

CERN COURIER

VOLUME 40 NUMBER 6 JULY/AUGUST 2000



DESY diversity

NEUTRINO ASTRONOMY

Studying physics and the universe through extra-terrestrial particles p17

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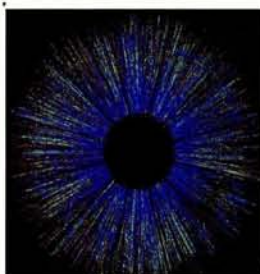
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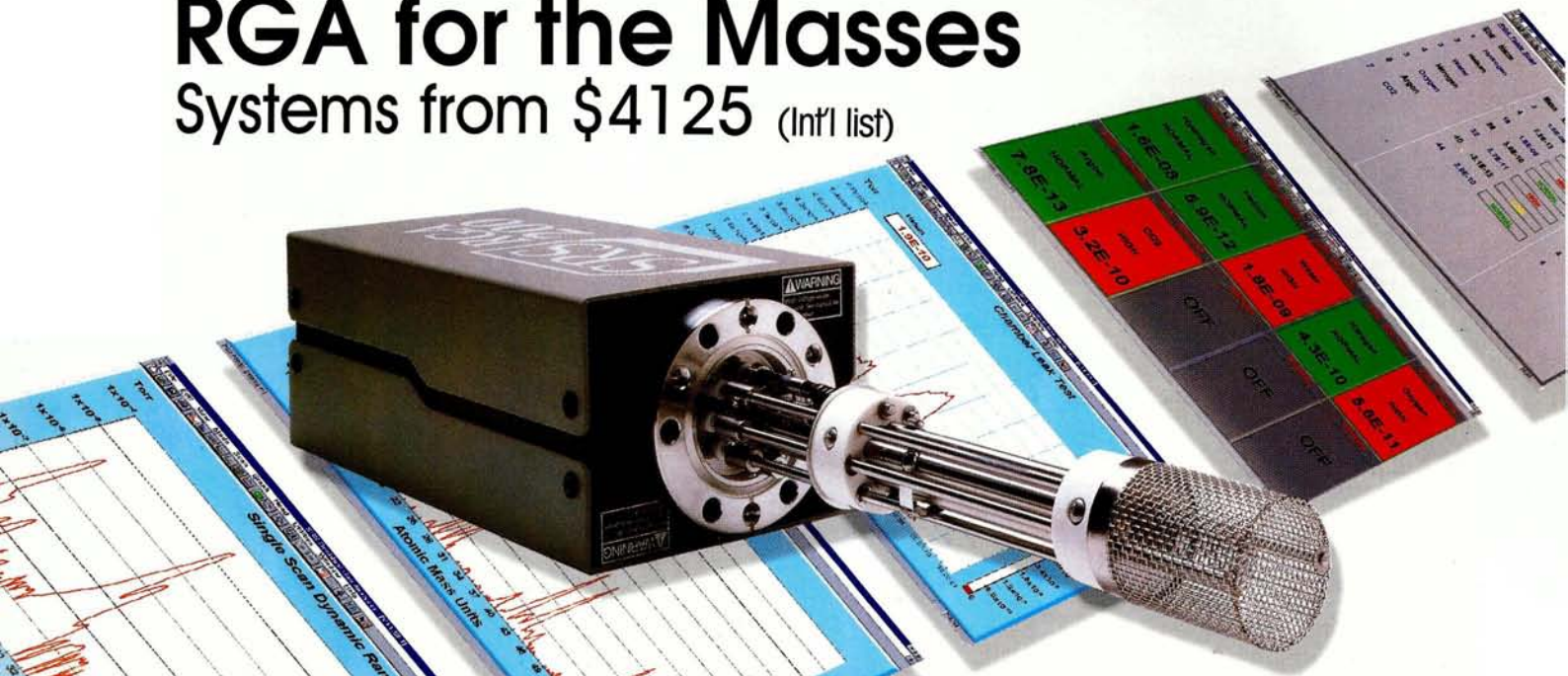
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Cover: On 23 May a major event marked 40 years of the DESY Laboratory in Hamburg and the opening of its Light for the New Millennium exhibition. The show was presented by NDR (Norddeutscher Rundfunk) Hamburg TV personality Bernd Seguin. (Photo DESY.) p6.

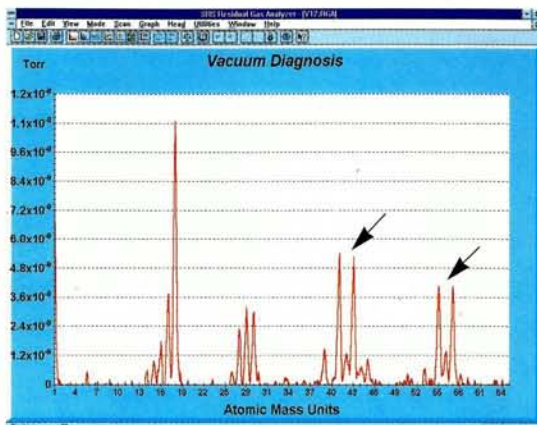
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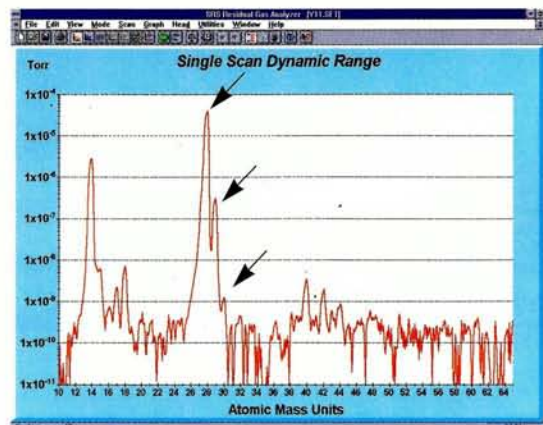


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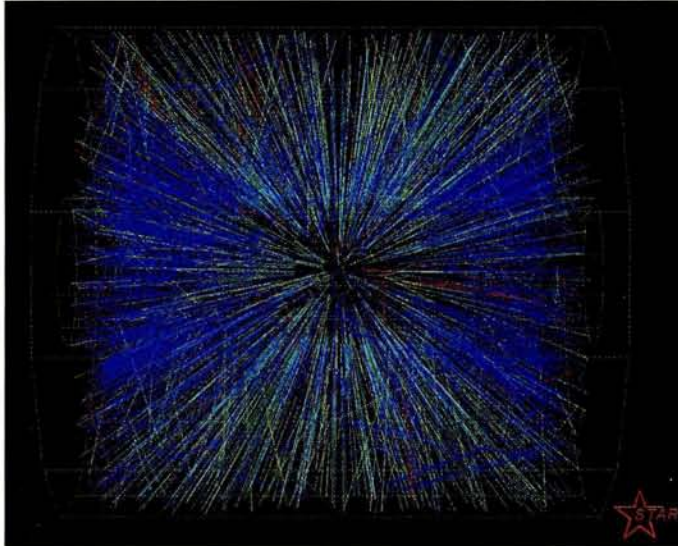


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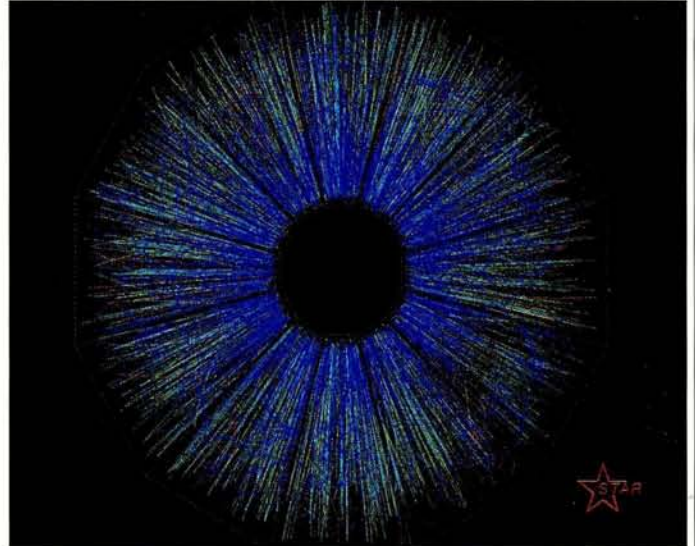


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RHIC begins smashing nuclei



Gold at STAR – side view of a collision of two 30 GeV/nucleon gold beams in the STAR detector at the Relativistic Heavy Ion Collider at Brookhaven.



