results from the energy scan, obtained mainly by the NA49 collaboration, have confirmed expectations. They indicate that rapid changes of hadron production properties occur within a narrow energy range of $\sqrt{s_{NN}} = 7–12$ GeV (V Friese *et al.* 2003). The figure on page 18 shows these latest results, together with earlier data from the SPS and the AGS, and data from the Relativistic Heavy-Ion Collider (RHIC). Data from proton–proton collisions are also included for comparison. The top panel of the figure shows that the number of pions produced per nucleon participating in the collision increases with energy as expected in both proton–proton and nucleus–nucleus reactions. However, the rate of increase in nucleus–nucleus collisions becomes larger within the SPS energy range and then stays constant up to the RHIC domain.

The most dramatic effect, shown in the middle panel of the figure, is seen in the energy dependence of the ratio $\langle K^+ \rangle / \langle \pi^+ \rangle$ of the mean multiplicities of K^+ and π^+ produced in central Pb+Pb collisions. Following a fast threshold rise, the ratio passes through a sharp maximum in the SPS range and then seems to settle to a lower plateau value at higher energies. Kaons are the lightest strange hadrons and $\langle K^+ \rangle$ count for about half of all the anti-strange quarks produced in the collisions. Thus, the relative strangeness content of the produced matter passes through a sharp maximum at the SPS in nucleus–nucleus collisions. This feature is not observed for proton–proton reactions.

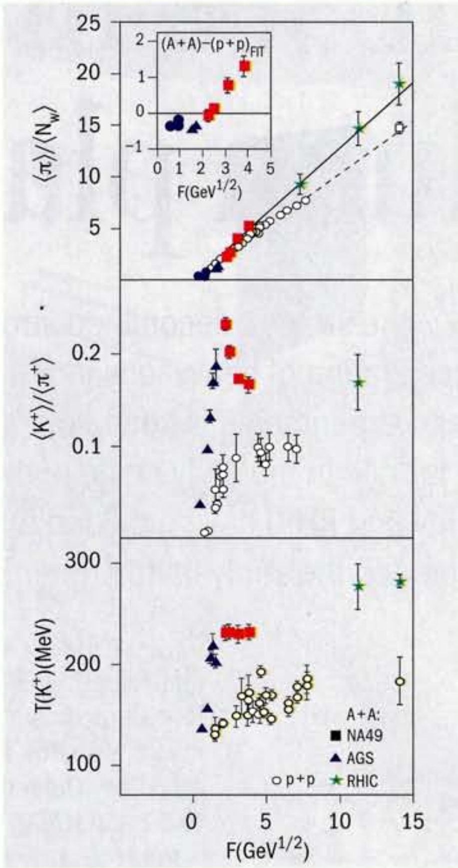
A third important result is the constant value of the apparent temperature of K^+ mesons in central Pb+Pb collisions at SPS energies, as shown in the bottom panel of the figure. The plateau at SPS energies is preceeded by a steep rise of the apparent temperature measured at the AGS and followed by a further increase indicated by the RHIC data. Very different behaviour is measured in proton–proton interactions.

So far, only the statistical model of the early stage reproduces ▷

the sharp maximum and the following plateau in the energy dependence of the $\langle K^+\rangle/\langle\pi^+\rangle$ ratio. In this model, the spike reflects the decrease in the number ratio of strange to non-strange degrees of freedom and changes in their masses when deconfinement sets in. Moreover, the observed steepening of the increase in pion production is consistent with the expected excitation of the quark and gluon degrees of freedom.

Finally, in the fireball of particles created in the collision, the apparent temperature is related to the thermal motion of the particles and their collective expansion velocity. Collective expansion effects are expected to be important only in heavy-ion collisions, as they result from the pressure generated in the dense interacting matter. The stationary value of the apparent temperature of K^+ mesons may thus indicate an approximate constancy of the early stage temperature and pressure in the SPS energy range due to the coexistence of hadronic and deconfined phases.

These results suggest the deconfinement phase transition exists in nature (and thus the quark–gluon plasma) and that in Pb+Pb collisions it begins to occur in the SPS energy range. From the composition of hadrons resulting from the decay of the fireball, the temperature at which the transition takes place can be estimated to be $T\approx 2\times 10^{12}$ K (170 MeV), coinciding with the limiting temperature of hadrons suggested at CERN many years ago by Rolf Hagedorn (see p30).



Collision energy dependence ($F\equiv(\sqrt{s_{NN}}-2m_N)^{3/4}/\sqrt{s_{NN}}^{1/4}\approx s_{NN}^{1/4}$, where m_N is the nucleon mass) of various hadron production properties (see text for details) measured in central Pb+Pb and Au+Au collisions (solid symbols), compared with results from p+p reactions (open dots). The changes in the SPS energy range (solid squares) suggest the onset of the deconfinement phase transition.

The observation of anomalies in the energy dependence of hadron production in Pb+Pb collisions in the SPS energy range requires further study. Analysis of data taken last year continues in search of further phenomena caused by the deconfinement phase transition, such as anomalies in the event-by-event fluctuations expected in the vicinity of the second-order critical end-point (M Stephanov, K Rajagopal and E Shuryak 1999). In future, it would be interesting to extend measurements of the energy dependence to central collisions of light nuclei as well as to proton–proton and proton–nucleus interactions. Such measurements should significantly constrain models of the collision process and, in particular, help us to understand the role played by the volume of the droplet of strongly interacting matter in determining the onset of the deconfinement phase transition.

Further reading

V Friese *et al.* (NA49 collaboration) 2003 www.arxiv.org/abs/ nucl-ex/0305017.

M Gaździcki and M Gorenstein 1999 *Acta Phys. Polon.* **B30** 2705.

M Gaździcki and D Röhrich 1996 *Z. Phys.* **C71** 55.

M Stephanov, K Rajagopal and E Shuryak 1999 *Phys. Rev.* **D60** 114028.

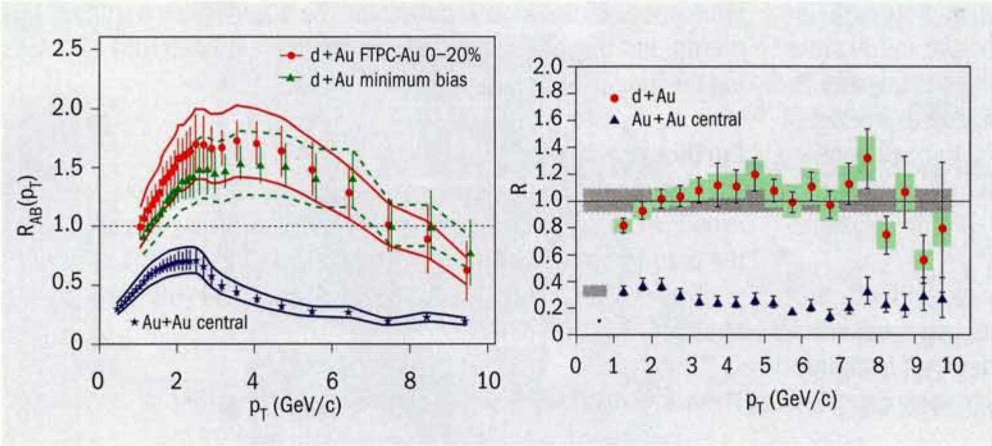
Marek Gaździcki, **Reinhard Stock**, *IKF Frankfurt University, and* **Peter Seyboth**, *MPI für Physik, Munich.*

Deuteron–gold collisions clarify 'jet quenching' results

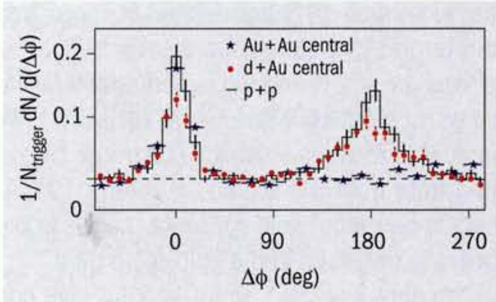
New measurements at RHIC provide further insight into heavy-ion collisions at high energies.

Since it began operation three years ago, the US Department of Energy's Relativistic Heavy-Ion Collider (RHIC) has produced an array of data that are rapidly shedding new light on unexplored territory in high-energy nuclear collisions. Results from the first gold–gold collisions at the new collider, recorded during the summer of 2000, immediately showed that the essential trend seen in fixed-target experiments at the Brookhaven AGS and CERN SPS continues as the collision energy is increased by an order of magnitude. Specifically, the concentration of energy deposited in the volume of space occupied by the colliding nuclei (the energy density) steadily increases with increasing collision energy. As a result, the multiplicity of particles produced in the most violent of the RHIC collisions is larger than any previously seen in subatomic interactions.

The early results have given clear indications that the origin of these particles involves extremes of density and temperature that are well into the range where the relevant degrees of freedom for nuclear interactions are expected to be those of quarks and gluons, not nucleons and mesons. Now it appears that measurements of high-energy phenomena due to the scattering of quarks and gluons



The ratio, R, of the rate of particle production at mid-rapidity in nuclear collisions to that seen in proton–proton collisions, plotted as a function of the particle transverse momentum. This ratio scales the observed production rates in nuclear collisions by the number of nucleon–nucleon collisions, and is 1.0 if there are no effects other than this scaling. In the RHIC data shown here at $\sqrt{s_{NN}}$ = 200 GeV, high-p_T particle production is clearly suppressed in central gold–gold collisions, while this suppression is not seen in the deuteron–gold collision data. Left, results for charged hadrons from the STAR experiment; right, π^0 production results from PHENIX.



Data from the STAR experiment show angular correlations between pairs of high transverse-momentum charged particles, referenced to a "trigger" particle that is required to have p_T greater than 4 GeV/c. The proton–proton and deuteron–gold collision data indicate back-to-back pairs of jets (a peak associated with the trigger particle at $\Delta\varphi$ = 0 degrees and a somewhat broadened recoil peak at 180 degrees). The central gold–gold data indicate the characteristic jet peak around the trigger particle, at 0 degrees, but the recoil jet is absent.

in collisions of heavy nuclei have provided an important new means for probing the realm of the predicted quark–gluon plasma.

The RHIC collision energy is high enough to produce direct scattering of quarks and gluons from the incoming nuclei. In this "hard scattering" – in the parlance of quantum chromodynamics (QCD) – a single pair of partons (quark, anti-quark, gluon) from the incoming nuclei strike each other directly with such force that they scatter with high momentum away from the initial beam direction. These interactions, which are relatively rare even in the highest energy collisions, give rise to localized sprays of energetic particles called "jets". These jets of hadrons are highly collimated along the axis of the initially scattered parton, and characteristically carry large components of momentum transverse to the axis of the colliding nuclei. Thus, while the average transverse momentum (p_T) of hadrons produced in nuclear collisions is a few hundred MeV/c, hard-scattering processes in very high-energy collisions give rise to a small tail in the p_T distribution that can extend out to tens of GeV/c.

Hard-scattering processes are well known in high-energy collisions of elementary particles, such as proton–proton collisions. Their observation was one of the early, compelling arguments for the existence of quark sub-structure in hadrons. By measuring the properties and momenta of the particles in a jet, one can reconstruct the kinematic and quantum properties of the initially scattered parton, and the measurements can be compared with readily calculable predictions of QCD.

These processes can now be seen at RHIC for the first time in nuclear collisions. They provide a direct signal of high-energy quarks or gluons emerging from the initial collision stage. Significantly, the early RHIC data from gold–gold collisions showed a deficit of high transverse-momentum particles from jets in collisions where the highest total number of particles is produced – that is, in the most violent collisions, where the evidence indicates that hot matter is formed. This effect, dubbed "jet quenching", is one of the most striking indicators of possible new physics in these collisions.

It may be that the observed deficit of high-energy jets in these collisions is the result of a slowing down, or quenching, of the most energetic quarks as they propagate through a newly formed medium consisting of a dense quark–gluon plasma. If this is the case, then these measurements can provide a quantitative means of determining the properties of the primordial matter, in effect providing a direct probe of the plasma with beams of energetic partons.

First, however, it is important to verify this energy-loss interpretation of the observed jet quenching in gold–gold collisions. Recent theoretical work has conjectured that in very high-energy nuclear interactions the initial-state density of partons (mostly gluons) becomes so high that the effective number of interacting particles in the collision saturates, limiting the number of hard-scattering events. Thus, another possible interpretation of the paucity of jets might simply be that the wavefunction of a nucleus during a high-energy collision is significantly different from that of a superposition of nucleons.

The question of whether the observed jet quenching is the result of initial-state saturation effects or energy loss due to a dense final-state medium, can be checked experimentally by colliding a nucleon with a nucleus and seeing if there is a difference relative to nucleon–nucleon collisions. Effects due to initial-state saturation effects, which are intrinsic to the properties of the nucleus, will appear in these collisions of a small probe with a heavy nucleus, whereas those due to energy loss in a dense medium, which should only be produced after the collision of two heavy nuclei, will not appear. To provide this comparison, RHIC carried out a two-month programme of deuteron–gold collisions, beginning in March 2003, with each beam accelerated to 100 GeV/ nucleon (as in the gold–gold collisions).

In the first results from this run, all four of the RHIC experiments (BRAHMS, PHENIX, PHOBOS and STAR) produced data showing ▷

no indication of suppression at large transverse momenta for deuteron–gold collisions, clearly indicating that the initial-state effects are small, and the suppression effect observed at large transverse momentum in gold–gold collisions is indeed due to jet energy loss. This result is strikingly illustrated by the back-to-back correlation data from STAR (see figure on p19). A recoil jet peak is present in deuteron–gold collisions, as it is in proton–proton collisions, but is suppressed in the gold–gold data.

The data analysed so far at RHIC give convincing evidence that high-energy collisions of heavy nuclei do indeed trigger the production of a hot, dense medium of final-state particles that is characterized by strong collective interactions at very high-energy densities. More needs to be done to determine the essential properties of this matter, but these latest results provide a major step toward unveiling the long-sought quark–gluon plasma.

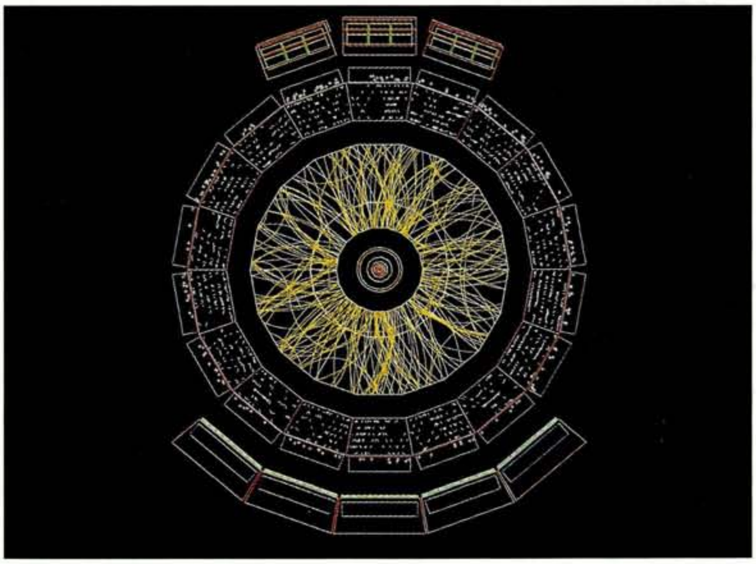
Further reading

The first results on deuteron–gold collisions from the four RHIC experiments are to be published in *Physical Review Letters*. For the preprints see: www.arxiv.org/abs/nucl-ex/0306021 (PHENIX); nucl-ex/0306025 (PHOBOS); nucl-ex/0307003 (BRAHMS); nucl-ex/0307007 (STAR).

Thomas Ludlam, *Brookhaven National Laboratory.*

ALICE prepares for still higher energies

Collisions of lead ions at the LHC will take heavy-ion physics into a new high-energy regime.



Simulation of a lead-lead collision in the ALICE detector; only a few per cent of the tracks generated in the collision are shown.

With the advent of Brookhaven's RHIC, ultrarelativistic heavy-ion physics has entered a new era of collider experiments. This will continue at CERN with the Large Hadron Collider (LHC) experiments and in particular ALICE, which is dedicated to the study of heavy-ion physics. At the LHC the centre-of-mass energy will increase by a factor of about 30 relative to RHIC energies. In collisions of two lead nuclei at the LHC, the energy density is expected to be up to one order of magnitude higher than that reached at RHIC. As a consequence, strongly interacting matter is predicted to be well within the high-temperature QCD phase, where quarks and gluons are deconfined far above the phase transition point.

The recent results from Brookhaven show that at the energies accessible at RHIC it is possible to probe the dense nuclear matter produced in gold-gold collisions through hadron production at high transverse momentum (see p18). The observation of a strong attenuation in the production of high transverse-momentum particles indicates the presence of a very dense initial state through which high-momentum partons have to plough their way into the vacuum.

Heavy-ion collisions at the LHC will not only allow access to much higher energy density, they will also probe this dense matter with a larger variety of hadron production processes at an order of magnitude higher transverse momentum. This puts the LHC in a perfect position for a detailed characterization of the properties of hot and dense QCD matter, as discussed by many theorists working in the field at the recent workshop held at CERN on "Hard probes in heavy-ion collisions at the LHC". ALICE will gain insight into both the physics of parton densities close to phase space saturation and the collective dynamical evolution of this dense nuclear environment. At LHC energies, the hard processes will contribute significantly to the total cross-section. The attenuation of the hard strongly interacting probes, which will be produced at sufficiently high rates, can be used to study the early stages of the collision. Weakly interacting probes will also become accessible and provide important benchmarks against which signals of the quark-gluon plasma can be searched for. The ratio of the lifetime of the quark-gluon plasma state to the time for thermalization is expected to be significantly larger than at RHIC, so that parton dynamics will dominate the expansion of the fireball and the collective features of the hadronic final state.