End view in the STAR detector of the same collision looking along the direction of the colliding beams. Approximately 1000 tracks were recorded in this event.

On Monday 12 June a new high-energy machine made its stage debut as operators in the main control room of Brookhaven's Relativistic Heavy Ion Collider (RHIC) finally declared victory over their stubborn beams. Several weeks before, Derek Lowenstein, chairman of the laboratory's collider-accelerator department, had described repeated attempts to get stable beams of gold ions circulating in RHIC's two 3.8 km rings as "like learning to drive at the Indy 500!"

With beams finally circulating in the collider's twin rings on a collision course at an energy of 30 GeV per nucleon, the waiting STAR detector captured the first spectacular images of particles streaming from a head-on collision point, showing an impressive shower of about 1000 tracks, but this was just a foretaste of bigger things to come. Soon, collisions were also seen by the BRAHMS, PHENIX and PHOBOS detectors.

The result is great news for the thousands of physicists, engineers and support staff who have been working since 1991 to get RHIC up and running, and for physicists everywhere who have been anticipating RHIC's debut.

"These are the most spectacular subatomic collisions ever witnessed by humankind, representing the culmination of many years of hard work," said Satoshi Ozaki, associate

laboratory director for RHIC. It was a proud moment for Ozaki, who returned to Brookhaven from Japan to oversee the construction and commissioning of this challenging machine.

The high temperatures and densities achieved in the RHIC collisions should, for a fleeting moment, allow the quarks and gluons to roam in a soup-like plasma – a state of matter that is believed to have last existed millionths of a second after the Big Bang. Information from RHIC experiments will round out the quark-gluon plasma knowledge gained through experiments using nuclear beams at lower energies at CERN's SPS synchrotron.

RHIC construction began in 1991, and the project was completed last year, when all parts of the machine were initially tested and operated as a complete system, but just short of physics operation. Construction and commissioning costs totalled \$600 million.

Nuclei destined for RHIC originate in the laboratory's Tandem Van de Graaff, proceed into the booster and then travel on to the venerable Alternating Gradient Synchrotron (AGS), which first came into operation in 1960. The AGS injects nuclear beams into RHIC for experiments.

For RHIC, bunches of nuclei are injected into each of the two rings. Then, with both

rings filled, the ions will be whipped to 70 GeV/nucleon. With stable beams coasting around the rings, the nuclei collide head-on, eventually at the rate of tens of thousands of collisions per second.

Principal RHIC components were manufactured by industry, in some cases through co-operative ventures that transferred technology developed at Brookhaven to private industry.

The RHIC tunnel is filled with 1740 superconducting magnets in two rings, which bend and focus the particles. Dipole and quadrupole magnets were built by the Northrop-Grumman Corporation on Long Island, and sextupole magnets were built by Everson Electric, in Bethlehem, Pennsylvania. Brookhaven built the corrector magnets and other special magnets.

The RHIC tunnel configuration provides for six areas where the circulating beams cross and where collisions take place. Four areas now contain detectors – two large ones, STAR and PHENIX, and two smaller assemblies, PHOBOS and BRAHMS. All together, close to 1000 scientists from 90 research institutions representing 19 countries are working on RHIC experiments.

For more information and to follow RHIC's progress, visit "<http://www.rhic.bnl.gov/>".

Unity in diversity – DESY turns 40



Birthday party – the central area of DESY's EXPO exhibition, *Light for the New Millennium*, which was the venue for the celebrations marking the 40th anniversary of the Hamburg laboratory on 23 May this year. (DESY.)

On 18 December 1959 the state contract was signed and DESY was born. However, like some monarchs, the German DESY laboratory in Hamburg chose a different date for its official birthday. On 23 May, 2400 people took their seats in a balloon-filled marquee to celebrate DESY's 40th birthday, with the theme "Unity in diversity".

DESY director-general Albrecht Wagner proudly welcomed many special guests. Particular welcomes were extended to 88-year-old Willibald Jentschke, a founding father and first director-general of the laboratory from 1959 to 1970, and to Mrs Becker-Wiik, widow of Bjorn Wiik, who was DESY director-general from 1993 until his tragic death last year. Wagner paid tribute to Wiik as a "great visionary" and revealed that donations to a research foundation created in his memory exceeded DEM 75 000 (see box).

Congratulations from German Chancellor

Bjorn Wiik Research Project

The World Laboratory Bjorn Wiik Research Project, created in honour of the late Bjorn Wiik, awards scholarships to young scientists from developing countries to enable them to pursue research and training at DESY in particle or accelerator physics, application of synchrotron radiation and high-performance computing. Mikhail Yurkov of Russia, who was one of the first winners of a Wiik scholarship, in recognition of his pioneering work on the FEL, was one of the keynote young speakers at the DESY anniversary event.

Gerhard Schroeder were conveyed by Edelgard Bulmahn, Federal Minister for Education and Research. She commended the "diversity" – the symbiosis of different research areas at DESY – a theme echoed by Hamburg deputy mayor Krista Sager, who stressed the benefit of doing applied as well as basic research. Sager also acknowledged the impact of DESY on Hamburg: every local resident has heard of DESY and is proud of the laboratory.

Strong emphasis was given to TESLA, a plan for a future TeV linear electron-positron collider running 33 km from DESY into Schleswig-Holstein. Ute Erdsiek-Rave, Schleswig-Holstein Minister for Education, Science, Research and Culture, joked that "Hamburg for once needs Schleswig-Holstein!"

Minister Bulmahn explained that TESLA would be undergoing detailed scrutiny in Germany this year, in comparison with parallel projects in the US and Japan. It is, she



VIP preview of the DESY exhibition. Left to right: Polish Science Minister Andrzej Wischniewsky, DESY director-general Albrecht Wagner, Minister Edelgard Bulmahn and DESY director for synchrotron radiation research Jochen Schneider. (DESY.)

believes, the project of the future. "I admire the foresight and courage of Bjorn Wiik in putting this project together," she said.

Five young physicists, representative of the diversity of nationalities under DESY's roof, presented an overview of research at DESY, focusing on the unique HERA electron-proton collider and the Free Electron Laser (FEL). Then party guests were granted "ein Sneakpreview" of the DESY exhibition, *Light for the New Millennium*, before the public opening.

The exhibition hall will eventually become an experimental area for the FEL project (p26). However, Albrecht Wagner is keen to find a permanent home for the exhibition, perhaps as a cornerstone of a new science museum in Hamburg. With the laboratory poised at another crossroads in its illustrious career, he looked forward to "another exciting chapter in the DESY history book".
Alison Wright, CERN.

UK phenomenology centre is created

After several months of negotiations, the UK Particle Physics and Astronomy Research Council has announced the establishment of an Institute for Particle Physics Phenomenology at Durham University. The director-designate is James Stirling.

The aim is to establish a broad-based, internationally competitive research activity in



James Stirling is director-designate of the new UK Institute for Particle Physics Phenomenology at Durham.

a key area. Phenomenology (the analysis, comparison and interpretation of data) is the bridge between theory and experiment. Durham already has a considerable international reputation in this field (see "<http://durpdg.dur.ac.uk/HEPDATA>"). The new

Institute will set out to make additional contributions to both the experimental and the wider UK theoretical programmes. Research will encompass accelerator and non-accelerator measurements, and the emphasis of the research should evolve with the UK experimental particle physics programme.

Experimentalists will participate in the activities of the new institute, which will host an extensive visitor programme and hold workshops and summer schools for the benefit of the whole UK particle physics community. The institute is expected to start up in October.

Meeting the ALICE data challenge

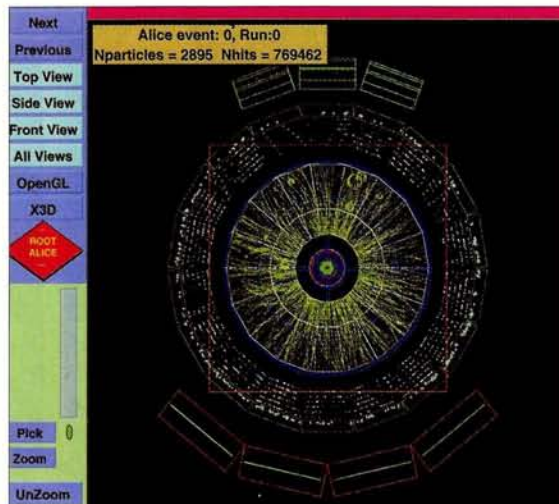
Imagine trying to record a symphony in a second. That is effectively what CERN's ALICE collaboration will have to do when the laboratory's forthcoming Large Hadron Collider (LHC) starts up in 2005. Furthermore, that rate will have to be sustained for a full month each year.

ALICE is the LHC's dedicated heavy-ion experiment. Although heavy-ion running will occupy just one month per year, the huge number of particles produced in ion collisions means that ALICE will record as much data in that month as the ATLAS and CMS experiments plan to do during the whole of the LHC annual run. The target is to store one petabyte (10^{15} bytes) per year, recorded at the rate of more than 1 Gbyte/s. This is the ALICE data challenge, and it dwarfs existing data acquisition (DAQ) applications. At CERN's current flagship accelerator LEP, for example, data rates are counted in fractions of 1 Mbyte/s. Even NASA's Earth Observing System, which will monitor the Earth day and night, will take years to produce a petabyte of data.

Meeting the challenge is a long-term project, and work has already begun. People from the ALICE collaboration have been working with members of CERN's Information Technology Division to develop the experiment's data acquisition and recording systems. Matters are further complicated by the fact that the ALICE experiment will be situated several kilometres away from CERN's computer centre, where the data will be recorded. This adds complexity and makes it even more important to start work now.

Standard components – such as CERN's network backbone and farms of PCs running the Linux operating system – will be used to minimize capital outlay. They will, however, be reconfigured for the task in order to extract the maximum performance from the system. Data will be recorded by StorageTek tape robots installed as part of the laboratory's tape-automation project to pave the way for handling the large number of tapes that will be required by LHC experiments.

The first goal for the ALICE data challenge



Alice in gigabyte land. This simulation shows a fraction of the tracks in a lead-ion collision, as would be seen by the ALICE detector at CERN's LHC collider.



One of CERN's StorageTek tape silos used in the ALICE data challenge.

was to run the full system at a data transfer rate of 100 Mbyte/s – 10% of the final number. This was scheduled for March and April 2000 so as not to interfere with CERN's experimental programme, which will get up to speed in the summer.

Data sources for the test were simulated ALICE events from a variety of locations at CERN. After being handled by the ALICE DAQ system (DATE) they were formatted by the ROOT software, developed by the global high-energy physics community. The data were then sent through the CERN network to the computer centre, where two mass storage systems were put through their paces for two weeks

each. The first, HPSS, is the fruit of a collaboration between industry and several US laboratories. The second, CASTOR, has been developed at CERN.

Although each component of the system had been tested individually and shown to work with high data rates, this year's tests have demonstrated the old adage that the whole is frequently greater than the sum of its parts: problems only arose when all of the component systems were integrated.

The tests initially achieved a data rate of 60 Mbyte/s with the whole chain running smoothly. However, then problems started to appear in the Linux operating system used in the DAQ system's PC farms. Because Linux is not a commercial product, the standard way of getting bugs fixed is to post a message on the Linux newsgroups. However, no-one has previously pushed Linux so hard, so solutions were not readily forthcoming and the team had to work with the Linux community to find their own.

That done, the rate was cranked up and failures started to occur in one of the CERN network's many data switches. These were soon overcome – thanks this time to an upgrade provided by the company that built the switches – and the rate was taken up again. Finally the storage systems had trouble absorbing all of the data. When these problems were ironed out, the target peak rate of 100 Mbyte/s was achieved for short periods.

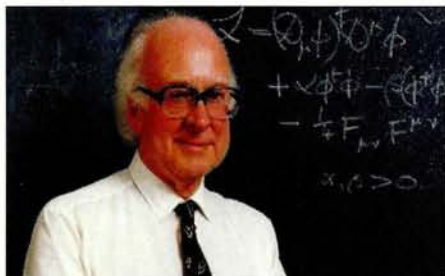
At the end of April the ALICE data challenge team had to put their tests on hold, leaving the CERN network and StorageTek robots at the disposal of ongoing experiments and test beams. During the tests, more than 20 Tbyte of data – equivalent to some 2000 standard PC hard disks – had been stored. The next milestone, scheduled for 2001, is to run the system at 100 Mbyte/s in a sustained way before increasing the rate, step by step, towards the final goal of 1 Gbyte/s by 2005. The ALICE data challenge team may not yet have made a symphony, but the overture is already complete.

Higgs is honoured in Edinburgh

As part of the recent UK Institute of Physics conference, Particle Physics 2000, in Edinburgh, a special symposium was held to celebrate the 70th year of Peter Higgs, after whom the elusive "Higgs field" is named. This field and its particles are responsible for the spontaneous symmetry breaking of the symmetry of electroweak interactions, so that, for example, the W and Z carriers of the weak force are heavy particles, while the electromagnetic photon remains massless. Finding the Higgs particle(s) is today's major particle physics goal.

The event opened with a talk by current Nobel prizewinner Gerard 't Hooft on the early days of gauge theories, in which he reminded the audience that in the 1960s these theories were widely regarded as of little relevance to particle physics. However, his supervisor, Martinus Veltman, insisted that all of his students read an obscure paper from the 1950s by Yang and Mills, so helping the 1970s resurgence of gauge field theories.

In the following talks, Peter Zerwas (DESY) reviewed the phenomenology of the Higgs particle at current and future colliders, and Pedro Teixeira-Dias (CERN) described the cur-



Peter Higgs – 70th birthday. At a recent symposium in Edinburgh to mark the event, he was presented with a T-shirt with a picture of his grandson – "the lightest Higgs".



rent experimental search for the Higgs at LEP.

The afternoon concluded with a lively talk by former CERN director-general Chris Llewellyn Smith on his long association with the search for the Higgs boson, which began as the theory convener of a workshop in 1980. He gave a vivid description of the physics involved in engineering the LHC collider, including a picture of the CERN administration building apparently "relocated" to one of the LHC experimental caverns. He had used this to show the CERN Council how big the pits needed to be, and was asked why

he wanted to move the administration building to the pit!

A theme of the meeting was that the Higgs is everywhere. In a public lecture by Frank Close on the origins of asymmetry, Higgs was seen to break the symmetry of an empty Coke can on which Close was balancing, causing Close's potential to collapse into an asymmetric state.

At the banquet, Ken Peach, director of particle physics at Rutherford Appleton Laboratory, gave a lecture from the pulpit of the former Highland Kirk. In this suitably Calvinist setting, he recalled his misspent



Industrial excellence for physics – the Crystal Award presented to Deggendorfer Werft und Eisenbau (DWE) GmbH by the CMS collaboration at CERN's LHC collider.

CMS contractors receive LHC collaboration awards

Three contractors involved in CERN's forthcoming CMS experiment's magnet project became the first beneficiaries of the collaboration's new awards scheme on 5 June. In the two-tiered scheme, major contractors deemed by the collaboration to have delivered exceptional service will receive the CMS Crystal Award. Other contractors are eligible for the CMS Gold Award.

CMS has initiated the scheme as a motivating factor for all of its contractors, and as a way of rewarding excellence. A panel of five has been established to consider award nominations made by CMS project leaders, and to make recommendations to the experiment's Collaboration Board. Criteria considered by the panel include strict adher-

ence to the terms and deadlines of a contract, a good working relationship and exceptional performance in terms of innovation.