The ALICE collaboration of about 1000 physicists and engineers from about 80 institutes in 28 countries around the world has already entered the construction phase of the detector. The main challenge of the experiment is to cope with the highest particle multiplicities anticipated in the lead-lead collisions and measure up to 15 000 particles in the ALICE central detector. The construction of the main components of the detector is advancing well, and the experiment will be ready to take the first data with the startup of the LHC in 2007.

Yiota Foka, *GSI Darmstadt*, **Karel Safarik**, *CERN EP, and* **Urs Achim Wiedemann**, *CERN TH.*

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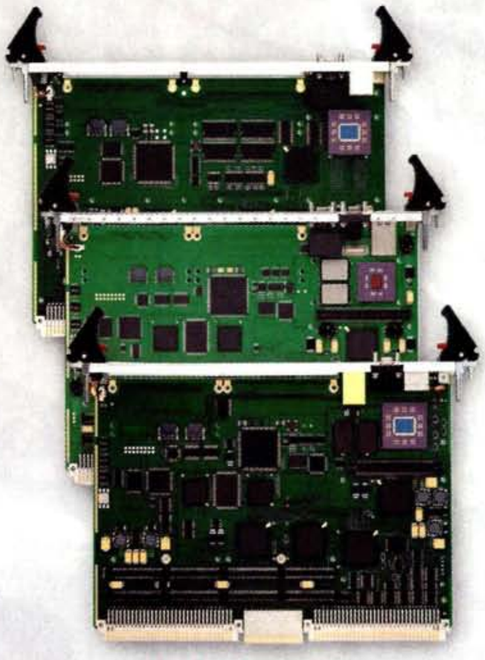

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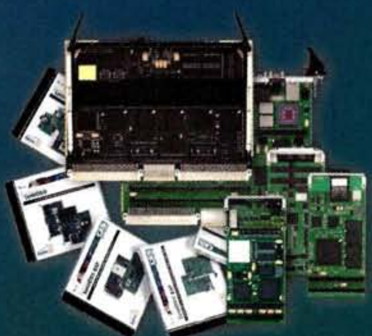

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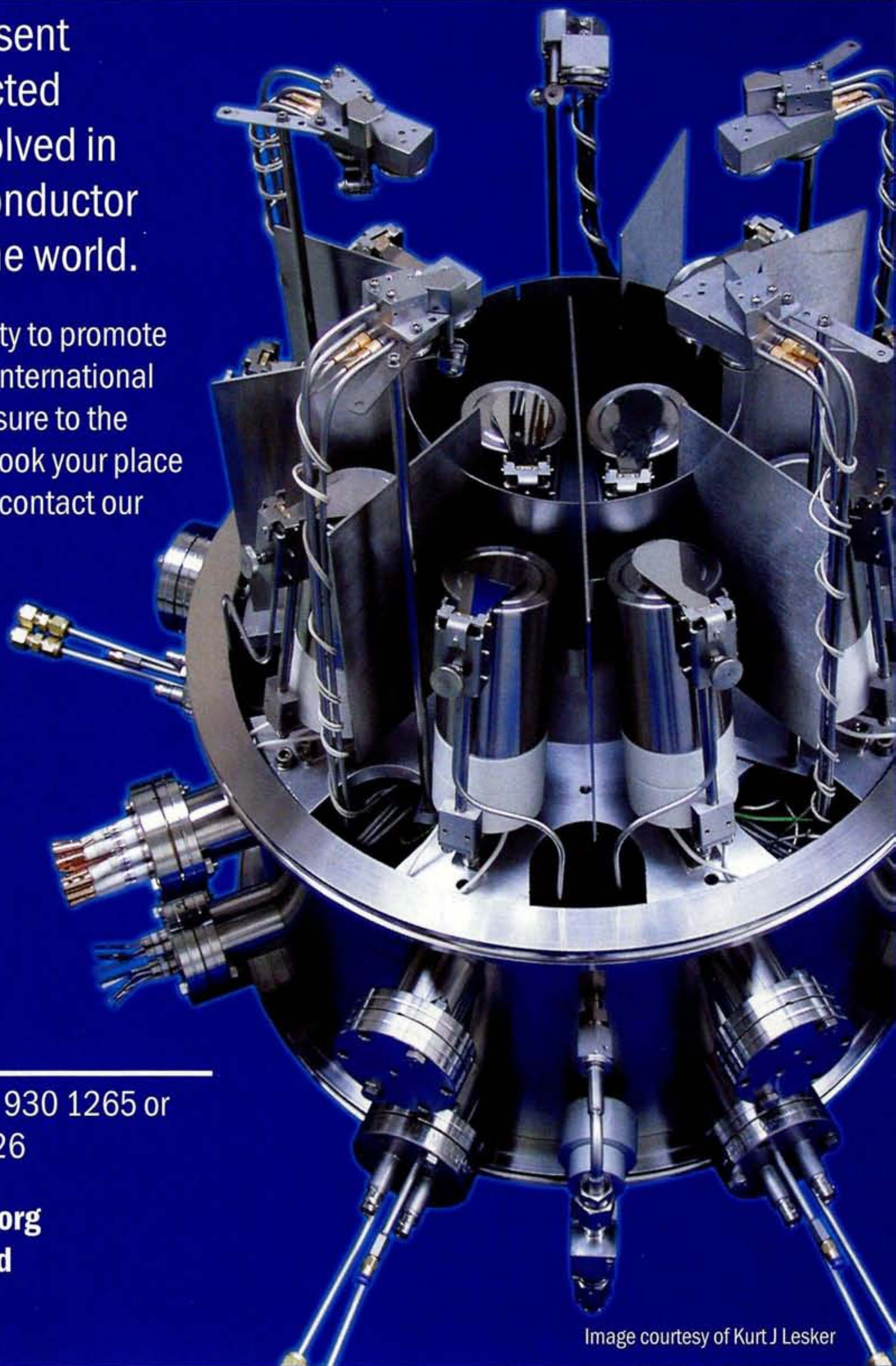

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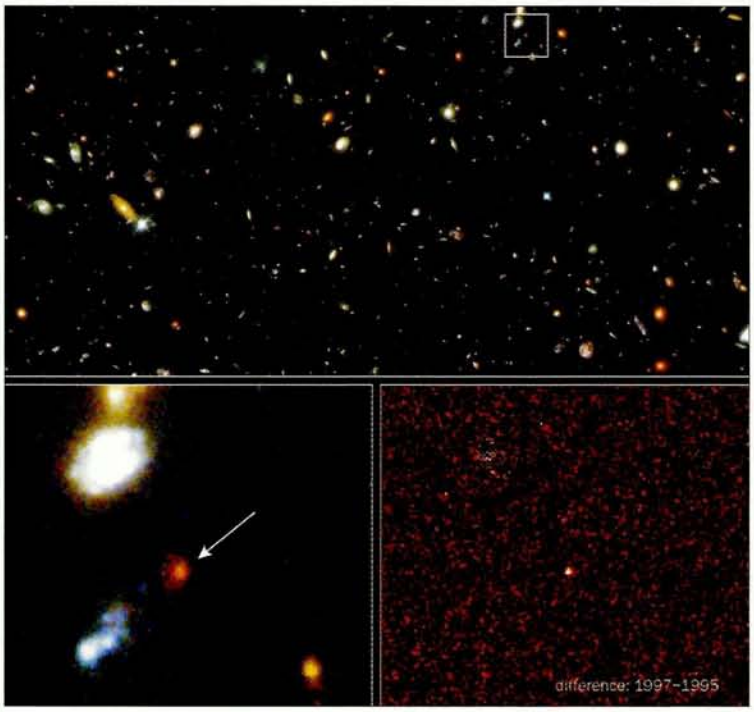
On the trail of dark energy



The detection and analysis of the most distant supernovae shows they are further away than expected, leading to the notion of some form of "dark energy" accelerating the expansion of the universe. These images from NASA's Hubble Space Telescope show supernova 1997ff in its cosmic neighbourhood (top), home galaxy (left), and the dying star itself (right). (NASA and A Riess, STScI.)

One of the most remarkable discoveries of recent years is that the universe appears to be dominated by some form of "dark energy", as **Eric Linder** explains.

Cosmology has recently achieved its version of a standard model, called the "cosmic concordance". This gives a broad picture of the components in the universe within the strongly tested framework of the hot Big Bang model. Of these components, only about 4% amount to the familiar baryons of the Standard Model of particle physics, and even some of these are "dark" or not evident directly from the light of distant objects. Another 20–25% is nonbaryonic dark matter, presumably either weakly interacting massive particles or axions, theorized elements of high-energy physics. But the majority of the energy density, some 70–75%, is detected only through its effect of accelerating the global expansion of the universe. This background energy, which is smooth out to scales larger than that of any matter structures such as clusters of galaxies, is named "dark energy".

Dark energy was first discovered in 1998 by two groups using supernovae as markers of cosmological distance as a function of time – the Supernova Cosmology Project led by Saul Perlmutter at Lawrence Berkeley National Laboratory and the High-z Supernova Search Team led by Brian Schmidt at Australian National University. Measurements indicated that distant supernovae were dimmer than expected from the cosmological inverse square law in a universe dominated by matter (S Perlmutter *et al.* 1999, A Riess *et al.* 1998). That is, they appeared to be further away than expected from the expansion rate of the universe if gravitation due to the matter contents were the main force. Some form of dark energy was required at the 99% confidence level, and in amounts sufficient to counteract, on cosmic scales, the gravitational attraction from the clustered matter.

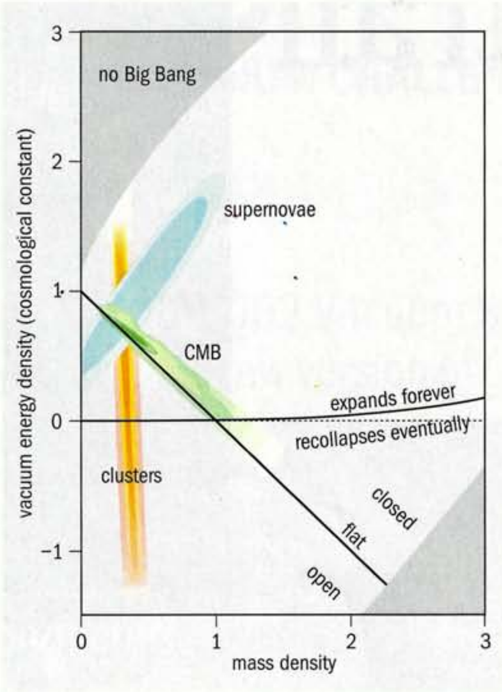
Since then, deeper and more precise supernova measurements and further lines of evidence confirm this conclusion (J Tonry *et al.* 2003, R Knop *et al.* 2003, D Spergel *et al.* 2003). Detailed measurements of the cosmic microwave background power spectrum, by the Wilkinson Microwave Anisotropy Probe satellite and by ground-based experiments, imply the presence of dark energy too. They also show that the spatial geometry of the universe is consistent with the flatness prediction of inflation. But observations of galaxy clusters tell us that the matter contribution to the total energy density can amount to only 20–30% of the needed critical density. Any two of the three lines of evidence imply that the dark energy composes roughly three-quarters of the energy density of the universe, while the third method provides a crosscheck. Such an amount of dark energy acts to accelerate the cosmic expansion.

The nature of dark energy

While gravitation due to matter or radiation is attractive, a sufficiently negative pressure p would offset a positive energy density ρ to give repulsive gravity under Einstein's equations (the gravitating density depends on $\rho+3p$), pulling on space to accelerate the expansion of the universe. Researchers often discuss this in terms of the equation of state ratio of the pressure to energy density: $w=p/\rho$.

Negative pressures are not a wholly exotic phenomenon. After all, one of the equations of expansion of the universe, the Friedmann equation, looks remarkably similar to the first law of thermodynamics: $d(\rho V)=-pdV$, where V is the volume considered. Negative pressure leads to an overall plus sign, turning this equation into something that looks like the tension in a spring or rubber band. Such a "springiness" of space was postulated soon after Einstein developed the general theory of relativity in his cosmological constant term, and Hermann Weyl attempted to link such a background energy to the quantum vacuum. If the vacuum is a true ground state then all observers must agree on its form. But the only Lorentz invariant energy-momentum tensor is the diagonal Minkowski tensor that has negative pressure equal and opposite to its energy density, that is, the cosmological constant has equation of state ratio $w=-1$. This would cause an accelerating universe.

So why are cosmologists not satisfied with identifying the cosmological constant with dark energy? In *The Hunting of the Snark* – the poem by Lewis Carroll, who was in fact Charles Dodgson, a mathematician at Oxford – when the explorers set sail to find the mysterious snark, the captain "had bought a large map representing the sea, without the least vestige of land: and the crew were much pleased when they found it to be a map they could all understand." The cosmological constant term is such a featureless sea, but there are two problems with using it to describe our universe. The expected sea level for the quantum vacuum is much higher than we observe: naively one should indeed have a featureless universe, with matter drowned by 120 orders of magnitude below the energy density of the cosmological constant. But the cosmic concordance measures only a factor of a few difference. Furthermore, the matter and radiation we see in the universe evolves with the expansion of the universe, while the cosmological constant does not. Even an order of magnitude equality between them occurs in only one characteristic timescale (e-folding), out of the 23 in the expansion of the universe since the well-understood epoch of nuclei formation in the early universe. (See S Weinberg 1989 and S Carroll 2001 for more on these fine-tuning and coincidence puzzles.)



Since the discovery, through Type Ia supernovae, that the expansion of the universe is accelerating and dominated by something like a vacuum energy density, this and other methods have added strong confirmation (supernova data: R Knop et al. *2003; CMB: D Spergel* et al. *2003; clusters: S Allen* et al. *2002). Today the picture is of a spatially flat universe consisting of only 30% dark matter and baryons, while 70% acts like an accelerating cosmological constant or dark energy.*

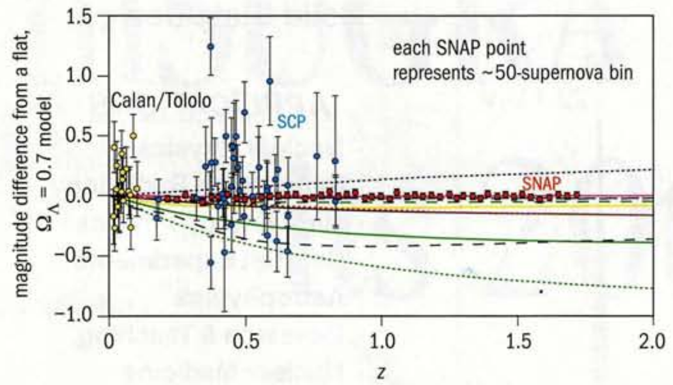
Hunting the dark energy

Researchers are thus driven to consider other explanations for the dark energy. Models with dynamical high-energy physics fields, often called "quintessence" when involving a simple scalar field, go some way toward alleviating the timing or coincidence puzzle, though there is still no clear underlying theory explaining the current effective energy density. Such a field would need an effective mass of 10^{-33} eV, that is, with a Compton wavelength of the order of the radius of the universe. However, there are rich attempts at phenomenology stretching back two decades (longer if scalar-tensor theories of gravitation are included). An early high-energy physics model was proposed by Andrei Linde in 1986, demonstrating how a linear potential could give rise to accelerating expansion. On the cosmology side, Robert Wagoner in 1986 examined how a general equation of state component would not only affect the expansion, but could be observationally probed with cosmological distance and age measurements.

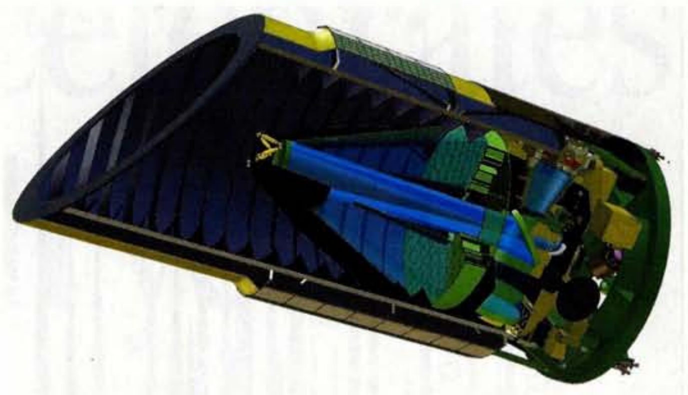
Both the modelling of and the investigation of the observational consequences of dark energy are now active industries within research in cosmology, covering a wide variety of the physics of the early and late universe. In general, the dark-energy equation of state will vary with time and so needs to be probed with observations over a range of epochs, or astronomical redshifts z (the fractional difference in the scale of the universe today relative to an earlier time). The major challenge over the next few years in cosmology will be to characterize the equation of state function $w(z)$. On the phenomenology front, one might hope for a natural, robust model to emerge, but the theorists' prolificness seems too great for this to settle the question. Indeed, models beyond scalar fields involving modifications of general relativity, extra dimensions, or quantum-phase transitions have also been proposed. Fortunately these can be written in terms of an effective $w(z)$ (E Linder and A Jenkins 2003) and subjected to cosmological measurements.