The first three awards were made during a CMS collaboration meeting at CERN. It is no accident that they all went to contractors working on the experiment's magnet, since that is the furthest advanced component of the new experiment. A Crystal Award went to Germany's Deggendorfer Werft und Eisenbau (DWE) GmbH, principal contractor for the CMS magnet yoke. DWE delivered the fifth and final wheel for the barrel part of the yoke on time and within budget just before the meeting began. Gold Awards were presented to two of DWE's subcontractors: Izhora of St Petersburg, which produced the 120 forged

youth as a student in Edinburgh, but seemed to remember attending a few field theory lectures by Higgs, which may account for his subsequent career. More recently he recalled an L3 speaker giving a seminar in Edinburgh describing the failure to find a Higgs at LEP, at the end of which it was pointed out that there was in fact a Higgs in the audience.

However, the most moving part of the Fest belonged to Higgs, who sported a T-shirt of his grandson, indicating the existence of a second light Higgs (evidence for supersymmetry?). He received an honorary fellowship of the Institute of Physics, and a piece of an LHC magnet from his colleagues, to which he responded in typically modest fashion. Apparently the famous Higgs particle was the result of only three weeks' work in the mid-1960s. The first two weeks were spent writing a paper and having it rejected by the referee on the grounds that quantum field theory was obscure and of little interest. The referee suggested that the paper might be improved by the addition of some practical consequences of the theory. The third week was spent providing these examples, which included the Higgs particle. The audience, which included a large fraction of graduate students, was suitably awestruck by the idea that a mere three weeks' work might be sufficient to get a particle named after you.

Steve Playfer, Edinburgh.

CERN and Pakistan strengthen agreement

Signed in Islamabad in May was an addendum to the Memorandum of Understanding between CERN and Pakistan, covering increased Pakistani involvement in the CMS experiment for CERN's LHC collider.

Pakistan is supplying six giant 25 ton support feet for the main "barrel" magnet of the CMS detector, as well as material for the magnet itself. Under the new agreement the National

Centre for Physics at Quaid-i-Azam University, Islamabad, will also supply 432 resistive plate chambers (RPCs) for the CMS forward muon system as part of a collaboration that also involves China, Italy, Korea and the US. In addition the front-end electronics boards for RPC read-out will be manufactured in Pakistan.

A major CERN delegation was recently in Pakistan for the signing of the new agreement.



On the right foot: CERN director-general Luciano Maiani at Taxila, Pakistan, with one of the 25 ton support feet for the magnet of the CMS experiment at CERN's LHC collider. These components are supplied by Scientific Engineering Systems of Taxila as part of Pakistan's contribution to the CMS collaboration.



DWE's subcontractors, Izhora and ZDAS of the Czech Republic received Gold Awards.

iron blocks making up the magnet yoke, and ZDAS of the Czech Republic, which made the brackets that will hold them all together in 12-sided wheels.



Islamabad, Pakistan: CERN research director Roger Cashmore (left) and Pakistan Atomic Energy Commission (PAEC) member (technical) Samar Mubarakmand sign an addendum to the Memorandum of Understanding between CERN and Pakistan covering increased Pakistani involvement in the CMS experiment for CERN's LHC collider. Behind them are (left to right) CERN advisor on non-member state matters John Ellis, Hafeez Hoorani of the National Centre for Physics, PAEC chairman Ishfaq Ahmad, National Centre for Physics director Riazuddin, CERN director-general Luciano Maiani, Quaid-i-Azam University vice-chancellor Tariq Siddiqui and CMS collaboration resources manager Diether Blehschmidt.

Czech physics scene is growing



At the ECFA meeting in Prague. Left to right: ECFA chairman Lorenzo Foà, Czech student Peter Homola and Czech ECFA representative Vladislav Simak.



Left to right: Jiri Niederle, president of the CERN/Czech collaboration committee; CERN director-general Luciano Maiani; and Czech Deputy Foreign Minister Hynek Kmonicek.

Particle physics in the Czech Republic is maturing fast. This was the message that emerged from the European Committee for Future Accelerators (ECFA) during its continual tour of CERN member states as it recently surveyed national activities at a meeting at the Masaryk Hostel of the Czech Technical University, Prague. (The hostel is named after Tomáš Masaryk, who was the first president of the Czechoslovakian Republic, from 1918 to 1935.)

At the ECFA meeting, policy issues in the Czech Republic were presented by M Potucek and Pavel Chraska, respectively deputy chairman and a member of the national Research and Development Council. This agency is proposing new rules for the organization finance of research and development. The keyword in these presentations was "changes", of which there have already been many since the 1989 "velvet revolution", but there are more to come.

One major purpose is to make the Czech system more compatible with that of the European Union countries. For example, scientific research was traditionally carried out almost entirely at the institutes of the Academy of Sciences while the universities were "just for

teaching". This has now changed. There has also been a drastic reduction in the number of people employed by the academy, from about 13 000 to about 6500. Several institutes of the academy have been closed.

After several difficult years there is now optimism in the air. The state support of R&D – 0.4% of national GNP in 1999 – is expected to be 0.6% in 2000 and to increase to 0.7% by 2002. One difficult remaining problem concerns how to attract young people, who are badly needed, because the average age in this sector is high. The salaries offered to young people are simply not attractive enough.

The status of high-energy physics in the Czech Republic was reviewed by J Niederle, president of the National Committee for Collaboration with CERN, and by J Hosek. The good news here is that there has been a sub-

stantial increase in the number of high-energy physicists in the Czech Republic since the ECFA last visited the country in 1994. The number of theorists has increased from 37 to 51 and that of experimentalists from 39 to 94. This is partially due to the change of orientation of scientists already in the system. The average age of permanently appointed staff is high – 48 for theorists and 51 for experimentalists.

So far the Delphi experiment at LEP has been the central activity of Czech experimental physics. For the future, ATLAS at the LHC will take over this role. However, Czech physicists also take part in a range of other experiments at CERN (ALICE, CERES, DIRAC, ISOLDE, NA57) as well as in several R&D projects. Outside CERN, Czech physicists participate in the D0 experiment at Fermilab and in H1 at DESY. Since 1998 the Czechs have also been involved with the Auger cosmic-ray project.

Across this now wide spectrum – in R&D, detector building, data analysis and theory – Czech physicists make an important contribution to the world particle physics effort in general and to the CERN programme in particular. At the meeting, Czech physicists described this contribution.

Charles University, Prague

The oldest university in central Europe, Charles University in Prague, was founded in 1348 by Charles IV, then Holy Roman Emperor and King of Bohemia. Austrian physicist and philosopher Ernst Mach was a professor there for 28 years (1867–95), during which time he proposed Mach's principle, which greatly influenced Albert Einstein's thinking in the formulation of his theory of gravity. Mach also served as rector of the University. Appointed professor at the university in 1911, Albert Einstein became aware there of the importance of tensor calculus for his work on general relativity. His student at Prague was Otto Stern. When Einstein left Prague the following year, he was succeeded by Philipp Frank.

Antiprotons spring surprises

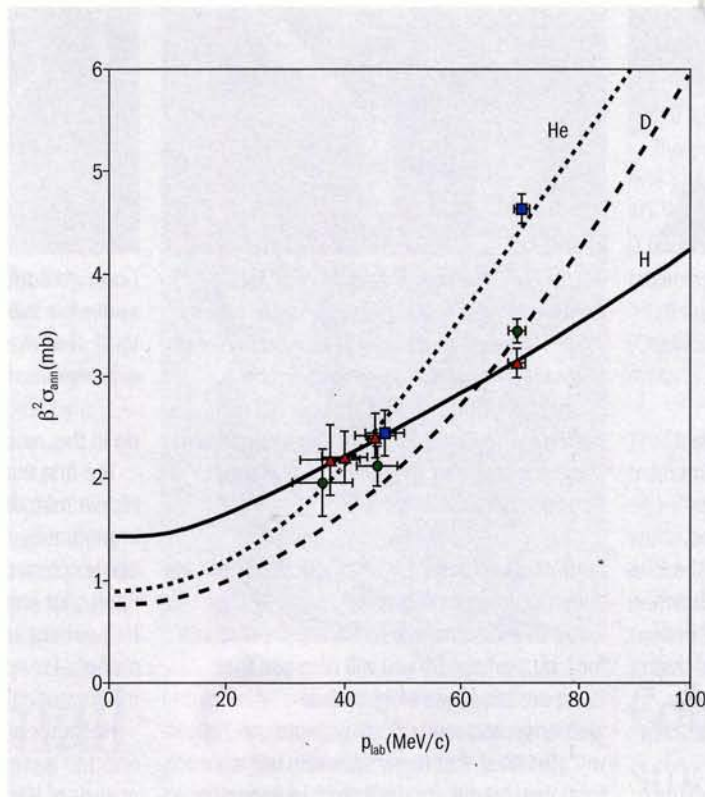
Experiments at CERN's low-energy antiproton ring (LEAR), closed in 1996, brought many very-high-precision and sometimes surprising antiproton results. Some continue to appear, the latest being the apparent independence of the size of the target of the antiproton-nucleus annihilation rate at very low energy. Clearly antiproton annihilation is a mysterious business.

Antiproton-nucleus annihilation was measured at LEAR by the OBELIX experiment at very low antiproton momenta, down to 40 MeV/c. This momentum seems quite large with respect to the characteristic momentum in particle-antiparticle systems bound by electromagnetic attraction (Coulomb force). For proton-antiproton, this is of the order of 4 MeV/c. Nevertheless, this attraction appears to be important and can even affect the annihilation rate.

In fact, in this energy range, Bethe's usual $1/v$ law is replaced by a $1/v^2$ one, where v is the relative velocity of the interacting particles.

This $1/v^2$ regime was predicted in 1948 by Wigner and is well known in atomic physics. In nuclear physics, in contrast, one usually encounters electromagnetic repulsion between protons, which gives rise to an exponential decrease of the reaction rate at low energies, a phenomenon that is particularly important in nuclear astrophysics.

The OBELIX experiment, for the first time, investigated with very high precision the behaviour of the reaction rate in a system with Coulomb attraction. In the figure, the measured antiproton-proton, antiproton-deuteron and antiproton-helium annihilation cross-sections are presented as a function of antiproton momentum.



Mysterious annihilation. Proton-antiproton (red triangles), antiproton-deuteron (green bullets) and antiproton-helium (blue squares) annihilation as measured by the OBELIX experiment at CERN's LEAR low-energy antiproton ring. The values are weighted by the square of the relative velocity of the annihilating particles. The curves show the results of a phenomenological analysis of the data. However, the large disparity between the curves – the deuteron and helium cases higher than proton-antiproton at higher momenta and lower at lower momenta – is not totally understood in terms of the basic nucleon-antinucleon annihilation.

These cross-sections are multiplied by the square of the relative velocity. For the proton-antiproton system, the situation is very clear: one can see that the product tends to a constant value with decreasing antiproton momentum. For a $1/v$ behaviour, this product should tend to zero. For the deuteron and helium cases, the analysis is more complicated.

This change of regime is instructive but not really unexpected. The most interesting observation comes from the comparison of the values of these three cross-sections. At high energies they are quite different – the antiproton-nucleus annihilation cross-sections are several times that for antiproton-

proton. Surprisingly, at low antiproton momentum, the antiproton-deuteron and antiproton-helium annihilation cross-sections drop to the proton-antiproton level or even below it.

An accurate analysis of these annihilations shows that this is not a kinematic effect; it is a direct result of the dynamics of the antiproton-nucleus interaction.

This was confirmed independently by another LEAR experiment – PS207 – which measured, for the first time, the shift and the broadening of the antiproton-deuteron atomic ground state. This extremely difficult experiment showed that the width of this level, entirely determined by the annihilation process, is approximately the same for antiproton-proton and antiproton-deuteron atoms.

A geometrical picture of annihilation would suggest that the probability of this process should increase with the number of possible annihilating partners – the number of nucleons in nuclei.

However, these experiments demonstrate clearly that this is not the case.

To understand the mystery, these experiments should be continued at lower energies and with heavier nuclei, not only to understand the dynamics of the annihilation process but also to measure the cross-sections.

This knowledge would be important, in particular for astrophysicists, who search for antimatter in the universe and need to know about the properties of low-energy matter-antimatter interaction. CERN's antiproton decelerator (AD), currently starting operations, will be a powerful tool in obtaining this precious antimatter information.
Konstantin Protasov, Institut des Sciences Nucléaires, Grenoble.

Celebrating the centenary of a conscience



One of Pauli's last major public appearances was at the 8th International ("Rochester") Conference on High Energy Physics, hosted by CERN in the summer of 1958.

Wolfgang Pauli, the "conscience of physics" was born in Vienna on 25 April 1900. Among the events organized to celebrate the Pauli centenary was a series of public lectures, Wolfgang Pauli and Modern Physics, at the ETH (Swiss Federal Technical High School) Zurich, where Pauli spent his career from 1928 until his death in 1958, except for an interval during the Second World War. The Zurich lectures focused on Pauli's life and work, and his scientific legacy, with a distinguished list of speakers. A Pauli exhibition, currently in Zurich, will be moved to CERN later this year.*

Pauli discovered many of the 20th century's major new directions for modern physics and went on to lay the foundations for much of what was to come – quantum mechanics, the Exclusion Principle, electron spin, quantum field theory, the neutrino hypothesis, spin and statistics, among others.

Contemporary physics is, of course, his greatest monument, but another is his prolific correspondence with contemporary scientists. CERN has become the home of this carefully accumulated and maintained Pauli archive, the source for a four-volume series of scientific correspondence, published by Springer.

One of Pauli's last major public appearances was at the 8th International ("Rochester") Conference on High Energy Physics, hosted by CERN in Geneva on 30 June – 5 July 1958. This was the first time that this meeting had been held outside the US. As chairman of the Fundamental Ideas session, Pauli began:

"This session is called 'fundamental ideas' in field theory, but you will soon find out, or have already found out, that there are no new



At the Zurich lectures celebrating the centenary of Wolfgang Pauli's birth. Left to right: Riccardo Barbieri (Pisa), who spoke on "From the neutrino hypothesis to the Standard Model"; André Rubbia (ETH Zurich), who covered "Neutrino experiments: past, present and future"; and Christoph Schmid (ETH Zurich).

fundamental ideas. So what you shall hear are substitutes for fundamental ideas, and it works in the same way as I am the substitute for a rapporteur. So you will also see that there are two kinds of ignorance – rigorous ignorance and more clumsy ignorance. You will also hear that many speakers will want to form new credits for the future. I am personally not very willing to give such credits but it is for everybody to choose what he wants to

Pauli polemics

Pauli became legendary not only for his physics but also for his vituperation and invective. Some examples:

At a seminar given by a young researcher: "Your first equation is already wrong, and your second does not follow from it";

Of a young physicist, Pauli retorted: "What, so young and already unknown?"

The Vienna-born Pauli asked another physicist: "When did you leave Vienna?" "1938," he replied. "I left in 1918," retorted Pauli. "My intuition was always good."

The festschrift *Das Gewissen der Physik* (the Conscience of Physics), edited by Charles Enz and Karl von Meyenn, from a 1983 meeting in Vienna to mark the 25th anniversary of Pauli's death, contains among a wealth of contributions a memorable collection of such anecdotes, compiled by Val Telegdi.



Ludwig Faddeev (left) of St Petersburg, who spoke on "Non-Abelian gauge theories", with Valentine Telegdi, who began his experimental physics career at ETH.

do in this respect."

The first three talks in the session were by Hideki Yukawa, Werner Heisenberg and Pauli. Immediately after Heisenberg's talk, "Non-linear spinor theory with indefinite metric", Pauli said sternly: "Regarding the papers of Heisenberg and collaborators on the spinor model...I reached the conclusion that they are mathematically objectionable."

Heisenberg persisted, but Pauli eventually retorted again: "I completely disagree with the answer of Heisenberg – not only unnatural but mathematically impossible."

Heisenberg countered: "Of course I again disagree completely with what Pauli said..."

After the young Murray Gell-Mann (aged 28) tried to establish some calm and order between the warring quantum veterans, Heisenberg commented: "I agree completely with what Gell-Mann just said. But at the same time I propose to postpone the discussion for half a year and then we will know more."

The ever-implacable Pauli concluded: "I think that is superfluous. In half a year the answer will be the same as Gell-Mann gave just now."

Half a year later, Pauli was dead, but his name will live for ever.