Three main routes to probing dark energy exist in cosmology. The first, and currently most favoured, involves mapping the expansion history of the universe. The second seeks to measure the growth rate of the formation of large-scale structures such as clusters of galaxies. The third involves the cosmic microwave background radiation – looking not for the time variation of the dark energy (since the cosmic microwave background photons effectively all come from the same redshift), but for the subtle spatial fluctuations in the dark-energy distribution on cosmic scales. Observations of Type Ia supernovae, which first discovered the dark energy in 1998, fall in the first category and seem the most promising. The second and third approaches are likely to run into limits imposed, respectively, by uncertainties involving entangled astrophysics and cosmic variance (intrinsic uncertainty due to observing only one universe). However, new methods and cross correlations between probes may eventually be practical.

In mapping the expansion history, cosmologists probe the deceleration due to the gravitation of matter and the acceleration due to dark energy at various epochs. Variations in the growth of distances reveal a picture of the cosmic environment, and hence the dynamic influence of dark energy, in the way that the width of tree rings indicates the Earth's climatic environment over time. Type Ia supernovae can be seen to great distances and calibrated in luminosity (made "standard candles" through detailed observations). Thus the measurement of the received flux directly indicates their distance, and hence the time in the past they exploded, while the redshift of the photons is simply the ratio of the size of the universe now relative to then. Together these give the exact expansion history.



Future data, here simulated, of binned distance-redshift measurements from SNAP, will allow detailed exploration of the nature of dark energy. In particular, we will gain clues to the underlying physics from the time variation of the dark-energy properties. The curves show a variety of high-energy physics models in the literature (adapted from Weller and Albrecht 2002).



Cutaway view of the SNAP satellite, showing its major elements. The 2 m telescope can precisely find and observe supernovae more than 10 billion light-years away. The wide-field, half-billion pixel imager and spectrograph accurately characterize their properties, calibrating the supernovae for use as cosmological "standardized candles". (Lawrence Berkeley National Laboratory.)

Future endeavours

The best current supernova data extend out only to redshift $z \approx 1$ (when the scale of the universe was $1/(1+z) = 1/2$ its current size) with any reasonable statistics, but they already constrain the averaged equation of state ratio to $w = -1.05^{+0.15}_{-0.20}$ (R Knop *et al.* 2003) or $w = -1.0^{+0.14}_{-0.24}$ (J Tonry *et al.* 2003). Clues to the underlying physical theory, however, reside in the dynamics, the time-varying function $w(z)$. A dedicated dark-energy mission, the Supernova/Acceleration Probe (SNAP) satellite, is being designed to determine the present value w_0 to 7% and derivative $w' = dw/dz$ to ±0.15 (1 σ, including both statistical and systematic uncertainties). Led by Michael Levi and Saul Perlmutter of the Lawrence Berkeley National Laboratory, the project involves over 100 scientists and engineers from more than 15 institutions, including France and Sweden. Launch is proposed for 2010.

Meanwhile, an intense research effort continues. One example is the European Dark Energy Network (EDEN), a proposed European Union research training network of 13 nodes (including CERN, led by Gabriele Veneziano), coordinated by Pedro Ferreira of Oxford. Models attempt to link dark energy to dark matter, extra dimensions, modifications of gravity and a zoo of simple and non-minimally coupled scalar fields. These predict a range of values for the equation of state ratio w_0, within the current constraints, and a wholly open variety of w', both positive and negative. Some even lead to an eventual reversal of the acceleration and a collapse of the universe. It is amusing that the first dark-energy model, the linear potential, possesses this quality. Future data will constrain the allowed parameters of classes of high-energy physics models and the fate of the universe, including how long we have left until a cosmic doomsday! (See R Kallosh *et al.* 2003 for the linear potential case leading to a Big Crunch and R Caldwell *et al.* 2003 for a Big Rip.)

Can signs of the nature of dark energy be uncovered at particle accelerators? It is difficult to see how. The energy scale of the physics is presumably of the order 10^{16} GeV, and by its "dark" nature the coupling to matter is vanishingly small. On scales smaller than the universe, the dynamical effect of dark energy is negligible. The entire dark-energy content within the solar system equals that of three hours of solar luminosity. Perhaps if the physics involves the modification of gravity or extra dimensions, a precise laboratory test could see a signature (see E Adelberger *et al.* 2003 for a current experiment). But the true hunting grounds for the nature of dark energy and the physics causing the acceleration of the universe lie in cosmology. Just as advances have been made in the past two decades in theory and observations beyond the simplistic view of early universe inflation as a pure deSitter phase – "sea without the least vestige of land" – so too will dark-energy studies delve deeper into fundamental physics. Instruments now being designed could tell us within the next decade whether we must come to grips with a minuscule but finite cosmological constant or some exciting new dynamical physics.

Further reading

For more information on SNAP, see http://snap.lbl.gov.

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Eric Linder, *Lawrence Berkeley National Laboratory and Center for Cosmology, Florida Atlantic University.*

mSUGRA celebrates its 20th year

The SUGRA20 conference recently celebrated the 20th anniversary of the invention of minimal supergravity grand unification, or mSUGRA, as **Paul Frampton** and **Pran Nath** describe.

Participants at the SUGRA20 conference, which was held at Northeastern University, Boston, including, in the front row second from left, Peter Nilles, then moving right, Sergio Ferrara, Ali Chamseddine, Pran Nath (conference chair), Richard Arnowitt, Bruno Zumino and Michael Duff. In the second row, fourth from left, Paul Frampton, then moving right, Stephen Barr, Jogesh Pati and Antonio Masiero.

The invention of minimal supergravity grand unification – mSUGRA – had a profound influence on the phenomenology of supersymmetry, and now mSUGRA is a leading candidate for yielding new physics beyond the Standard Model. A current assessment of mSUGRA in the search for unification and supersymmetry was the focus of the SUGRA20 conference held on 17–20 March at Northeastern University in Boston, where mSUGRA first evolved 20 years ago.

In supersymmetry, each particle has a superpartner – a sparticle – with a spin that differs by half a unit. The particles and sparticles should have the same mass, for example the mass of a quark should be equal to that of its superpartner, the squark, but this is contrary to observation. A mechanism for breaking supersymmetry is therefore crucial if theories that include supersymmetry are to confront experiment.

Models based on so-called global supersymmetry or rigid supersymmetry lead to a pattern of sparticle masses that are also in contradiction with experiment – for example, a squark mass may lie below the quark mass. They also yield a cosmological constant that is in gross violation of observation. However, both these obstacles are removed in supergravity grand unification and its minimal version, mSUGRA, which was first formulated by Ali Chamseddine, Richard Arnowitt and Pran Nath at Northeastern University in 1982 (Chamseddine *et al.* 1982).

The framework of supergravity grand unification is the so-called applied supergravity, where matter (quarks, leptons and Higgs particles) is coupled with supergravity and the potential of the theory is not positive definite. The breaking of supersymmetry in mSUGRA takes place through a "super Higgs" effect where the massless gravitino, which is the spin 3/2 partner of the graviton, becomes massive by "eating" the spin 1/2 component of a chiral super Higgs multiplet. This is a phenomenon akin to the Higgs–Kibble mechanism through which the W boson gains mass by absorbing the charged compo- ▷

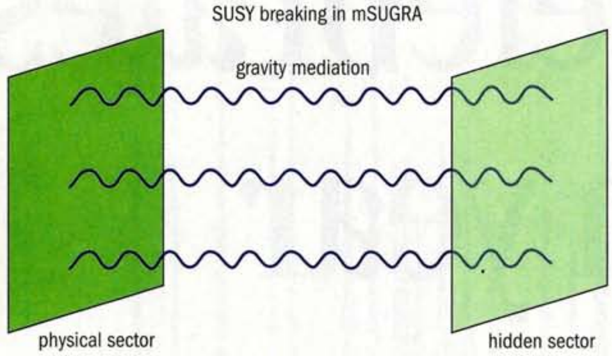

Fig. 1. The communication of supersymmetry breaking from the hidden to the physical sector by gravity.

nent of a Higgs doublet in the Glashow–Salam–Weinberg model.

mSUGRA has an ingenious mechanism to protect the electroweak scale from "pollution" by the high-energy scales of the Planck mass M_{Planck} (2.4×10^{18} GeV) and the grand unification mass M_{GUT} (2×10^{16} GeV). In mSUGRA, supersymmetry breaking occurs in the hidden sector and is communicated by gravitational interactions to the physical sector, where physical fields such as leptons, quarks, Higgs and their superpartners reside (see figure 1). Since the vacuum energy of the theory is not positive definite, it is possible to fine-tune the vacuum energy to zero (or nearly zero) after the spontaneous breaking of supersymmetry, and so avoid any contradiction with experiment. Further, as a consequence of the communication between the hidden and physical sectors, soft breaking terms arise in the physical sector. These give masses to sparticles and generate non-vanishing trilinear couplings among scalar fields. Thus, for example, the squarks and selectons gain masses of the size of the electroweak scale and fall within reach of colliders such as the Tevatron at Fermilab and the Large Hadron Collider (LHC) at CERN.

A remarkable aspect of the hidden-sector/physical-sector mechanism is that the mass generation in the physical sector does not involve terms of the size of M_{Planck} – which is fortunate given the large size of M_{Planck}. A similar result was found by Riccardo Barbieri of Pisa, Sergio Ferrara of CERN and Carlos Savoy of Saclay, who also achieved soft breaking through the hidden-sector mechanism (Barbieri *et al.* 1982). Equally remarkable is the result found by Chamseddine, Arnowitt and Nath that the grand unification scale M_{GUT} cancels in the computation of soft parameters (Chamseddine *et al.* 1982, Nath *et al.* 1983). The soft parameters are thus shielded effectively from the high-energy scales of M_{Planck} and M_{GUT}. There are many later analyses where grand unification within supergravity has been discussed in further detail (Hall *et al.* 1983, Nilles 1984). In mSUGRA, universality of the soft parameters leads to a suppression of the flavour-changing neutral currents that is compatible with experiment. Furthermore, the mSUGRA model can be easily generalized to include non-universalities in certain sectors of the theory, maintaining consistency with experiment.

mSUGRA provides a dynamical explanation of the electroweak symmetry breaking that splits the weak nuclear force from electromagnetism and gives mass to the W and Z bosons. In the Standard Model this is done by giving a negative squared mass to the Higgs field, which can be considered contrived. In mSUGRA the breaking of supersymmetry naturally triggers the breaking of electroweak symmetry and leads to predictions of masses of sparticles lying in the 100 GeV–TeV energy range.

The SUGRA20 conference opened with talks that looked at the current and future prospects for experimental tests of mSUGRA. Xerxes Tata of Hawaii discussed the constraints on the sparticle masses from various experiments including the recent Brookhaven experiment on $g_\mu-2$. Speakers in several other talks pointed out that the most direct test of mSUGRA and other competing models will come in accelerator experiments at Run II of the Tevatron, at the LHC and at the Next Linear Collider (NLC). Such tests for the Tevatron were outlined by Michael Schmitt of Northwestern, while Frank Paige from Brookhaven National Laboratory and Stephno Villa of California, Irvine, discussed the possibilities for the ATLAS and CMS detectors at the LHC. Richard Arnowitt from Texas A&M discussed similar tests for the NLC.

mSUGRA also possesses the remarkable feature that it provides a natural candidate – the so-called neutralino – for cold dark matter in the universe. The talks by Howard Baer of Florida and Keith Olive of Minnesota revealed that the predictions of cold dark matter in mSUGRA and its extensions are consistent with the most recent data from the satellite experiment, the Wilkinson Microwave Anisotropy Probe. David Cline from UCLA later outlined future dark-matter experiments (GENIUS, ZEPLIN) to test mSUGRA and other competing models.

There were also talks in several areas complementary to the main theme of the conference. Mary K Gaillard of Berkeley discussed the connection of SUGRA models to strings, while the idea of conformal quiver gauge theories with a novel type of grand unification at about 4 TeV was explained by Paul Frampton of North Carolina. Other more theoretical ideas included talks on strong gravity by Ali Chamseddine from Beirut, on M theory by Michael Duff of Michigan, and on non-commutative geometry by Bruno Zumino from Berkeley.

Northeastern University, as a key player in the birth of mSUGRA 20 years ago, provided an ideal location for SUGRA20. While mSUGRA remains only a model, more than 100 participants at the conference expressed optimism that future experimental data may convert it from a theoretical model to an established theory.

Further reading

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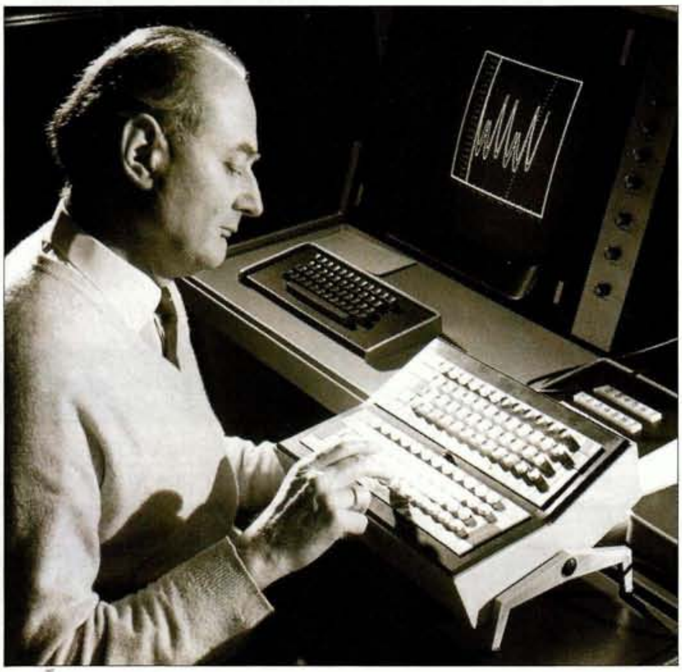
The programme of the SUGRA20 conference can be found at http://www.sugra20.neu.edu.

Paul Frampton, *University of North Carolina at Chapel Hill, and* **Pran Nath**, *Northeastern University, Boston.*

The tale of the Hag

Johann Rafelski and **Torleif Ericson** recall Rolf Hagedorn's discovery of a limiting temperatu



Rolf Hagedorn, seen here working at CERN in 1968.

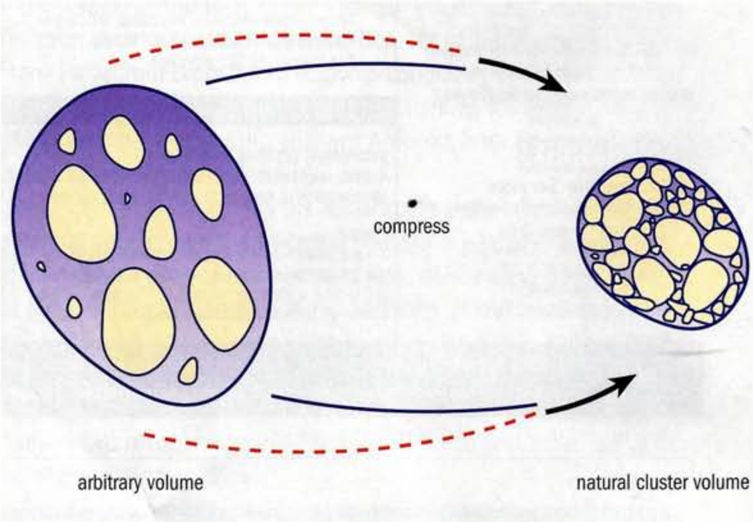


Fig. 1. An illustration of the statistical bootstrap idea. When a drop comprising hadronic particles and resonances is compressed to the "natural volume", it becomes another more massive resonance. This process then repeats, creating heavier resonances, which consist of hadron resonances, which in turn consist of resonances, and so on.

Collisions of particles at very high energies generally result in the production of many secondary particles. When first observed in cosmic-ray interactions this effect was unexpected, but it led to the idea of applying the wide body of knowledge of statistical thermodynamics to multiparticle production processes. Prominent physicists such as Enrico Fermi, Lev Landau and Isaak Pomeranchuk made pioneering contributions to this approach, but because difficulties soon arose it did not initially become the mainstream for the study of particle production. However, it was natural for Rolf Hagedorn to turn to the problem.

Hagedorn, who died earlier this year (see obituary, p45), had an unusually varied educational and research background, which included thermal, solid-state, particle and nuclear physics. His initial work on statistical particle production led to his prediction, in the 1960s, of particle yields at the highest accelerator energies at the time at CERN's proton synchrotron. Though there were few clues on how to proceed, he began by making the most of the "fireball" concept, which was then supported by cosmic-ray studies. In this approach all the energy of the collision was regarded to be contained within a small space–time volume from which particles were radiated, as in a burning fireball.

Several key ingredients brought from early experiments helped him to refine the approach. Among these observations, the most noticeable was the limited transverse momentum of the overwhelming majority of the secondary particles. Also, the elastic scattering cross-section at large angles was found to drop exponentially as a function of incident energy. Such behaviour strongly suggested an inherently thermal momentum distribution.

However, many objections were raised in these pioneering days of the early 1960s. What might actually be "thermalized" in a high-energy collision? Applying straightforward statistical mechanics gave too small a yield of pions. Moreover, even if there was a thermalized system in the first place, why was the apparent temperature constant? Should it not rise with incident beam energy?