*The Pauli exhibition will be in CERN's Main Building from 17 August until 26 September, and a ceremony will take place in the Council Chamber on Monday 11 September, beginning at 4.30 pm. This will include short presentations from Maurice Jacob (chairman of the Pauli Committee), Konrad Osterwalder (Rektor of the ETH Zurich), Luciano Maiani (director-general of CERN) and Charles Enz (University of Geneva) on Pauli's life and legacy.

Edited by Alison Wright

Except where otherwise stated, these news items are taken from the Institute of Physics Publishing's news service, which is available at "http://physicsweb.org".

Measuring gravity with precision...

Since its introduction in the 17th century, the gravitational constant, G , has been difficult to measure to great accuracy owing to the intrinsic weakness of the gravitational force. A new measurement of G from researchers in Washington is the most accurate value yet, improving on the previous world best by a factor of 10.

The group modified the technique of Cavendish's 200-year-old torsion balance experiment with a thin, flat, rectangular plate hung vertically on a torsion fibre as the pendulum, and melon-sized stainless steel spheres as attractor masses, sitting on a turntable



around the pendulum. As the turntable rotates, the gravitational forces exerted by the spheres try to twist the torsion fibre. However, a computer-controlled feedback mechanism adjusts the speed of the turntable, keeping the pendulum twisting to a minimum – an important factor for accuracy.

The acceleration of the turntable is recorded and gives the value of G as $6.67390 \times 10^{-11} \text{ m}^3/\text{kg/s}^2$, with an uncertainty of 0.0014%. Combined with data from the Lageos satellite, more "best ever" results can be derived: the mass of the Earth is $(5.97223 \pm 0.00008) \times 10^{24} \text{ kg}$ and the Sun's mass is $(1.98843 \pm 0.00003) \times 10^{30} \text{ kg}$. AIP

This torsion balance apparatus, adapted from the idea of Cavendish's 1797 original experiment, has yielded the most accurate value yet for the gravitational constant, G , by measuring the attraction between a plate pendulum (in the central column) and metal spheres rotating on a turntable around it.

...and to small distances

Meanwhile, a second torsion balance experiment in Washington has been checking the validity of Newton's inverse square law of gravitational attraction over very small distances.

Recent theories suggest that the relative weakness of gravity compared with the other forces may be due to the presence of extra dimensions: while most particles are confined in conventional space-time, gravitons are free to roam through the extra dimensions and

hence the gravitational force we experience is diluted. A breakdown of the inverse square law at very small distances would be a consequence of such models.

Using a disc-shaped pendulum suspended above a second rotating disc and shielded from electrical effects by a copper membrane, the researchers have demonstrated that Newton's law holds down to distances as small as $150 \mu\text{m}$. Even shorter distances will be explored next.

An implication of the extra dimensions idea is that the unification scale for the four forces could shift from a massive 10^{19} GeV to as little as 10^4 GeV , thereby opening up some very interesting possibilities for CERN's Large Hadron Collider (March p7). AIP

Constant with a small 'c'

Studying gamma radiation arriving from distant gamma-ray bursters, a Boston physicist has concluded that the speed of light is constant to an unprecedented degree of accuracy.

First detected in the 1970s, the flashes of gamma rays last as little as 0.001 s but with energies per photon of up to 1 million times the energy of optical light. Their short duration and great distance travelled make the bursts a precise probe of special relativity, particularly of the postulate that the speed of light is a constant, independent of its source velocity.

If the speed of the rays depended on the velocity of the emitting material, the initial pulse would spread out in time as it propagated towards us. Estimating the speed of the material and the distance to the bursts, the small spread in photon arrival times during a burst implies that the speed of rays is independent of the velocity of their source to more than one part in 10^{20} – the most stringent test, by a factor of about 10^{11} , of special relativity ever made possible.

Such constancy merits a grander name than "velocity of light", suggest some researchers, proposing the "Einstein constant". AIP

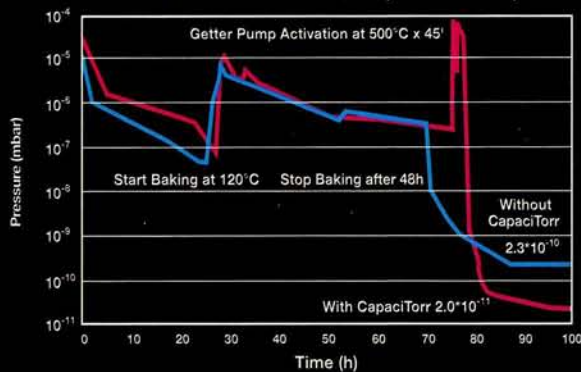
Avalanches avoided with quantum dots

Toshiba researchers in Cambridge, UK, have developed a quantum dot instrument capable of detecting a single photon. Unlike current devices, such as the photomultiplier tube and the avalanche photodiode, it does not rely on avalanche amplification of the signal and is therefore less prone to noise.

Inside a sandwich of gallium arsenide and aluminium gallium arsenide is a layer of quan-

tum dots, each just a few nanometres in diameter (May p9). When a photon hits the device, an electron escapes from one of the quantum dots and is detected by a change in resistance in a conducting layer just a few nanometres above the dots. So far the device only operates at 4 K, but the researchers' next target is 77 K, and ultimately room temperature operation.

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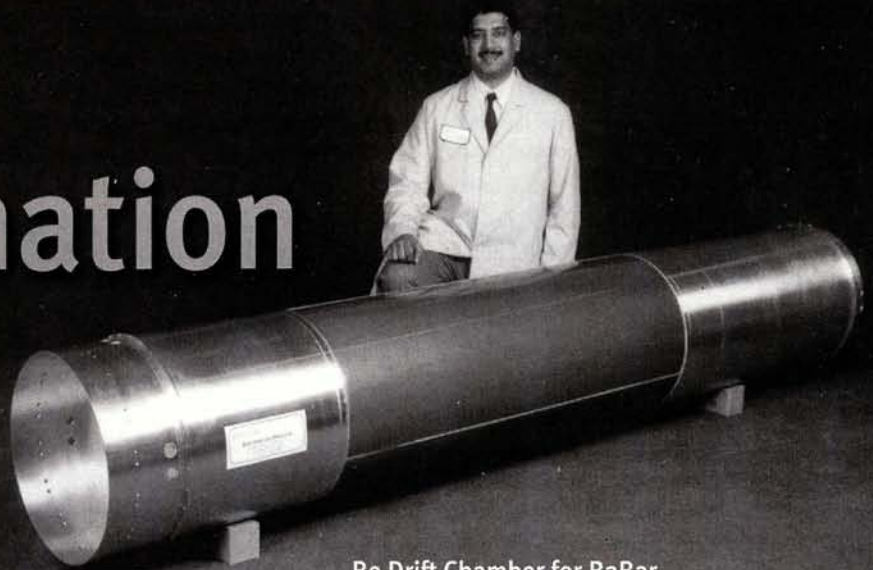
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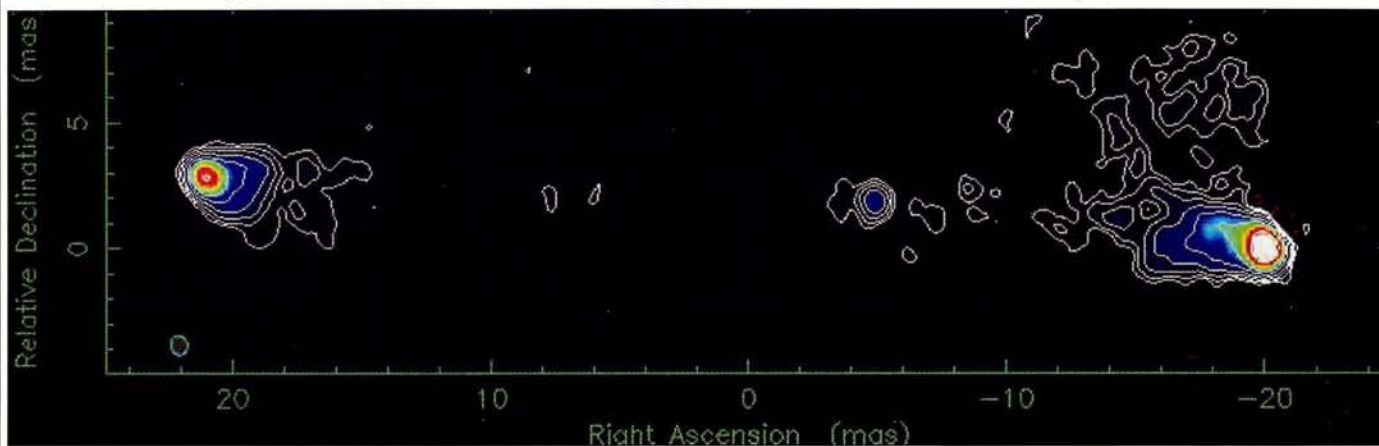
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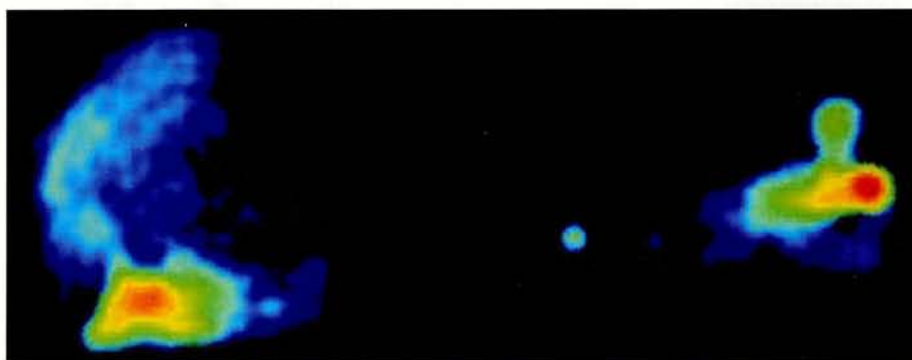
Youngest radio galaxies observed



Baby radio galaxy 1943+546 (left) is 336 light years across. Its big brother 3C295 (right) is 64 000 light years across. (A Polatidis and P Leahy.)

A new class of baby radio galaxy has been discovered using very long baseline interferometry. The sources, dubbed compact symmetric objects, are the youngest radio galaxies ever observed – a mere 1000 years old – and are expected to reveal clues to the birth and evolution of these cosmic powerhouses.

Such extreme sources could have links with gamma-ray bursts and high-energy cosmic rays. Radio galaxies are a well known phenomenon, characterized by enormous jets, up to millions of light years across, shooting out charged particles at up to almost the speed of light. Bright spots of emission are seen at the



end of the jets where the particles plough into the surrounding intergalactic medium, depositing around 10^{44} erg/s in energy.

The new galaxies are almost identical but on a smaller scale. Astronomers from the Onsala Space Observatory in Sweden and the

Max Planck Institute, Bonn, imaged them with 17 different radio telescopes around the Earth simultaneously. They calculate that the jets are expanding at around a fifth of the speed of light and therefore are around a 1000 years old – babies on cosmic timescales.

Magnetic fields point to high-energy rays

New evidence for strong intergalactic magnetic fields may help to solve the mystery of ultrahigh-energy cosmic rays. These particles can reach energies of more than 10^{20} eV – 100 million times as high as particle beams produced in accelerators on Earth.

At the May meeting of the American Physical Society, Phil Kronberg of the University of Toronto presented low-frequency (75 MHz) radio images of parts of the Great Wall supracluster of galaxies. The observations showed a diffuse synchrotron glow in the regions outside the galaxy clusters, revealing

the presence of magnetic fields.

New combined X-ray and radio observations of the clusters has improved the accuracy of measurements of both the magnetic field strength and the density of space in these regions. The team measured the Faraday rotation (the rotation of the plane of polarization) of the radio waves.

The results show intergalactic magnetic fields that are many times stronger than those within the much denser disc of the Milky Way. This means that a significant amount of energy is stored within the intergalactic gas.

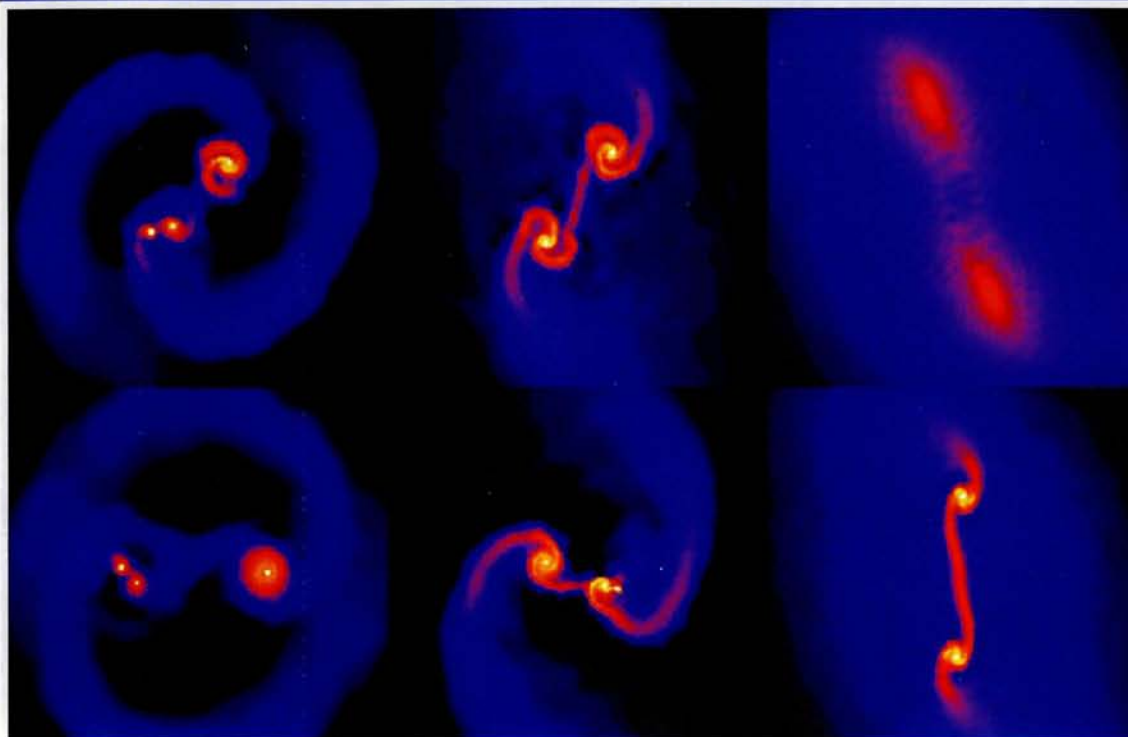
This raises important questions about the origin of magnetic fields – whether they were seeded by the first generations of stars and galaxies or result from earlier activity when the universe was less than 1 s old.

Large Magellanic Cloud X-ray signal lost in black hole

Newton, the European Space Agency's new X-ray observatory (April p11), was undergoing routine calibration, imaging a known, stable X-ray source in the Large Magellanic Clouds, when all of a sudden, the signal mysteriously disappeared.

LMC X3 is a well known black hole candidate and the cut-off in its X-ray emission is entirely unexpected. X-rays come from the hot gas and dust swirling around the black hole as it is sucked towards the centre.

Picture of the month



This simulation shows the evolution of a triple star system over several hundred thousand years. The birth of stars is usually a secret affair, shrouded by dense clouds of dust. By comparing such simulations with observations of young star systems, astronomers can now find out more about the initial conditions. This work was carried out at the Institute of Astronomy in Cambridge, UK. (Matthew Bate.)