It is to Hagedorn's great credit that he stayed with his thermal interpretation, solving the problems one after the other. His particle-production models turned out to be remarkably accurate at predicting yields for the many different types of secondaries that originate in high-energy collisions. He understood that the temperature governing particle spectra does not increase, because as more and more energy is poured into the system new particles are produced. It is the entropy that increases with the collision energy. If the number of particles of a given mass (or mass spectrum) increases exponentially, the temperature becomes stuck at a limiting value. This is the Hagedorn temperature T_H. It is nearly 160 MeV, about 15% above the mass of the lightest hadron, the pion.

edorn temperature

– in effect a melting point for hadrons – and its influence on the physics of strong interactions.

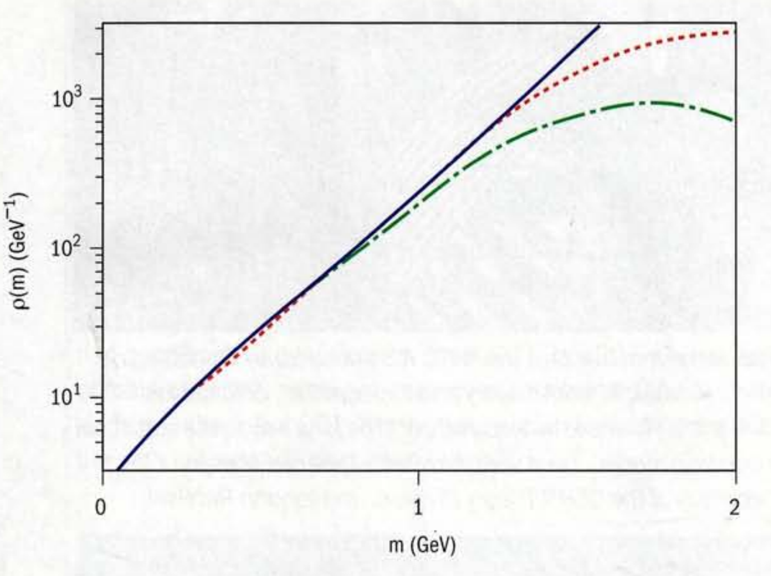


Fig. 2. The smoothed mass spectrum of hadronic states as a function of mass. Experimental data: long-dashed green line with the 1411 states known in 1967; short-dashed red line with the 4627 states of 1996. The solid blue line represents the exponential fit yielding T_H=158 MeV.

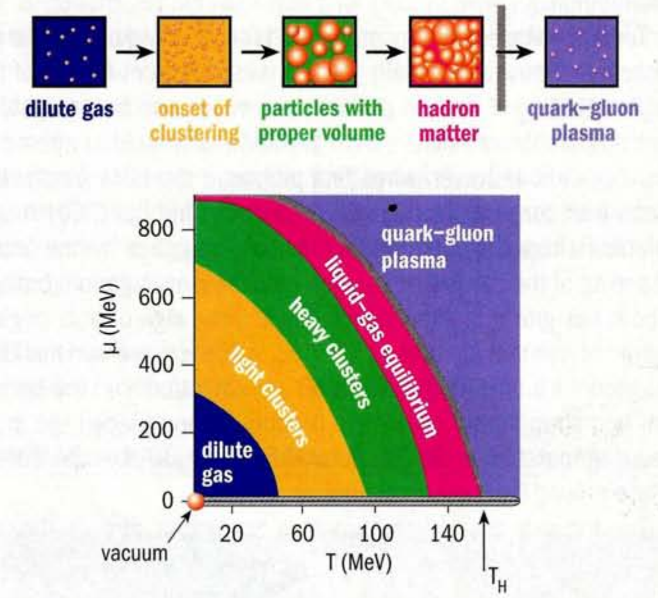


Fig. 3. The different regions of the statistical parameter plane (temperature, T, and the baryochemical potential, μ), according to the statistical bootstrap model of hadronic matter.

Since the more massive resonances eventually fragment into less massive ones to yield the observed secondary particles as the "bottom line", this solved the problem of the pion yield. The factor $1/n!$, which originated in the quantum indistinguishability of identical particles, had plagued the statistical calculations that focussed on pions only. Now it had become unimportant as each one of the many states was unlikely to have a population, n, exceeding 1. At long last agreement between experiment and statistical calculations prevailed.

The statistical bootstrap model

Once the physical facts had been assembled, Hagedorn turned his attention to improving their theoretical interpretation, and in considering the experimental finding that the formation of resonances dominates the scattering cross-section, he proposed the statistical bootstrap model (SBM). In a nutshell, in the SBM each of the many resonant states into which hadrons can be excited through a collision is itself a constituent of a still heavier resonance, whilst also being composed of lighter ones. In this way, when compressed to its natural volume, a matter cluster consisting of hadron resonances becomes a more massive resonance with lighter resonances as constituents, as shown in figure 1.

One day in 1964, one of us (TE) ran into Hagedorn, who was bubbling over to a degree we had not seen before. His eyes were lit up as he described all these fireballs: fireballs going into fireballs living on fireballs forever and all in a logically very consistent way. This must have been soon after he had invented the statistical bootstrap. He gave the impression of a man who had just found the famous philosophers' stone, and that must have been exactly how he felt about it. Clearly Hagedorn immediately recognized the importance of the novel idea he had introduced. It was very interesting to observe how deeply he felt about it from the very beginning.

Using the SBM approach for a strongly interacting system, Hagedorn obtained an exponentially rising mass spectrum of resonant states. Today, experimental results on hadronic level counting reveal up to almost 5000 catalogued resonances. They agree beautifully with theoretical expectations from the SBM, and as our knowledge has increased, the observed mass spectrum has become a better exponential, as illustrated in figure 2. The solid blue line in figure 2 is the exponential fit to the smoothed hadron mass spectrum of the present day, which is represented by the short-dashed red line. Note that Hagedorn's long-dashed green line of 1967 was already a remarkably good exponential. One can imagine that the remaining deviation at high mass in the top right corner of the figure originates in the experimental difficulties of discovering all these states. ▷

The important physics message of figure 2 is that the rising slope in the mass spectrum is the same as the falling slope of the particle momentum spectra. The momentum spectra originate in the thermalization process and thus in reaction dynamics; the mass spectrum is an elementary property of strong interactions. The SBM provides an explanation of the relationship between these slopes, and explains why the temperature is bounded from above. Moreover, since the smallest building block of all hadronic resonances is the pion, within the SBM one can also understand why the limiting temperature is of the same magnitude as the smallest hadron mass $T_H \cong m_\pi$.

Today the Hagedorn temperature T_H is like a brand name, and the concept of an exponentially rising mass spectrum is part of our understanding of hadron phenomena, which can be understood using approaches different from the SBM, such as that offered by dual models. However, when first proposed the SBM was looked upon with considerable scepticism, even within the CERN Theory Division where Hagedorn worked. As time has gone by, the understanding of the particle-production process that Hagedorn brought about has grown in significance, such is the sign of truly original work, of something that really had influence on our thinking. Hagedorn's article (Hagedorn 1965), which introduced the statistical bootstrap model of particle production and placed the maximum temperature in the vocabulary of particle physics, has found a place among the most cited physics papers.

The accurate description of particle production, through the conversion of energy into matter, has numerous practical implications. Even in the very early days, Hagedorn's insight into the yields and spectra of the produced secondaries showed that neutrino beams would have sufficient flux to allow a fruitful experimental program, and this gave a theoretical basis for the planning of the first neutrino beams constructed at CERN.

Rolf Hagedorn (right) at the NATO Advanced Study Workshop on "Hot Hadronic Matter: Theory and Experiment", Divonne-les-Bains, 1994, where he lectured on: "The long way to the statistical bootstrap model". He is seen here with Tatiana Faberge, secretary of the CERN Theory Division, and Johann Rafelski.

Quark–gluon plasma

At the same time that the SBM was being developed, the newly discovered quarks were gaining acceptance as the building blocks of hadrons. While Hagedorn saw a compressed gas of hadrons as another hadron, in the quark picture it became a drop of quark matter. In quark matter at high temperatures gluons should also be present and as the temperature is increased asymptotic freedom ensures that all constituents are interacting relatively weakly. There seems to be nothing to stop a dense assembly of hadrons from deconfining into a plasma of quarks and gluons. It also seems that this new state of matter could be heated to a very high temperature, with no limit in sight. So what is the meaning of the Hagedorn temperature in this context?

In the SBM as conceived before quarks, hadrons were point particles. A subtle modification is required when considering quarks as building blocks. Hadrons made of quarks need a finite volume that grows with hadron mass. One of us (JR) worked on this extension of the SBM with Hagedorn at the end of the 1970s and in the early 1980s. We discovered that at the Hagedorn temperature, finite-size hadrons dissolve into a quark–gluon liquid. Both a phase transition and a smoother transformation are possible, depending on the precise nature of the mass spectrum. The most physically attractive alternative was a first-order phase transition. In this case the latent heat is delivered to the hadron phase at a constant Hagedorn temperature T_H. A new phase is then reached wherein the hadron constituents – the quarks and the gluons – are no longer confined. The system temperature can now rise again.

Within the study of hot hadronic matter today, the Hagedorn temperature is understood as the phase boundary temperature between the hadron gas phase and the deconfined state of mobile quarks and gluons (see figure 3). Several experiments involving high-energy nuclear collisions at CERN's Super Proton Synchrotron (SPS) and at RHIC at the Brookhaven National Laboratory are testing these new concepts. Nuclei, rather than protons, are used in these experiments in order to maximize the volume of quark deconfinement. This allows a clearer study of the signature of the formation of a new phase of matter, the quark–gluon plasma (QGP).

The current experimental objective is the discovery of the deconfined QGP state in which the hadron constituents are dissolved. This requires the use of novel probes, which respond to a change in the nature of the state of matter within the short time available. More precisely, the heating of hadronic matter beyond the Hagedorn temperature is accompanied by a large collision compression pressure, which is the same in magnitude as the pressure in the very early universe. In the subsequent expansion, a collective flow velocity as large as 60% of the velocity of light is exceeded at RHIC. The expansion occurs on a timescale similar to that needed for light to transverse the interacting nuclei.

In the expansion-cooling process of QGP formed in nuclear collisions, the Hagedorn temperature is again reached after a time that corresponds to the lifespan of a short-lived hadron. A break up – that is, hadronization – then occurs and final-state hadrons emerge. Hagedorn was particularly interested in understanding the hadronic probes of QGP produced in hadronization. He participated in the initial exploration of the strangeness flavour as a signal of QGP formation.

In February 2000 the totality of intriguing experimental results obtained at the SPS over several years was folded into a public announcement stating that the formation of a new phase of matter was their best explanation (*CERN Courier* April 2000 p13 and May 2000 p25). The key experimental results, including, in particular, strangeness and strange antibaryon enhancement, agreed with the theoretical expectations that were arrived at when one assumes that the QGP state was formed.

In mid-June 2003 the researchers at RHIC announced results that show that this new phase of matter is highly non-transparent to fast quarks, which is once more along the lines of what is expected for QGP (see p18). Many researchers believe that the deconfined phase has therefore been formed both at the SPS and at RHIC. The thrust of current research is to identify the conditions that are necessary for the onset of QGP, and to understand the initial reaction conditions in dense matter (see p17). In 2007 when a new domain of collision energy becomes accessible at CERN's Large Hadron Collider, hot QGP in conditions similar to those present in the early universe will be studied (see p20).

In the next few years, the study of hadronic matter near the Hagedorn temperature will also dominate experimental efforts in the field of nuclear collisions, in particular at the new international experimental facility to be built at the GSI laboratory in Darmstadt, Germany. The richness of the physics at hand over the coming years is illustrated in the phase diagram in figure 3, which was obtained from the study of the SBM. Here, the domain is spanned by the temperature, T, and the baryochemical potential, μ, which regulates the baryon density.

In almost 50 years the understanding of the physics related to the Hagedorn temperature has changed. In the beginning it was merely the maximum temperature seen in proton–proton collisions. It then became the SBM inverse slope of the mass spectrum. Today, it denotes the phase boundary between hadron and quark matter. Moreover, as recent work in string theory has shown, Rolf Hagedorn will not only be remembered for the physics of hot hadronic matter: his name is already attached to a more general family of elementary phenomena that originate in the methods he developed in the study of strong interaction physics.

Further reading

R Hagedorn 1965 *Nuovo Cim. Suppl.* **3** 147.

Torleif Ericson, *CERN, and* **Johann Rafelski**, *University of Arizona.*

Frontier techniques for particle physics and beyond

Giorgio Chiarelli reports from the 9th Pisa Meeting on Advanced Detectors, held this year on the island of Elba.

The final week of May saw the traditional gathering of the Frontier Detectors for Frontier Physics Conference (FD4FP) at the 9th Pisa Meeting on Advanced Detectors. The meeting was the sixth to be held on the island of Elba, and more than 300 participants – including physicists and representatives of the high-tech industries involved in the R&D of high-energy particle physics – discussed the latest results from the work that lies at the core of experimental particle physics: the design, building and running of particle detectors.

Participants enjoy one of the plenary sessions at the 9th Pisa Meeting on Advanced Detectors.

The 250 oral and poster contributions were divided among seven sessions covering different aspects of the field: calorimetry, tracking with solid-state devices, tracking with gaseous detectors, detectors for fundamental physics and astroparticle physics, front-end electronics, trigger and data acquisition, and particle identification. As has been the case for many years, a special session was also devoted to the application of particle detectors and particle-physics techniques to other fields.

The first day – opened by Lello Stefanini of Pisa, chairman of the FD4FP Executive Board, and Umberto Dosselli of Padova, on behalf of the International Advisory Committee – saw Richard Wigmans of Texas Technical summarize the current state of detector R&D. Wigmans stressed the growing importance of the use of particle detectors in other fields, first and foremost in astroparticle physics. This is a trend that is not only supplying different areas of research with new tools, but that also provides new challenges for detector builders. Guido Altarelli of CERN presented a clear view of the physics that lies ahead, that is, the basis for R&D in the field. Looking to the future, Les Robertson of CERN discussed the prospects and needs of computing in the era of the Large Hadron Collider (LHC), and also described the aims and status of the Grid. Rolf Heuer of Hamburg brought the audience up to date with worldwide initiatives and new ideas about the linear collider and how it can be established as a global project.

Whilst it is almost impossible to summarize a week full of presentations and discussions, and give proper recognition to everyone, a selection of the contributions should give a flavour of the topics discussed. For example, in the Gas Detectors session, Werner Riegler from CERN presented a detailed study of the behaviour of resistive plate chambers. By going back to the drawing board and slowly but carefully studying space charge effects, he showed how a suppression factor of 10^7 for the collected charge can be explained in these devices.

Talks on experiences with large solid-state detectors highlighted the obstacles to be overcome when running such devices. Contributions by BaBar and CDF showed that only ingenuity, dedication and a continuous R&D effort can provide "smooth" data taking, as the unexpected (to be understood as the "not thought of") is always round the corner! As Brian Petersen of Stanford described, the excellent performance of the BaBar vertex detector is due to daily dedication as well as vigorous R&D. In this context, it was a pleasure to listen to William Ashmanskas of Chicago describe the excellent performance of the CDF trigger on secondary vertices – a device first presented at the Pisa Meeting in 1984. This provided an encouraging message for the LHC groups who are now building astonishingly large detectors that will shed light on the Higgs particle and other new physics.

R&D is the cornerstone on which detectors are built, and Valeri Saveliev of DESY/Obninsk State showed how continuous efforts in the field of solid-state photomultipliers is now paying off. Ready-to-use devices are now available and provide a new tool for the physics of the future.

The quest for detectors for the new generation of experiments (both ground and space based) for astroparticle physics has found a response in the particle-physics community. At Elba, several presentations tackled the complex issues of the deployment of large and elaborate devices both on Earth and in space. From the well- ▷

advanced AMS experiment to be installed on board the International Space Station, to the Auger Observatory being built and commissioned in Argentina, the techniques born in high-energy physics are being used to unveil the secrets of the universe. The search for gravitational waves requires much more than Newton's apple, and those commissioning the large interferometers Ligo and Virgo are already thinking ahead, as described by Riccardo DeSalvo from Caltech.

While the use of results from particle physics in medicine is a well-established tradition that began with X-rays, participants in the large conference room of Hotel Hermitage had the chance to find out about aspects of the application of particle-physics techniques in other fields. Roberto Pani of Rome presented the efforts involved in the transfer of technology from high-energy physics to industry (the Italian "IMI Project"), while Jean-Marie Le Goff from CERN explained the basics of such efforts. On a lighter note, Carl Haber from LBL showed how metrology and pattern recognition, developed to build the ATLAS vertex detector, can provide the opportunity to listen to old, invaluable recordings that might otherwise be lost forever.

R&D on detectors would not be so fruitful without the involvement of industry. Representatives from high-tech firms all over the world displayed their products in individual stands throughout the week and discussed their current and future projects in plenary sessions as well as private conversations.

For those who were unable to attend the conference, a live webcast was available and this can still be seen on the website at www.pi.infn.it/pm/2003, along with the full conference programme.

Three young participants received the "Pisa Meeting Award" for their work and presentations. The International Award Committee selected Silvia Schuh (centre) from CERN for her poster contribution on the ATLAS MDT, Marco Amoretti from Genova (right) for his presentation on the results of the ATHENA experiment at CERN, and Satoshi Mihara (left) from Tokyo for his contribution on the R&D of the calorimeter for the MEG (Mu-e-gamma) experiment at PSI.

Giorgio Chiarelli, *INFN, Pisa.*

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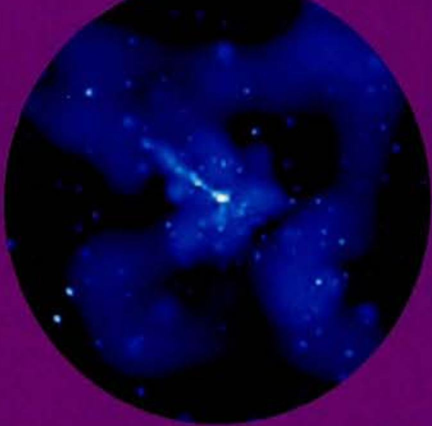

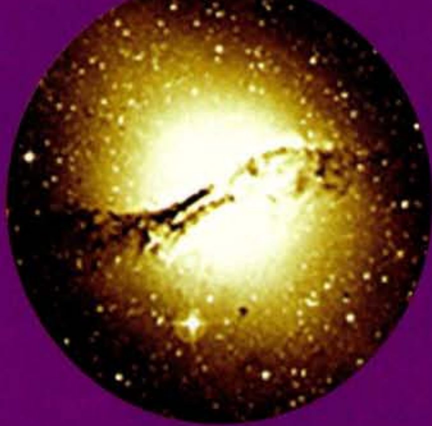

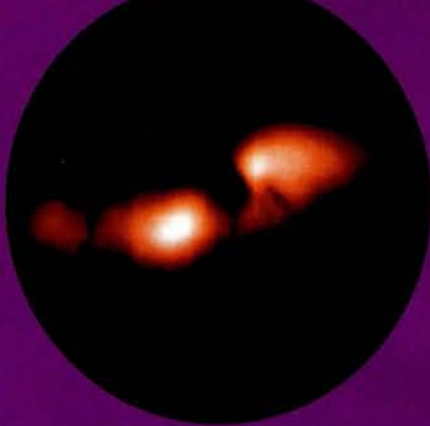

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Image 1: NASA/CXC/ M. Karovska et al. - Image 2: Digitized Sky Survey U.K. Schmidt Image/STScl. - Image 3: NRAO/VLA/ Schiminovich et al.

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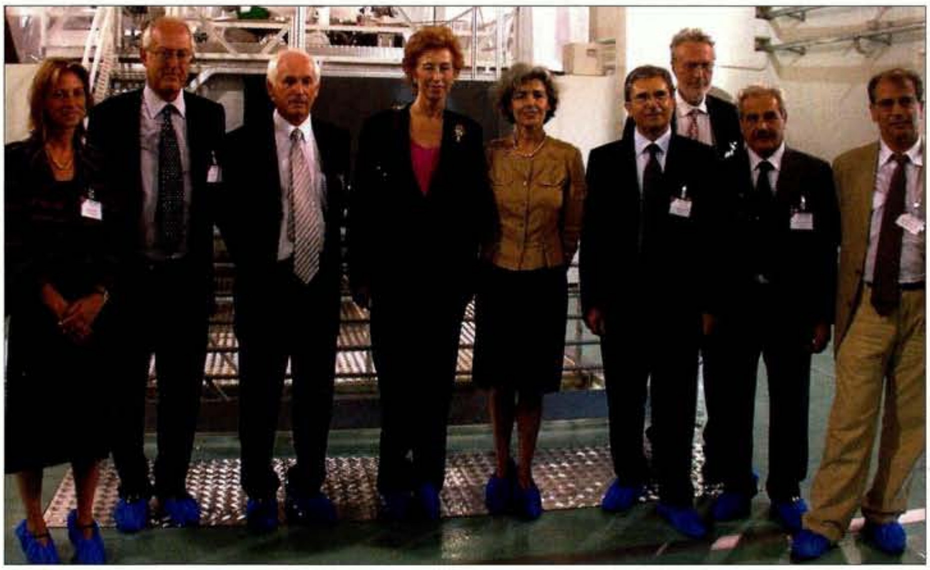
LABORATORIES

Virgo to search for gravitational waves

The Virgo interferometer for the detection of gravitational waves, located at Cascina near Pisa, was inaugurated on 23 July. The frequency range of Virgo – from 10 to 6000 Hz – coupled with very high sensitivity, should allow detection of the gravitational radiation produced by supernovae and the coalescence of binary systems in the Milky Way and in outer galaxies, for example in the Virgo cluster.

The Virgo detector consists of a Michelson laser interferometer with two orthogonal arms 3 km in length. Multiple reflections between mirrors located at the extremities of each arm extend the effective optical length of each arm up to 120 km. In order to be sensitive only to gravitational waves, the whole interferometer is completely isolated from the rest of the world, with each of the optical components isolated via an elaborate 10 m high system of compound pendulums. To avoid perturbations due to residual gas the light beams propagate under ultra-high vacuum, and the two beam pipes, each 3 km long and 1.2 m in diameter, form one of the largest ultra-high vacuum vessels in the world. The interferometer has already passed its initial running tests and within the next few months the working of all of the component systems will be verified.

"The mirrors, which are made with nanometer precision, and its sophisticated mechanical systems make Virgo one of the most sensitive instruments in the global network, which also includes the American LIGO, the Anglo–German GEO and the Japanese TAMA," said Adalberto Giazotto, Virgo's scientific coordinator.



Guests at the Virgo inauguration ceremony, including Letizia Moratti (fourth from the left), the Italian minister for education and research, and Claudie Haigneré (fifth from the left), the French minister for research and new technologies.

An aerial view of Virgo on the plain of the river Arno in Cascina near Pisa.

The Virgo project is the outcome of more than 10 years collaborative research and development between the National Institute of Nuclear Physics (INFN) in Italy and the National Scientific Research Centre (CNRS) in France. It currently operates in the context of the European Gravitational Observatory (EGO), a consortium created by INFN and CNRS. Italy's minister for education and research, Letizia Moratti, and the French minister for research and new technologies, Claudie Haigneré, attended the inauguration ceremony.

APPOINTMENTS

Llewellyn Smith to head UK fusion research

Former director-general of CERN, Chris Llewellyn Smith, has been appointed as director of the Culham Laboratory, UK, where the UK Atomic Energy Authority carries out a national research programme, as well as operating the Joint European Torus (JET) facilities on behalf of its European Partners under the European Fusion Development Agreement. Llewellyn Smith was CERN's director-general from 1994 to 1998, during which time the Large Electron Positron collider was successfully upgraded and the Large Hadron Collider was approved. He then became president and provost of University College London between 1998 and 2002. As director of Culham, where he succeeds the late Derek Robinson, who died in December 2002, Llewellyn Smith will be responsible for developing and implementing the strategy for the UK's fusion research programme.

LABORATORIES

JINR celebrates 50 years of high-energy physics

This year sees the 50th anniversary of the start of high-energy physics in Dubna, Russia, at what was to become the Laboratory of High Energies (LHE). The foundation of the laboratory was initiated by the P Lebedev Institute of Physics, where in 1944 Vladimir Veksler, later the first director of the LHE, discovered the principle of phase stability, which underlies cyclic accelerator performance at high energies.

Under Veksler's guidance, the specifications of a new particle accelerator – the synchrophasotron – were worked out in 1949/50, and in 1953 the Electrophysics Laboratory (EPL) was set up to conduct research in high-energy physics at the machine. On 26 March 1956, EPL became part of the Joint Institute for Nuclear Research (JINR) and was named the Laboratory of High Energies. The synchrophasotron began operation in April 1957 with a proton energy of 10 GeV. At the time it was the largest accelerator in the world and reached the highest energies until the start-up of CERN's proton synchrotron in 1959.

JINR's synchrophasotron was the world's highest energy accelerator when it started up in 1957.

The research programme at the LHE was worked out and realized under the guidance of Veksler, Moissey Markov and Ivan Chuvilo, who later became the second director of the LHE. The experiments were aimed primarily at the study of deep elastic scattering processes at the lowest and highest momentum transfer, as well as at multiparticle production in hadron–nucleon interactions.

Aleksander Baldin, the third director, later introduced a new trend with research into the interaction processes where the quark structure of nuclei is revealed – relativistic nuclear physics (RNP). The start of RNP research at the LHE took place with experiments on the production of cumulative particles in nuclear reactions.

The development of the synchrophasotron made it possible to accelerate deutrons in 1971. With the introduction of a new injector – a linear accelerator at 20 MeV – a unique system, used for the first time at an accelerator, of electron beam and laser sources of highly charged ions and a polarized deutron source provided physicists with beams of light nuclei up to sulphur, as well as beams of polarized nucleons and deutrons. The polarized deutron beam of record energy and the polarized proton beam, together with the unique quasimonochromatic polarized neutrons obtained from beams due to stripping, and the polarized proton target, have opened a new way to research in spin physics.

In 1993 the nuclotron, the first superconducting accelerator of nuclei, was put into operation. During development of the nuclotron, whose design and construction was headed by Baldin, unusual solutions were found in acceleration technology and techniques in superconducting magnets. These were later developed in larger accelerator centres elsewhere.

Today the LHE, headed by Aleksander Malakhov, is an accelerator centre for a wide range of research in the energy interval where the transition from the effects of the nucleon structure of the nucleus to the demonstration of asymptotic behaviour in nuclear interactions takes place. The laboratory has international scientific co-operation with CERN, many physics centres in Russia, JINR member states, centres in the US, Germany, Japan, India, Egypt and other countries.

● An international seminar dedicated to the 50th anniversary of the V M Veksler and A M Baldin Laboratory of High Energies (VBLHE) at the JINR will be held in Dubna on 2–4 October 2003. The seminar is organized by the JINR with the support of the Russian Federation Ministry of Atomic Energy, the Ministry of Industry, Science and Technology, the Russian Foundation for Fundamental Research and the International Scientific and Technical Centre. For more information, see www.lhe.jinr.ru, or e-mail: main@lhe.jinr.ru or cekpet@lhe.jinr.ru.

APPOINTMENTS

Catherine Cesarsky to head up the IAU

The General Assembly of the International Astronomical Union (IAU), meeting in Sydney, Australia, has appointed the ESO director-general, Catherine Cesarsky, as president elect for the period 2003–2006. The IAU is the world's foremost organization for astronomy, uniting almost 9000 professional scientists on all continents. Cesarsky, seen here with Ron Ekers of the Australia Telescope National Facility and the new president of the IAU, is the first female scientist to receive this high distinction. She will become president of the IAU in 2006.

European Physical Society awards particle physicists

The opening morning of the International Europhysics Conference on High Energy Physics, HEP2003, on 21 July, was the occasion for the presentation of the 2003 prizes of the High Energy Physics Board of the European Physical Society (EPS).

The EPS High Energy and Particle Physics Prize was awarded to David Gross, David Politzer and Frank Wilczek "for their fundamental contributions to quantum chromodynamics". By demonstrating that the theory is asymptotically free, they paved the way for showing that the theory is correct. Gross is currently director of the Kavli Institute for Theoretical Physics, Santa Barbara; Politzer is with the California Institute of Technology, and Wilczek is at Massachusetts Institute of Technology.

The Young Physicist Prize was awarded to Guillaume Unal of Orsay "for his contribution to the analysis of NA48 data, whereby direct CP violation in K decays was established". Unal has been involved in most aspects of the experiment and has been the driving force in the physics analysis.

The Gribov Medal was awarded to Nima Arkani-Hamed of Harvard "for his original approaches to hierarchy problems in the theories of fundamental interactions. In particular, for considering the possibility of large extra dimensions where only gravity can propagate and exploring its broad phenomenological implications."

Arkani-Hamed has authored several influential works exploring possible explanations of the observed hierarchies of physical scales in the theories of fundamental interactions.

The Outreach Prize was awarded to Rolf Landua of CERN and Nicolas Tracas of Athens. While active as spokesman of the ATHENA collaboration, Landua has efficiently collaborated in many outreach activities at CERN, including events with a European dimension such as "Physics on Stage" and "Life in the Universe". Tracas has been very active and successful in promoting the public image of physics in Greece, in particular through programmes for high-school teachers, and through activities such as "Physics on Stage". He has also been active in translating CERN's outreach material into Greek for use by Greek students and teachers.

Berlin's Humboldt University has awarded its 2003 Lise Meitner Prize for outstanding PhD work in physics to Lars Meinhold for his diploma thesis on "Stochastic oscillations in cytolic calcium concentration". The prize is sponsored by the Association of Friends and Sponsors of Physics at the Humboldt University Berlin, where Meinhold studied. He is interested in biophysical applications and has investigated the dynamics of calcium in intercell space and developed cluster models. Meinhold is now at the University of Heidelberg, where he is continuing his research. The Lise Meitner Lecture at the award ceremony was given by Herwig Schopper, former director-general of CERN, on "Fundamental research as a gateway to human understanding".

CAS steams ahead under new head Brandt

A specialized course on Synchrotron Radiation and Free-Electron Lasers, which was held on 2–9 July in Brunnen, Switzerland, was the first under the leadership of Daniel Brandt, the new head of the CERN Accelerator School (CAS). Brandt, who is an accelerator physicist, has been at CERN since 1981, working on aspects of LEP from the early days of design and throughout most of its operation. More recently, his responsibilities have included the LHC Heavy Ions Programme.

Brandt became head of CAS in January, taking over from Ted Wilson, who retired from CERN in March (*CERN Courier* May 2003 p37). The latest course in Brunnen was run in collaboration with the Paul Scherrer Institute (PSI) and was attended by 58 students, not only from Europe and North America, but also from Brazil, Taiwan and South Africa. A particular highlight was a visit to the Swiss Light Source at the PSI in Villigen, which allowed the students to visualize the theoretical aspects of the course. Brandt is seen here on the footplate of the old Rigi steam engine, during the school's excursion to Mount Rigi.

ALICE presents its first award to industry

On 19 June, the French company STMicroelectronics received the first ALICE award to industry. STMicroelectronics made available to the ALICE collaboration the design of one of its most advanced circuits, the TSA1001. This has been integrated into the ALTRO (ALICE TPC Read Out) chip designed by the CERN EP-ED group.

As with the other experiments being prepared for CERN's Large Hadron Collider, ALICE has to push data handling and processing technologies well beyond the current state of the art. In particular, ALICE, which aims to study quark–gluon plasma (see p20), has to operate efficiently in two widely differing running modes: the proton–proton mode with very frequent but quite small events, with few particles produced, and the heavy-ion mode with relatively low rate, but extremely large events, with tens of thousands of particles produced.

These requirements call for a single chip with circuits to digitize, process, compress and store the information of a large number of channels. ALTRO, the chip produced by STMicroelectronics and the ALICE collaboration for the Time Projection Chamber (TPC), meets this challenge perfectly.

The development of the ALTRO chip is the result of the joint effort of several ALICE teams from CERN, GSI, Heidelberg and Lund. Due to its versatility and excellent performance, the chip is now being considered for two other parts of the ALICE detector, the Forward Multiplicity Detector (FMD) and the Photon Spectrometer (PHOS), as well as for an upgrade of the Time Projection Chamber in the STAR experiment at Brookhaven National Laboratory.

Members of the ALICE collaboration, together with representatives of the French company STMicroelectronics, at the ALICE award ceremony on 19 June.

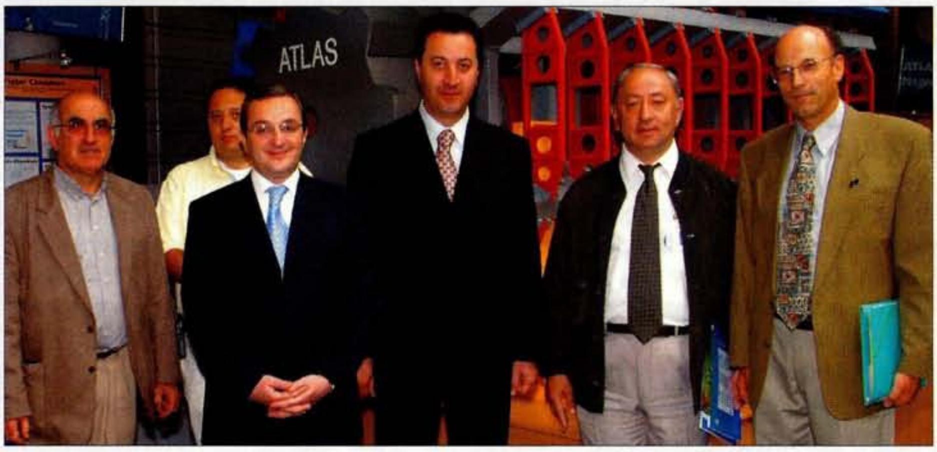
Friends and colleagues recently celebrated the 65th birthday of A P Balachandran during a meeting on Spacetime and Fundamental Interactions: Quantum Aspects, which was held on 26–31 May in Vietri sul Mare, near Napoli in Italy. Balachandran (or "Bal" as he is more usually known) has played a crucial role in the introduction of topological ideas in quantum physics, and in particular in the development of Skyrmions as a model for low-lying baryons. More recently, he has been active in noncommutative geometry and "fuzzy" physics. Bal, seen here on the right of the picture talking at the meeting with Giuseppe Marmo of Napoli, has been on the faculty at Syracuse University since 1964. He has also played a central role in the development of theoretical physics in the Napoli area, with several collaborators from the universities of Napoli and Salerno, including some of his former students from Syracuse.

CERN

Poland extends connections with CERN

Andrzej Budzanowsk (front left), director-general of the Cracow Institute of Nuclear Physics (HNINP), and Lyn Evans (front right), LHC project leader, shake hands after signing the collaboration agreement. Behind, from left to right, are Grzegorz Polok, deputy director-general of HNINP, Blazej Skoczen, in charge of the LHC cryomagnet interconnections, and Claude Détraz, CERN's director for fixed target and future programmes.

The Cracow Institute of Nuclear Physics (HNINP) signed a collaboration agreement with CERN on 26 June, under which a team of 22 Polish physicists, engineers and technicians will come to CERN to assist with the inspection of LHC assembly work. The team will have the task of inspecting the 1700 interconnections between the LHC magnets. These interconnections have to ensure continuity of the vacuum chamber and the superconducting cable, and the cryogenic, helium supply, main magnet and corrector magnet systems. The Polish scientists will start their inspection work in April 2004.



The Armenian minister for trade and economic development, **Karen Chshmaritian**, visited CERN on 4 July and toured the ATLAS experimental cavern and assembly hall. He is seen here (centre) in front of a model of ATLAS, together with (from left to right) **Aram Kotzinian** of JINR, **Marzio Nessi** from ATLAS, **Zohrab Mnatsakanian**, Ambassador at the permanent mission of the Republic of Armenia to the United Nations in Geneva, **Alexandre Sissakian**, vice-director of JINR, and **Peter Jenni**, ATLAS spokesman.

India attends first CERN Council meeting as observer

The CERN Council welcomed an Indian delegation to its first meeting on 20 June, following the granting of observer status to India last December. Indian scientists have been working with CERN since the 1960s, a collaboration formalized in a co-operation agreement in 1991 and extended for a further decade in 2001. In the framework of the 1996 protocol signed with the Indian Department of Atomic Energy, India became one of the first non-member states to make significant contributions to the LHC. Indian scientists are also valued members of the ALICE and CMS collaborations, and Indian IT expertise is being put to good use in Grid computing projects through additional protocols signed in 2002. Anil Kakodkar (right), Atomic Energy Commission chairman, who led the delegation is seen here at the meeting with Thettalil Seetharam, minister (disarmament), permanent mission of India to the United Nations in Geneva.

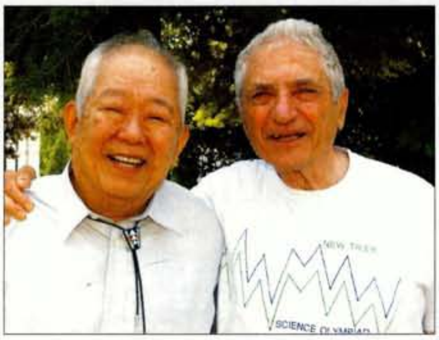
MEETINGS

A **Workshop on Heavy Quarkonium**, the second of the Quarkonium Working Group, is being held at Fermilab on 20–22 September. For more details see www.qwg.to.infn.it/WS-sep03.

The 9th International Workshop on Polarized Solid Targets and Techniques, jointly organized by the universities of Bochum and Bonn, will be held on 27–29 October at the Physikzentrum in Bad Honnef, Germany. Topics will include the use of polarized solid targets in particle-physics experiments, as well as related aspects in other applications. Details are available at http://poltarg03.ep1.rub.de.

CERN

Takeshi Sasaki (centre), president of the University of Tokyo, visited CERN on 29 July when the renewal of the memorandum for the academic exchange agreement between the university and CERN was signed. Sasaki toured the LHC magnet test hall, the ATLAS underground cavern and assembly hall and visited the Antiproton Decelerator (AD) and Computer Centre. He is seen here in the AD experimental area with the spokesman of ASACUSA, **Ryogo Hayano** of Tokyo (left), and **Makoto Fujawara** of RIKEN and ATHENA.



Masatoshi Koshiba (left), from the International Centre for Elementary Particle Physics, Tokyo, Japan, and winner of the 2002 Nobel Prize for Physics, visited CERN on 8 July, where he gave a seminar, and in a less formal moment was photographed with fellow Nobel laureate (1989) **Jack Steinberger**, from CERN.

LETTERS

CERN Courier welcomes letters from readers. Please e-mail cern.courier@cern.ch. We reserve the right to edit letters.

Peyrou remembered

I was very sorry to learn that Charles Peyrou has died (*CERN Courier* June 2003 p25, p33). It would be presumptuous of me to comment on his many contributions to physics, for most were beyond my level of understanding. Rather I would like to share some of the memories I have from the period 1957–1962, when I worked for him as a technician.

Right from the beginning Charles demonstrated an astute judgement of people. He created a team with members from all the participating nations of the period, which worked hard and, at the right times, played well together. He was an excellent communicator and an accomplished linguist. Although occasionally he could present a somewhat severe expression, there was always a timely anecdote not far from the surface. Often, when thinking, he would light up a Gauloise and pace up and down, and having got his ideas in order we would be expected to walk with him to discuss the outcome; at least it kept us fit! Other eccentricities included having meetings in the open air and repairing to the Chalet restaurant for a working lunch and the occasional game of table football (which he was never any good at!).

Charles was always prepared to listen to others' ideas, even if they contradicted his own. However, one had to be prepared to be thoroughly grilled, often to the point of exhaustion. There were many problems to be resolved in cryogenic engineering at that time and although he enjoyed the elegant solution he would usually opt for the most simple. Once the serious business of experimentation started, he would always offer advice, encouragement and support, irrespective of the time, day or night.

Many years after I had left CERN we bumped into each other, almost literally, in San Francisco airport. I recognized him, but would he remember me? He did and we sank a few scotches waiting for our respective flights. There is no doubt my time working for Charles had a beneficial effect on my subsequent career and quality of life, for which I will be forever grateful, and for that he has my heartfelt thanks.
Alan Maybury, Nailsea, UK.

Coloured quarks

I enjoyed reading in the June issue of *CERN Courier* (p30) that two distinguished theorists, Yoichiro Nambu and Albert Tavkhelidze, shared the Bogoliubov Prize. In the July/August issue (p36) it was noted that another distinguished theorist, Oscar Greenberg celebrated his 70th birthday. Early versions of coloured quarks were proposed by Greenberg, Nambu and Tavkhelidze nearly 40 years ago.
Gabriel Karl, Guelph, Canada.

NEW PRODUCTS

CeramTec North America's Ceramaseal Division has launched a new line of differentially pumped viewports for extreme high-vacuum applications. The viewport optics include zinc selenide and Cleartran, and have an antireflective coating and 98% minimum transmission rate. Further information can be found at www.ceramaseal.com.

Singulus Technologies has a new TIMARIS thin-film sputtering system for MRAM (magnetic random access memory) wafers. The first system is equipped to handle 150 and 200 mm wafers, while a second will process 300 mm wafers. For further details contact Bernhard Krause, tel: +49 6181 982 8020.

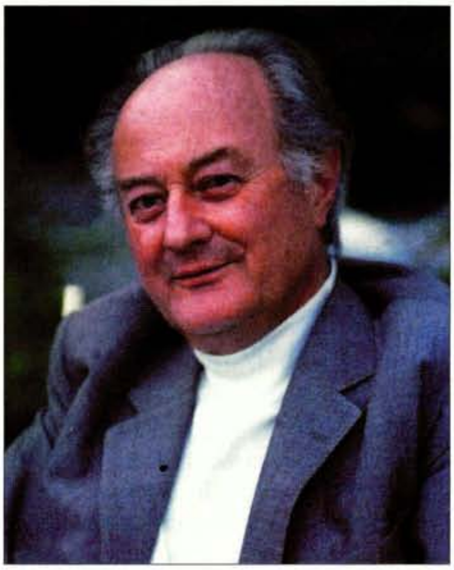
Thermo Vacuum Generators has announced new magnetic rotary vacuum feedthroughs in its MRD series. The new feedthroughs feature a high torque and high lifetime magnetic coupling, eliminating a key source of leaks and contamination in high-vacuum applications. For further information contact Richard Stratford, tel: +1 408 965 6523, e-mail: richard.stratford@vacgen.com, or see www.thermovacgen.com.

ZBD Displays offers grating-aligned liquid-crystal displays that allow images to be kept on display indefinitely without power or after the power is turned off. The technology also enables complex displays with good contrast, brightness and viewing angle. More details are available at www.zbddisplays.com.

Leybold has opened a new sales and service facility in Shanghai. It is the company's third facility in China, the others being in Guangzhou and Tianjin. For more information contact Christina Steigler, tel: +49 221 347 1261, e-mail: christina.steigler@leyboldvakuum.com.

OBITUARIES

Rolf Hagedorn 1919–2003



Rolf Hagedorn, the theorist who introduced the concept that hadronic matter has a melting point, died on 9 March in Geneva.

As a young man Hagedorn was deeply marked by the upheavals of the war years in Europe. He studied physics and mathematics at Göttingen and graduated with a diploma in 1950 and a doctorate in 1952 on thermal solid-state theory, under Richard Becker. He also worked at the Max Planck Institute for Physics.

In 1954 Hagedorn had the opportunity to go to Geneva, where he initially helped with accelerator design for the new CERN organization. He joined the CERN Theory Group after its transfer from Copenhagen to Geneva in 1957, and he was a senior physicist in the division when he retired in 1984. After his retirement Hagedorn remained an active emeritus researcher.

As an accelerator physicist, Hagedorn developed theoretical predictions for the particle spectra observed when CERN's proton synchrotron first began operation. This was important for the planning and implementation of the first neutrino beams. He then developed the statistical theory of meson production in considerable detail up to very high energies. It was as a consequence of these studies that he found that one should expect a limiting temperature in hadronic collisions, the "Hagedorn temperature". This picture has had a major impact on theoretical thinking and on our understanding of the properties of hot hadronic matter, which is now important in the heavy-ion programme (see p30). Since the picture is applicable to any exponentially rising particle mass spectrum, it is also influencing the development of string theories.

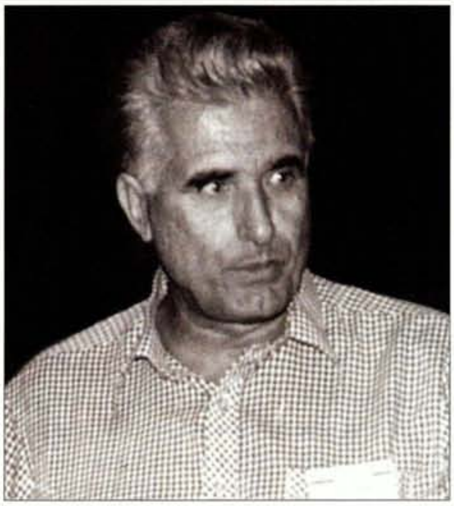
Hagedorn developed some novel statistical physics methods, leading to the technical expertise we wield today in this field. He was also instrumental in the development of one of the earliest user-friendly interactive computing programs for algebraic manipulations, the SIGMA.

Rolf Hagedorn was a person of the highest scientific integrity and standards of reasoning. He was always willing to help colleagues and his comments were usually penetrating and deep. He will be much missed by friends and colleagues alike.

Torleif Ericson, CERN, and Johann Rafelski, University of Arizona.

• The CERN Theory Division is planning to hold a Hagedorn Memorium Symposium at CERN on 28 November 2003. For full details see http://wwwth.cern.ch.

Dubravko Tadiç 1934–2003



Dubravko Tadiç, a leading figure in Croatian particle physics, passed away on 6 February. Born in Zagreb in 1934, Tadiç graduated from the University of Zagreb in 1958, during the time of Vladimir Glaser, Borivoj Jaksic and Gaja Alaga. He studied for his PhD under Alaga on problems in nuclear beta decay and the structure of weak interactions, and then developed his research in parity violation, and in particular in parity-violating nuclear interactions. Subsequently, his main field of research became elementary particle physics, specifically electroweak interactions and quark models.

Tadiç began his international career in Birmingham at the time of Rudolf Peierls, and later worked at Brookhaven. He continued his connection with international science throughout his life, but unfortunately did not live to see his dream of Croatia becoming a full CERN member state.

Tadiç had a leading role in academic life in Zagreb and Croatia, and became the leader of a research group at the Rudjer Boskovic Institute early on in his career. He then became head of the theory division at the Faculty of Sciences (PMF–Zagreb) and a member of the Croatian Academy. Tadiç introduced particle physics to many physicists who are now leaders in Croatian science, and he always shared his joy of research with collaborators and in particular with younger colleagues. The style and standard by which he influenced the young researchers was often recognized as "the Zagreb school".

Tadiç accepted the challenge that questioned whether high-quality scientific work could still be done in a small country that suffers from a huge brain drain. He instigated numerous conferences in nuclear and particle physics in Croatia including, among others, the well established series of "Adriatic meetings". He was also extremely supportive of the development of particle physics in Split and of participation in the CMS experiment. Dubravko Tadiç will be deeply missed by the physics community and by his collaborators and friends.

S Pallua and I Picek, PMF–Zagreb, D Denegri, CERN/Saclay.

Frans Verbeure 1942–2003

Frans Verbeure, head of the Particle Physics Group at the University of Antwerp, passed away on 8 June after a long illness.

Born on 6 February 1942, Verbeure began his research career in the early 1960s, under the leadership of Fernand Grard, at the Laboratoire des Hautes Energies in Brussels. His research initially centered around the vigorous bubble-chamber physics programme, which had started in Saclay and continued at CERN. When the Universitaire Instelling Antwerpen (UIA) was created in 1972, he became the youngest professor in the Physics Department, and remained there until his untimely death.

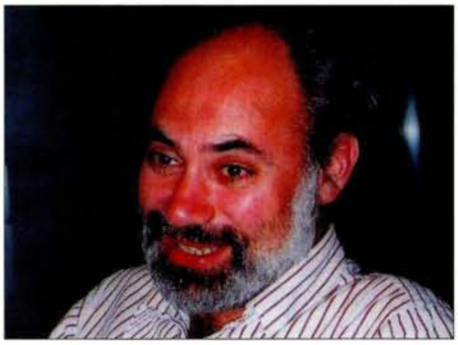
Recognizing the importance of national, as well as international, collaboration, Verbeure associated his research group closely with the other experimental particle-physics groups at the Université Libre de Bruxelles and the Vrije Universiteit Brussel. In the early 1980s, under his leadership, the UIA group expanded its activity from bubble-chamber experiments to "hybrid" experiments. When the time of the bubble chambers was over, the group took part in the Belgian effort in DELPHI at LEP, and over the past eight years Verbeure's efforts were directed towards the active participation of his group in the CMS experiment at the LHC.

Verbeure's talents as an efficient administrator were recognized early in his career, and he took on several important duties as head of the Physics Department, dean of the Science Faculty, president of the University Research Council and vice-rector of the UIA. He was also an active member of the Belgian Federal Council for Research Policy and the Flemish Interuniversity Council. For two years he became dean of the European Academy of Sciences and Arts, and last but not least was a member of the Belgian delegation in the CERN Council and Committee of Council. In all these activities, his actions were inspired by a great sense of duty and service to the community.

Despite all these roles, Verbeure never lost his excitement for particle physics. As permanent secretary of the International Symposia on Multiparticle Dynamics (ISMD) he ensured the continuing success of this series of conferences in a field to which he devoted a major part of his research. As a scientist he always had a clear grasp of the problems at hand and of the most efficient way to solve them. Frans Verbeure was admired and respected by his collaborators and students and will be remembered as an extremely kind and helpful colleague and friend, full of joy, optimism and activity.

From his colleagues and friends.

Ian Kogan 1958–2003



Ian Kogan, an outstanding theoretical physicist and professor at Oxford University, died of heart failure on 4 June.

Ian was born into a Jewish family on 14 September 1958 in Glazov, a small town in the northern Urals, far from the cultural centres of what was then the Soviet Union. Life in the town revolved around a uranium plant, where Ian's parents worked for more than 40 years. Ian graduated from the Moscow Institute of Physics and Technology in 1981, completing his education in parallel at the Institute of Theoretical and Experimental Physics (ITEP). That he came to the ITEP was fortunate both for Ian and the institute. The ITEP Theory Department, with its creative atmosphere and respect for deep thought, was just the right place for him.

Ian began his professional career in hadron physics, a topic he repeatedly returned to. His scientific horizons rapidly expanded though, and within three years he was an early explorer of Chern–Simons electrodynamics. His interests were remarkably broad – from quantum chromodynamics to solid-state physics, from financial market fluctuations and risk assessment to string theory, from quantum gravity to conformal field theory. This was a unique quality in the age of narrow specialization, and in every field he left a profound imprint.

Ian was one of the co-discoverers of phase transitions in strings and more recently of the logarithmic conformal field theory and theory of multi-gravity. He championed the application of logarithmic conformal field theory and string theory in solid-state physics, and it would be fair to say that he circumnavigated theoretical physics. He had the spirit of a pioneer, at the front line of research and quite often beyond, and he had the stamina to go in directions others did not have the courage to pursue.

Ian's attitude to physics was romantic. His admiration of the beauty of the laws of nature never faded and was as strong in 2003 as it was in 1980 at the beginning of his physics journey. He was always simmering with ideas and often had more than he could possibly sort through. He shared his ideas generously with his students at Oxford University and Balliol College, of which he became a permanent member in 1994.

During the two decades of his professional career, Ian published almost 200 scientific papers involving 60 collaborators. Indeed, his soul and mind were open to all and he had many friends, not only in Russia, England and the US, but throughout the world. Ian was truly cosmopolitan, in the best sense of the word.

Ian was a daydreamer, both in physics and in life. He combined a childish joyful attitude with the wisdom and seriousness of a great man. He was a very kind person and helping those in need was natural to him. He drove through life in the fast lane, always wanting to understand more and to do more, and was at the peak of his creative powers, full of plans for the future, but his heart could not cope. It suddenly stopped, after he had given a long afternoon seminar on multi-gravity the day before at ICTP in Trieste. When such people leave us, the world becomes emptier and colder. His death is a tragedy for the entire physics community.

Mikhail Shifman, University of Minnesota.

RECRUITMENT

For advertising enquiries, contact *CERN Courier* recruitment/classified, Institute of Physics Publishing, Dirac House, Temple Back, Bristol BS1 6BE, UK.
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Rates per single column centimetre: mono $66/€72/£44, single colour $69/€75/£46, full colour $72/€78/£48. Please contact us for more information about publication dates and deadlines.

Scientific Staff Position

The National Synchrotron Light Source Department (NSLS) of Brookhaven National Laboratory presently has a unique opportunity for a scientist to work in the Accelerator Division under the direction of J. Murphy. The position requires a Ph.D. in accelerator physics or related field and significant experience in the areas of the design, commissioning and operation of storage ring light sources. The scientist will be actively involved in the R&D for the next light source at the NSLS as well as the continued development of the existing NSLS facility.

Interested candidates should submit a CV indicating position #MK2621 to: M. Kipperman, Brookhaven National Laboratory, Bldg. 185, P.O. Box 5000, Upton, NY 11973-5000. BNL is an equal opportunity employer committed to workforce diversity.

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Wilson Fellowships

Fermilab supports particle physicists early in their careers by providing unique opportunities for self-directed research in experimental particle physics. The fellowships are awarded on a competitive basis to Ph.D. physicists of exceptional talent as evidenced by their contributions to the field in their postdoctoral work. Fellows will work at Fermilab in areas of experimental particle physics of their choice. Wilson Fellowships are tenure track positions with an initial term appointment of three years.

Each candidate should submit a curriculum vitae and a detailed statement of research interests and proposed activities, and should arrange to have four letters of reference sent to the address below. Application materials and letters of reference should be received by October 31, 2003.

Materials, letters and requests for information should be sent to:

Patricia L. McBride
Chairman, Wilson Fellows Committee
Fermi National Accelerator Laboratory MS234
P.O. Box 500
Batavia, IL 60510-0500

E-mail: mcbride@fnal.gov

More information can be found at our web site:
http://www.fnal.gov/pub/forphysicists/fellowships/wilson.html

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Universität Karlsruhe (TH)

Am Institut für Theoretische Teilchenphysik der **Fakultät für Physik** der Universität Karlsruhe (TH) ist eine

Professur (C3) für Anwendungen der Informatik in der Physik

(Nachfolge Prof. Dr. H.-M. Staudenmaier)

zum 1. Oktober 2004 wieder zu besetzen.

Zum Aufgabenbereich der Professur gehört die Vertretung des Fachgebiets "Anwendungen der Informatik in der Physik" in Forschung und Lehre. Als Forschungsgebiet ist Computational Physics mit Schwerpunkt Elementarteilchenphysik vorgesehen. Eine Kooperation mit den vorhandenen Arbeitsgruppen der theoretischen und experimentellen Elementarteilchenphysik ist erwünscht. Die Mitarbeit im Sonderforschungsbereich/Transregio "Computational Particle Physics" wird erwartet. Vorausgesetzt werden Habilitation oder gleichwertige wissenschaftliche Leistungen sowie Lehrerfahrung.

Die Universität Karlsruhe ist bestrebt den Anteil an Professorinnen zu erhöhen und begrüßt deshalb die Bewerbung entsprechend qualifizierter Frauen. Schwerbehinderte Bewerber/Bewerberinnen werden bei gleicher Eignung bevorzugt berücksichtigt.

Im Falle einer erstmaligen Berufung in ein Professorenamt wird das Dienstverhältnis zunächst grundsätzlich befristet; Ausnahmen von der Befristung sind möglich.

Bewerbungen mit den üblichen Unterlagen, einer Darstellung der bisherigen Forschungs- und Lehrtätigkeit sowie fünf ausgewählten Sonderdrucken eigener Publikationen sind bis zum

15. Oktober 2003

an den **Dekan der Fakultät für Physik, Universität Karlsruhe (TH), 76128 Karlsruhe** zu richten.

Experimental Particle and Nuclear Physics

The Physics Department of the Massachusetts Institute of Technology invites applications for a faculty position in experimental particle and nuclear physics starting July 1, 2005 (earlier appointment may be possible in case of exceptional circumstances). Currently, the research groups in the Division and LNS have strong interests in QCD (PHOBOS, BLAST, Jefferson Lab, Mainz and STAR), flavor physics, and electroweak Symmetry breaking (BaBar, CDF, ATLAS and CMS), dark matter searches (AMS) and neutrino physics (SuperKamiokande). Faculty at MIT teach undergraduate and graduate physics courses and supervise graduate and undergraduate participation in research. Candidates must show promise in teaching as well as in research. Preference will be given to applicants at the Assistant Professor level.

Applicants should submit a curriculum vitae, a publications list, and a brief description of research interests and goals. Applicants must also arrange for three letters of reference to be sent directly to the search committee chair. Application materials should be sent directly to Professor Richard K. Yamamoto, Chair, Experimental Particle and Nuclear Physics Search Committee, MIT, 77 Massachusetts Avenue, 26-421, Cambridge, MA 02139-4307. The deadline for applying is August 15, 2004.

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Imperial College London

Department of Physics

Professor/Reader in High Energy Physics
Lecturer in High Energy Physics

The High Energy Physics Group in the Physics Department at Imperial College London is expanding its activities in neutrino physics and will make two appointments to build this up. The aim is to form a team which, with present staff and a planned expansion in the area of neutrino factory R&D, will become a major force in accelerator-based neutrino research. The group is currently active in the design of a future neutrino factory and is already heavily involved with the MICE experiment to investigate muon cooling. The goal is to increase this activity and in addition participate in one of the 'superbeam' experiments planned for later this decade.

The first appointment will be a senior person at Professor or Reader level. S/he will be expected to lead the group's efforts in the 'superbeam' experiment, as well as contribute generally to the team goals. Candidates for this post are required to have an international reputation and at least 15 years' experience in experimental particle physics research. Previous involvement with an accelerator or non-accelerator neutrino experiment would be an advantage.

The second appointment will be at Lecturer level and is to work in the neutrino team outlined above. It will be made after the senior appointment in order to enable the senior appointee to contribute to the selection.

The Imperial High Energy group is one of the largest in the UK with a broadly based experimental programme embracing CMS, Babar, D0, LHCb, ZEUS and the UK Dark Matter experiment in addition to the neutrino activities. There is a strong tradition of detector development and construction, which has led to key activities in these experiments. Further details can be found at www.hep.ph.imperial.ac.uk

Starting dates will be by negotiation but early 2004 is anticipated. The salary for a professorial position is by negotiation. For a Reader, it will be in the range £38,846 to £42,092 and for the Lecturer position in the range £31,755 to £35,813 (both include London Allowance).

Those appointed are expected to establish an independent research programme and to demonstrate a commitment to teaching excellence for both undergraduate and postgraduate students.

Application forms are available from Ms Paula Brown, email: paula.brown@imperial.ac.uk Completed applications should include (1) a curriculum vitae, (2) a list of publications, (3) a statement of research interests and (4) the names and addresses of three referees. They should be sent to Professor P J Dornan FRS, Physics Department, Blackett Laboratory, Imperial College London, SW7 2AZ, UK, from whom further details can be obtained by e-mailing: p.dornan@imperial.ac.uk

Closing dates:
For the Professor/Reader position: 13 October 2003.
For the Lecturer position: 3 November 2003.

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

MAX-PLANCK-GESELLSCHAFT

The Max Planck Institute of Physics is one of the world's leading research institutes, focused on particle and astroparticle physics from both an experimental and a theoretical perspective. Our research activities currently comprise participation in the accelerator-based experiments ATLAS at CERN, H1 at DESY and STAR at BNL, as well as in the gamma ray telescope MAGIC at La Palma Observatory, the CRESST dark matter search at Gran Sasso, and the future space mission EUSO.

Together with the MPI of extraterrestrial Physics we operate the Halbleiterlabor (HLL), a laboratory devoted to the development of semiconductor detectors for both institutes' research projects.

The Max Planck Insitute of Physics is seeking a highly qualified

experimental physicist

with an interest in particle and astroparticle physics and proven expertise in the development of innovative semiconductor detectors. The successful candidate is expected to lead our HLL semiconductor laboratory group with a staff of about 10 scientists, engineers and technicians after the retirement of its present leader.

Job description
- active contributions to the R&D of semiconductor detectors
- a leading role in shaping the activities at HLL
- participation in the institute's physics research programme
- acquiring funds and research grants from industry and public funding agencies

Qualifications required:
- management experience (project and personnel)
- leading-edge contributions to the development of semiconductor detectors
- experience in process and device simulation of semiconductor detectors
- experience in the integration and qualification of detector systems
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The position is permanent, with a salary according to the German federal pay scale up to a level of BAT Ia, depending on experience and qualification. Applications from women are particularly welcome. The Max Planck Society is committed to employing more handicapped individuals and especially encourages them to apply.

More information on the institute can be found on our internet homepage, www.mppmu.mpg.de

Interested scientists are invited to send their application (including CV, list of publications, summary of research interests, and the names of three referees) within 1 month after publication of this advertisement to

Max-Planck-Institut für Physik
Prof. Dr. Siegfried Bethke
The Managing Director
Föhringer Ring 6
80805 München, Germany

POSTDOCTORAL RESEARCH FELLOWS

The Division of Medical Imaging Physics of the Russell H. Morgan Department of Radiology and Radiological Science at the Johns Hopkins University is seeking applicants for several Postdoctoral Research Fellow positions. Candidates with a Ph.D. in medical physics, other specialties of physics, engineering, mathematics and related fields are encouraged to apply. The successful applicants will join a Division currently consisting of 5 faculty members, 2 Research Associates and ~10 Research Assistants/Trainees who are actively involved in medical imaging physics research especially in the areas of radiography, CT, nuclear medicine imaging, SPECT and PET. Active research projects include medical imaging instrumentation, Monte Carlo simulations, computer phantom design, quantitative 2D, 3D and 4D image reconstruction methods, internal dosimetry, small animal CT, SPECT and PET imaging techniques, image quality assessment, observer performance experiments and ROC analysis, and clinical trials of image reconstruction and processing methods. Experience in these and related areas is desirable but not essential. Strong computer, communication, and writing skills are desirable as is a willingness to work in a multidisciplinary collaborative environment. The projects are supported by several federal and industry research grants and contracts.

For further information, please contact Benjamin M. W. Tsui, Ph.D.
(Tel: 443-287-4025, E-mail: btsui1@jhmi.edu). Johns Hopkins University is an equal opportunity employer.

The department of Experimental High Energy Physics forms, jointly with the departments of Theoretical High Energy Physics and Astronomy, the High Energy Physics Institute Nijmegen, HEFIN.
The department is part of the sub-faculty of Physics and the Faculty of Science, Mathematics and Computer Science of the University of Nijmegen. It is also part of the national institute for subatomic physics in the Netherlands, NIKHEF, and participates in the national research school for subatomic physics, OSAF. For its research, the department utilises the facilities of the accelerator laboratories CERN in Geneva, Switzerland, and Fermilab in Chicago, USA. In the past years the department intensively worked on the L3 and L3 cosmic experiments at CERN. Currently, most effort is devoted to the D0 experiment at Fermilab. The group has substantial commitments in the preparation of the ATLAS experiment at CERN.
In the future there will be room for new experiments within the framework of the NIKHEF programmes. The department actively participates in the R&D to prepare for future projects.

The EHEF department has an opening for a

full professor in Experimental Physics (m/f)

Applicants are invited with an excellent track record and leadership in Experimental High Energy Physics.

Requirements

- Candidates are expected to be able to participate in all aspects of Experimental High Energy Physics, including data analysis and interpretation.
- The successful candidate must be able to acquire funding from external sources, through grants and other means.
- The new professor will participate in teaching both general undergraduate and more specialised graduate courses, and must demonstrate good didactical ability.
- Operational knowledge of the Dutch language is required in one year and ability to teach in Dutch after two years.
- The candidate must be able and willing to take on the usual share in administrative duties.

Information

General information about the EHEF department can be found at **http://www.hef.kun.nl/**
Further information can be obtained from Prof. dr. S.J. de Jong, chair of the EHEF department (tel: +31 24 3652168, email: **sijbrand@hef.kun.nl**) or from the chair of the search committee Prof. dr. J.J. ter Meulen (tel: +31 24 3653022, email: **htmeulen@sci.kun.nl**).

Application

Letters of application, including curriculum vitae, list of publications and the names and contact information of at least three references, should be received before September 30 by: Personnel Department FNWI, c/o Mrs. M. van Hout, P.O. Box 9010, 6500 GL Nijmegen, the Netherlands.
Quoting the vacancy number: 62.03.42. The University of Nijmegen is an equal opportunity employer.

UNIVERSITY OF NIJMEGEN

IN DEI NOMINE FELICITER

GLAST LAT
Instrument Operations Center Manager

AT STANFORD UNIVERSITY

Stanford Linear Accelerator Center (SLAC) at Stanford University is one of the world's leading research laboratories. We design, construct, and operate state-of-the-art electron accelerators and related experimental facilities for use in high-energy physics and synchrotron radiation research.

We are seeking a qualified individual for the position of Gamma-ray Large Area Space Telescope (GLAST) Large Area Telescope (LAT) Instrument Operations Center (IOC) Manager. The LAT will be the principal instrument on GLAST, a high-energy gamma-ray observatory that will be launched in 2006 and will carry out observations for a minimum of 5 years. Stanford University is the lead institution of an international collaboration that is building the LAT instrument.

You will lead a team of scientists and engineers and will have overall responsibility for the on orbit health and safety of the LAT instrument. Other responsibilities will also include LAT operations, engineering and science data processing, maintaining instrument flight software, preparing command uploads, generating LAT team scheduling requests, and supporting the GLAST LAT collaboration's science investigations. During instrument integration and test, you will support the online processing and calibration activities. You will also be responsible for the operational interfaces to the NASA Mission Operations Center and Science Support Center. You will be encouraged to be an active participant in the science investigations of the collaboration.

Excellent organizational and interpersonal skills are required. A PhD in astronomy or physics, plus extensive experience (>5 years) is required. A familiarity with operations facilities for large-scale space-based or ground-based experiments is preferred.

The appointment will be for a physicist or astronomer in the Research Division and may be made for a fixed-term or on a continuing basis.

Qualified applicants should send a CV, cover letter, and at least three references to: employment@slac.stanford.edu.

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Interested candidates should submit a CV indicating position number MK2583 to: M. Kipperman, Brookhaven National Laboratory, Bldg. 185, P.O.Box 5000, Upton, New York 11973-5000. BNL is an equal opportunity employer committed to workforce diversity.

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Ion Source Physicist

Competition #917

Located in Vancouver, British Columbia, **TRIUMF** is Canada's national research facility for particle and nuclear physics. Based on a large 500MeV cyclotron, accelerating a high intensity negative hydrogen beam and extracting several simultaneous beams for a variety of experiments and applications, the facility is now being expanded to become a primary world centre for experiments with exotic ions, at low energies for condensed matter and other studies, or accelerated to higher energies for astrophysics and nuclear physics.

We are currently seeking an Ion Source expert who will provide leadership in the development of novel ion sources and explore new beam formation techniques. The goal is to expand the inventory of rare exotic beams, to maximize corresponding ion beam fluxes and to optimize high intensity H- ion sources.

The person we seek will have an academic background equivalent to a PhD in physics, with at least 6 years of post-doctoral ion source research activity acquired in a major accelerator laboratory. All candidates must provide a list of publications and accomplishments that are recognized by the international ion source community. Scientific productivity will be a criterion of excellence. Thesis supervision in the field of ion sources will be considered an asset. Priority will also be given to candidates with demonstrated hands-on ability and familiarity with different ion sources and related techniques such as high voltage platforms, vacuum technology, electro-magnetic fields, beam diagnostic devices, etc. A demonstrated ability to direct research and to interact effectively with other scientists, engineers and technicians, and to work as part of a team is a must. The position is considered equivalent to faculty at a Canadian university.

TRIUMF invites qualified applicants to submit resumes, including contact details for three referees, and quoting salary expectations and **Competition #917** to: **TRIUMF, Human Resource Department, 4004 Wesbrook Mall, Vancouver, BC, V6T 2A3. Fax (604) 222-1074.** Applications will be reviewed on an incoming basis. Closing date for applications is **October 15th, 2003.** Please note that in the event where two final applicants are equally qualified, preference will be given to the Canadian citizen or permanent resident. EOE

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SCIENTIST/STAFF SCIENTIST/SENIOR STAFF SCIENTIST

The Lawrence Berkeley National Laboratory (LBNL) has a position open for a career appointment in the category of Scientist, Staff Scientist or Senior Staff Scientist to work in the Advanced Light Source (ALS) Accelerator Physics Group. The incumbent is expected to support present and future accelerator projects at the ALS and LBNL. The work is targeted at optimizing the performance and implementing major upgrades of the ALS and developing future light sources at LBNL. The incumbent is expected to participate in planning and implementing R&D studies, carrying out experimental studies at the ALS, publishing experimental and research results in refereed journals, and presenting results via oral presentation at various meetings, conferences, and peer reviews.

Knowledge of and experience with beam physics issues associated with beam dynamics in storage rings, as well as experimental techniques for studying beam dynamics is essential. It is also desirable that the applicant have some familiarity and experience with collective instabilities and feedback. Must be independent and able to design, guide, and carry through projects. Must have a PhD degree in Physics or equivalent experience.

Note: This appointment will be made at the level of Scientist, Staff Scientist or Senior Staff Scientist. Appointment at the Scientist level may be made for an exceptional candidate just past PhD. Appointment at the Senior Staff Scientist level will be based on international recognition, and an extensive and outstanding record of scientific lea0dership and research. The Senior Staff Scientist will also require a more substantive leadership role in upgrades of the ALS and future accelerators at LBNL along with an expectation to make a substantial scientific and/or technical contribution. The Senior Staff Scientist is viewed as a fully developed professional with a distinguished record of scientific accomplishments.

To apply, please submit your CV, publication list, and list of references to afnsemployment@lbl.gov or via U.S. Mail to Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 937-600, Berkeley, CA 94720. Please reference job# AF/016325/JCERN. Berkeley Lab is an EEO/AA employer.

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Stanford Linear Accelerator Center

Faculty Position in Theoretical Elementary Particle Physics

The Stanford Linear Accelerator Center at Stanford University invites applications from outstanding candidates from all areas of elementary particle theory, for a tenure-track or early-career tenured faculty appointment. Candidates should have demonstrated their ability to carry out independent research in theoretical particle physics at the highest level. The position includes opportunities for classroom teaching and supervision of Stanford graduate students. The position allows a close interaction with the experimental program at the Stanford Linear Accelerator, and with the program of the new Kavli Institute for Particle Astrophysics and Cosmology.

Applicants should submit a curriculum vitae, publication list, statement of current research interests and future plans, and should arrange for four letters of recommendation to be sent to: **Professor Michael E. Peskin, Theory Group, MS 81, SLAC, 2575 Sand Hill Road, Menlo Park, CA 94025-7015.** All material should arrive by **October 1, 2003.**

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DEPUTY DIRECTOR OF ACCELERATOR OPERATIONS

(Position #AR2470)

Thomas Jefferson National Accelerator Facility (Jefferson Lab) in Newport News, Virginia, USA, is an internationally recognized laboratory engaged in fundamental scientific research in nuclear and particle physics based on the Continuous Electron Beam Accelerator Facility (CEBAF). The laboratory is operated for the US Department of Energy under management of the Southeastern Universities Research Association (SURA). In addition to operating CEBAF, the laboratory also operates a Free Electron Laser (FEL) facility. As a result of its core strength and competency in RF superconductivity, the laboratory is a major partner in many national and international projects such as the SNS, CEBAF 12 GeV Upgrade, RIA and TESLA.

In addition to the operating facilities and projects, the laboratory embodies its key theoretical and experimental expertise in particle and light beams and RF superconductivity in two centers of excellence: the Center for Advanced Studies of Accelerators and the Institute for Superconducting Radiofrequency (SRF) Science and Technology, with associated computer and laboratory facilities. The laboratory also has a highly specialized world-class particle source/injector group.

In order to further enhance its core competencies in the physics and technology of accelerators, lasers, particle beams, and synchrotron radiation, Jefferson Lab is currently seeking qualified candidates for the position of Deputy Director of Accelerator Operations. The incumbent in this position will assist the Director of Accelerator Operations in technical leadership of the operations of the CEBAF accelerator at Jefferson Lab in all technical areas and will be an integral part of the senior management of the Accelerator Division. The successful candidate will take major responsibility for the day-to-day operation of the CEBAF accelerator, technical supervision and guidance as appropriate of all technical personnel from Operations and other departments in the Accelerator Division engaged in the performance and operations of accelerator systems, the long range planning of accelerator operations, and provide support to the Director of Operations in creating and implementing a long-range vision for the development of the reliability and performance of the accelerator, both at its current configuration and in preparations for its imminent energy doubling upgrade. The candidate will interact with accelerator physicists, microwave superconductivity specialists, engineers and other technical staff in assessing, initiating and implementing planned configuration changes to the accelerator in order to meet the requirements of the physics users. At the discretion of the Director of Accelerator Operations, the candidate will periodically brief the user community on the performance of the accelerator, as well as the present and planned capabilities. In addition, the candidate will participate in the ongoing accelerator research program at Jefferson Lab as an associate member of the Center for Advanced Studies of Accelerators and/or the Institute for SRF Science and Technology. As Deputy Director of Accelerator Operations, the incumbent will lead the accelerator operations in the absence of the Director. Direct supervisory responsibilities may include up to a dozen individuals consisting of major group leaders and performance integrators and in absence of the Director of Operations, responsibility for up to 100 scientists, engineers, computer scientists, operators and technicians.

Candidates should have a Ph.D. in physics or engineering and at least 10 years of experience in particle accelerator physics, including a minimum of 5 years of direct experience of accelerator operations. The candidates must have excellent communication and leadership skills and demonstrate good judgment. The candidates should have functional knowledge of beam dynamics in accelerators and of all the accelerator systems, including RF, magnets and power supplies, beam diagnostics, control systems, etc. Knowledge of superconducting cavities would be a plus, but is not a requirement.

For prompt consideration, please apply on-line at www.jlab.org/jobline or send resume and salary history to Jefferson Lab, ATTN: Human Resources Administrator, 12000 Jefferson Avenue, Newport News, VA 23606, Fax: (757) 269-7559, E-mail jobline@jlab.org.

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BOOKSHELF

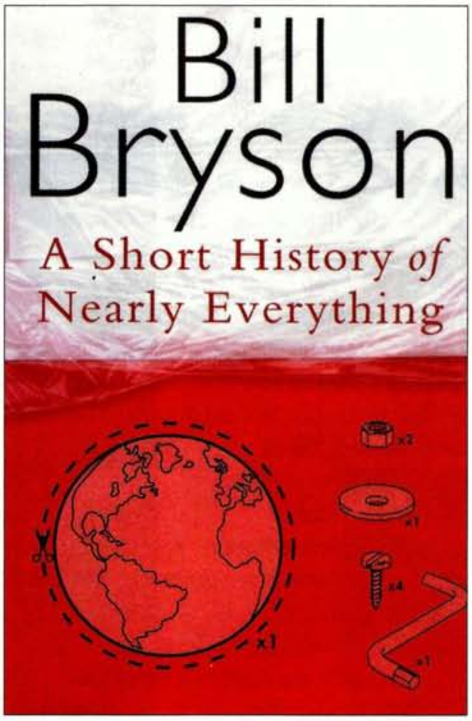
A Short History of Nearly Everything
by Bill Bryson, Doubleday. ISBN 0385408188, £20. (Broadway, ISBN 0767908171, $27.50 in the US.)

Bill Bryson simply could not write another paragraph about being presented with a disappointing dish of food, he explained on a book tour in May. Fortunately, he had other ideas. The writer best known for his humorous travel accounts was struck by how little he really knew about the planet he called home. The result is the modestly titled *A Short History of Nearly Everything*.

Any scientist – or for that matter science journalist – inclined to resent Bryson's hubris will find much to feel smug about in this book. There are a number of errors, some of them cringeworthy, and Bryson draws from popular sources such as *The Economist* at least as frequently as he does from scientific papers or his own reporting.

But to dwell on such technicalities would be to overlook the fact that Bryson has written an entertaining and informative 500-page book about science, which in itself is an accomplishment. Quirky characters from the history of science make up a large part of Bryson's material, but a larger theme is his sense of wonder at details of this universe we are lucky enough to inhabit. He spurns scientific notation, instead illustrating very large and very small amounts with passages such as: "If you could fly backwards into the past at the rate of one year per second, it would take you about half an hour to reach the time of Christ, and a little over three weeks to get back to the beginnings of human life. But it would take you 20 years to reach the dawn of the Cambrian period. It was, in other words, an extremely long time ago and the world was a very different place."

From analogies like this, as well as from Bryson's apocalyptic depictions of the havoc that supervolcanoes, meteor impacts, or climate change would wreak on civilization as we know it, the reader is left with a sense of mankind's rare and precarious place in the universe. We are here only because our ancestors (human and otherwise) were in the right place at the right time; we are anomalous inhabitants of a bacteria-dominated planet; we have existed as a species for a pitifully brief period of time. This thread runs through the book, weaving a coherent whole from what otherwise might have been nothing more than a motley assemblage of big numbers, interesting facts and comically eccentric scientists.



The book is at its best when Bryson goes into the field (or the lab or museum). Through him we meet the Reverend Robert Evans, an Australian "titan of the skies" who hunts supernovae from his back sun deck; Paul Doss, a Harley-Davidson-riding Yellowstone National Park geologist; and Len Ellis, who has studied mosses behind the scenes at London's Natural History Museum for the past 27 years. With these conversations, Bryson paints a picture of what day-to-day science is like.
Shawna Williams, CERN.

Quantum Chromodynamics – High Energy Experiments and Theory by Günther Dissertori, Ian G Knowles and Michael Schmelling, Oxford University Press. ISBN 0198505728, £60.

Thirty years have passed since quantum chromodynamics (QCD) was introduced, and it has now become the generally accepted theory of strong interactions. This book is intended to give an overview of the various aspects of QCD in lepton–nucleon scattering, in e^+e^- annihilation and in hadron–hadron scattering.

The authors begin with a general introduction to the quark model and its features, such as the colour quantum number. This ends with a demonstration of the QCD Lagrangian, and the theory is then presented in detail, followed by applications to e^+e^- annihilation, to lepton–hadron scattering and to purely hadronic reactions. In particular, there is a detailed description of the integro-differential DGLAP equations for describing scaling violations. The various aspects of the renormalization group equations are also described, including the quark mass terms. Deep-inelastic scattering is discussed, to leading order and next-to-leading order, together with the BFKL equations, the Drell–Yan process and a number of hadronization models.

A description of the related experimental work follows, starting with accelerator systems and ending with the detectors, in particular the ALEPH detector at LEP. The authors then move on to describe the general concepts of QCD analysis in e^+e^- annihilation, in lepton–nucleon scattering and for hadron colliders. The discussion centres on structure functions and distribution functions. The HERA results are described, both for neutral and charged-current interactions, along with results from neutrino–nucleon scattering. Here, the gluon distribution in the nucleon and the strange quark distribution are also considered, as well as the various sum rules (Adler sum rule, Gross–Llewellyn Smith sum rule, Gottfried sum rule, sum rules for polarized structure functions). This is followed by a description of aspects of hadronic processes, such as the Drell–Yan process, and the production of direct photons.

The authors devote a special chapter to a detailed discussion of the strong coupling constant. This is deduced from the ratio R, measured in e^+e^- annihilation, from R_τ, from sum rules, from the physics of heavy flavours and from measurements at hadronic colliders. Tests of the gauge structure of QCD, and especially of the colour factors, are considered next, followed by an analysis of the leading-log results of QCD.

The final chapters look at the difference between quark and gluon jets, and various aspects of fragmentation (multiplicities, momentum spectra, string effects, colour coherence, Bose–Einstein correlations and colour reconnection). Appendices on elements of group theory, dimensional regularization and scaling violations in fragmentation functions are also included. Exercises are provided after each chapter and the solutions are described at the end of the book.

The book concentrates on those aspects of QCD that have been tested in experiments. The largely unknown features of the theory, when it comes to the low-energy properties and confirmation, are only superficially discussed. Aimed at graduate students, ▷

post-doctoral physicists and professional researchers in particle physics, this book can be recommended to both experimentalists and theorists interested in QCD.
Harald Fritsch, University of Munich.

Fundamentals of Electroweak Theory by Jiri Horejsi, Charles University Prague, The Karolinum Press. ISBN 8024606399, €50 ($50).

This book is an introduction to electroweak theory at the graduate-student level. The first 100 or so pages are dedicated to the old weak interaction theory, from Enrico Fermi to Nicola Cabibbo. The remainder of the book then goes on to describe the modern standard gauge theory of electroweak interactions.

Overall, I had a favourable impression on reading this book. The main qualities are clarity, formal simplicity and a good sense of physics. Tree-level unitarity constraints and the good behaviour of amplitudes at large energies are often used as guiding principles for the discussion of Standard Model couplings. A number of exercises are proposed at the end of each chapter.

One drawback is the absence of an adequate discussion of the experimental tests of electroweak theory and, in general, of the phenomenological aspects that are currently of interest. There is not even a summary or any basic calculations about the properties of the W, the Z and the Higgs particles. One or two further chapters on modern collider physics, covering the past 20 years of electroweak phenomenology, would provide a useful completion to this book.
Guido Altarelli, CERN.

Books received

Universal fluctuations by Robert Botet and Marek Ploszajcak, World Scientific. Hardback ISBN 9810248989, £46 ($68). Paperback ISBN 9810249233 £24 ($36).

In this book, the authors present the appearance of universal limit probability laws in physics and their connections with the recently developed scaling theory of fluctuations. They conclude by describing how a new description of hadronic matter is appearing as the consequence of this approach.

Towards a nonlinear quantum physics by J R Croca, World Scientific. Hardback ISBN 9812382100, £31 ($46).

The author presents evidence that Heisenberg's uncertainty relations are not valid in all cases, and goes on to derive a more general set of uncertainty relations.

Advances in non-linear dynamos by Antonio Ferriz-Mas and Manuel Núñez (eds), Taylor and Francis. Hardback ISBN 041528788X, £80.

The latest in a series on the fluid mechanics of astrophysics and geophysics, this book presents an updated and coherent view of recent advances in the field, with contributions from leading authors. A useful reference book for postgraduates and researchers, it covers both kinetic and dynamo approaches to the subject.

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Technology brings the world to Africa

Harry McConnell, director of the Interactive Health Network and chief executive officer of the International eHealth Association, explains why communication technologies are so important for health and development in Africa.

Mozambique was the host to an extraordinary event in July involving African heads of state, leading medical experts and major funding agencies for health and development. Uniquely, this interaction was part of a special session of the summit of the African Union, and the participants spoke from different venues around the world via communication technologies.

The incoming president of the African Union, President Chissano of Mozambique, presided over the conference, which saw African heads of state interacting with key stakeholders, including the World Health Organization (WHO), the World Bank, the UK Department for International Development, the US government and the Gates Foundation. This is the first time that heads of state have opened their doors to the world in such a way as a formal part of any international summit. The African Union showed tremendous initiative in leading the way on this, and the technology facilitated it in a way that increased the interaction and input from the major international agencies.

Mozambique also demonstrated its technological capacity to host such an event, using ISDN, several satellite systems and digital radio to link the summit, which was held in the capital Maputo, with 22 African nations, Geneva, London, New York, Washington, DC, and Dublin, via videoconference. Graça Machel moderated the discussion from Maputo. The Interactive Health Network organized the event, which was also broadcast around the world on the Web, radio and television. CERN participated with the WHO from Geneva, where CERN's Manjit Dosanjh was in the chair.

The outcome of this unique combination of technology was a highly interactive session that resulted in a new declaration on the role of African states in combating HIV, malaria and tuberculosis. The Prime Minister of Mozambique, Pascoal Mocumbi, Peter Piot of UNAIDS and African heads of state representing each region, all gave key addresses on this important topic. President Olusegun Obasanjo of Nigeria outlined the role of the New Partnership for Africa's Development (NEPAD), and President Yoweri Museveni of Uganda spoke of his country's approach to reducing the incidence of HIV. The session showed a new way forward for governance and global interaction in setting policy for the critical issues in health and development.

the role of science in the information society
CERN, Geneva, 8-9 December 2003

As a follow up to this event, the Interactive Health Network and the International eHealth Association are collaborating with CERN in an effort to establish a pan-African health communications network for HIV, malaria and tuberculosis, with awareness, education, research, clinical care and effective policy implementation as central goals.

I see three key elements in this network. First, it should provide access to essential information on best practice and evidence-based medicine. International agencies currently rely mainly on information generated outside of Africa in making decisions. However, evidence-based practice in other countries does not necessarily apply to Africa. Exchange of information must occur between health professionals within Africa to ensure that the best information is available and used appropriately. This will require a unique integration of education, research and point-of-care access, with communication between researchers and clinicians that maximizes the experience of patients and clinicians working in their own environment in Africa.

A second key element is the prevention of illness through effective communication. The most effective public health initiatives so far have been led by Africans promoting measures to reduce the rate of infection at the grass-roots level. The Ugandan approach to the HIV epidemic is one such example. Radio, television and satellite can all be effective means of transmitting essential public health messages, giving communities the education they need to help themselves.

Thirdly, the network must facilitate meaningful policy making by empowering leaders. Policy makers and leaders can only make decisions based on the information available to them. Familiarity with the experiences of other healthcare systems can help avoid repeating the mistakes of others. Transparency and effective leadership are thus inseparable, and can be promoted through effective communications.

Africa has a unique opportunity to "leap-frog" its policies with respect to information and communication technologies (ICTs). It has the potential to benefit more than any other region from innovative ICT use in health. There are many underutilized networks in Africa that can make ICTs available in even the most remote areas, and their use can help to achieve health equity in Africa.

● CERN will host a conference in December to discuss the potential uses for ICTs in health and other fields. Co-organized by ICSU, TWAS and UNESCO, the Role of Science in the Information Society (http://cern.ch/rsis) will precede the World Summit on the Information Society, as a side event to the summit.

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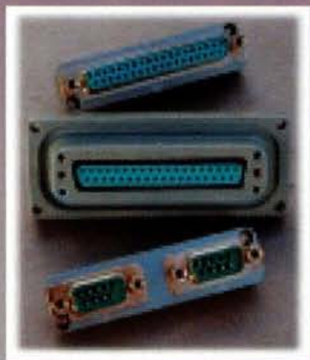

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