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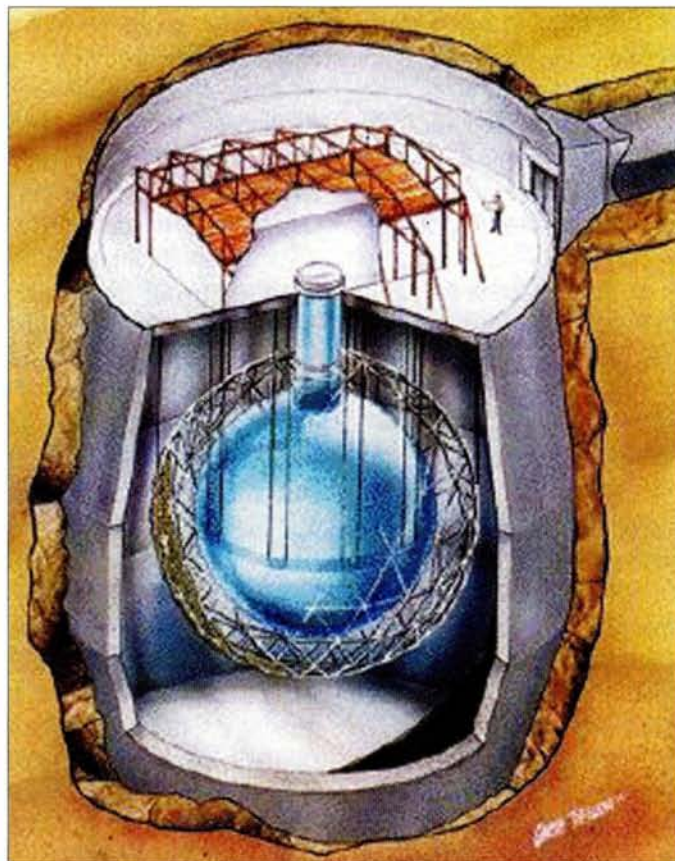
The beginning of a new science

Over the 45 years since their discovery, neutrinos have changed from being a physics oddity into one of experimental physics' most powerful tools. Here, pioneers *John Bahcall* and *Raymond Davis* relate the evolution of the study of extra-terrestrial neutrinos, and provide some stimulating pointers for astronomers and physicists embarking on new observational ventures.

The possibility of observing solar neutrinos began to be discussed seriously following Holmgren and Johnston's experimental discovery in 1958 that the cross-section for the production of beryllium-7 by the fusion of helium-3 and helium-4 was more than a thousand times as large as had been previously believed. This led to Willy Fowler and Al Cameron suggesting that boron-8 might be produced in the Sun in sufficient quantities (from beryllium-7 and protons) to produce an observable flux of high-energy neutrinos from boron-8 beta decay.

Looking inside the Sun

We begin our story in 1964, when we published back-to-back papers in *Physical Review Letters*, arguing that it was possible to build a 100 000 gallon detector of perchloroethylene that would measure the solar neutrino capture rate on chlorine. Our motivation was to use neutrinos to look into the interior of the Sun and thereby test directly the theory of stellar evolution and nuclear energy generation in stars. The particular development that made us realize that the experiment could be done was the demonstration by



Canada's Sudbury Neutrino Observatory, containing a kiloton of heavy water, announced its first results at the Neutrino 2000 meeting at Sudbury in June.

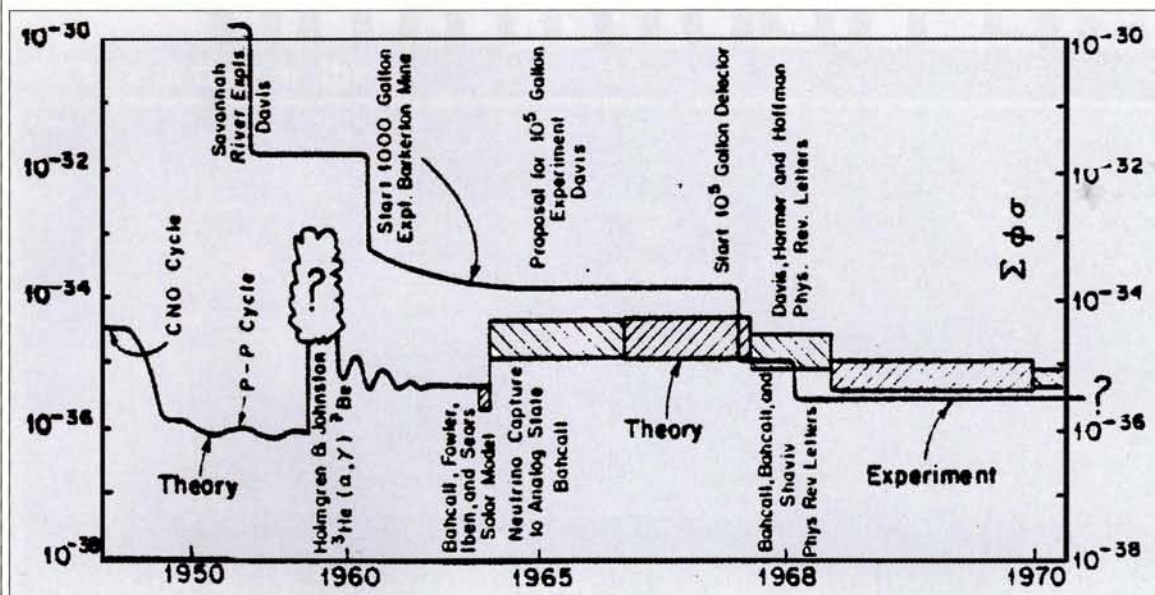
John Bahcall, in late 1963, that the principal neutrino absorption cross-section on chlorine was 20 times as large as had been previously calculated, owing to a super-allowed nuclear transition to an excited state of argon.

Proposals, then and now

If you have a good idea today, you are likely to require many committees, many years and many people to get the project from concept to observation. The situation was very different in 1964.

As Ray Davis was a member of the Brookhaven chemistry department, we presented our case to Dick Dodson, who was chairman of the Brookhaven chemistry department, and to laboratory director Maurice Goldhaber. Dodson was excited about the possibility of supporting a fundamental new direction within the chemistry department. Goldhaber, on the other hand, was sceptical about all astrophysical calculations, but was intrigued by the nuclear

physics of the neutrino analogue transition. Following only a few weeks of consideration, the project received the required backing from Brookhaven, and Dodson and Davis visited the Atomic



The early evolution of neutrino astronomy from a viewgraph from a 1971 colloquium by Ray Davis at Brookhaven. The experimental upper limit is shown by the thick black curve and the range of theoretical values by the cross-hatched region. The units are captures per target atom per second (10^{-36} capture/target atom/s = 1 SNU).

Energy Commission (AEC) to inform the people in the chemistry division of the plans to begin a solar neutrino experiment. The way was paved by Charlie Lauritsen and Fowler, who had strong scientific and personal connections with the AEC as a result of their wartime work. The project received a warm welcome at the AEC.

A small team, comprising Davis, Don Harmer (on leave from Georgia Tech) and John Galvin (a technician who worked part-time on the experiment), designed and built the experiment. Kenneth Hoffman, a young engineer, provided expert advice on technical questions. The money came from Brookhaven's chemistry budget. Neither of us remember a formal proposal ever being written to a funding agency. The total capital expenditure to excavate the cavity in the Homestake Gold Mine in South Dakota, build the tank and purchase the liquid was \$0.6 million (in 1965).

Solar neutrino experiments

During 1964–1967, Fred Reines and his group worked on three solar neutrino experiments in which recoil electrons produced by neutrino interactions would be detected by observing the associated light in an organic scintillator. Two of the experiments, which exploited the elastic scattering of neutrinos by electrons, were actually performed and led to a higher than predicted upper limit on the boron-8 solar neutrino flux. The third, which was planned to detect neutrinos absorbed by lithium-7, was abandoned after the initial chlorine results showed that the solar neutrino flux was low.

These experiments introduced the technology of organic scintillators into the arena of solar neutrino research, a technique that will only finally be used in 2001 when the BOREXINO detector begins to detect low-energy solar neutrinos. Also during this period, Bahcall investigated the properties of neutrino–electron scattering and showed that the forward peaking from boron-8 neutrinos is large – a feature that was incorporated 25 years later in the Kamiokande (and later SuperKamiokande) water Cerenkov detectors.

The first results from the chlorine experiment were published in *Physical Review Letters* in 1968, again in a back-to-back comparison between measurements and standard predictions. The initial

results have been remarkably robust; the conflict between chlorine measurements and standard solar model predictions has lasted over three decades.

The main improvement has been in the slow reduction of the uncertainties in both the experiment and the theory. The efficiency of the Homestake chlorine experiment was tested by recovering carrier solutions, by producing argon-37 in the tank with neutron sources and by recovering chlorine-36 inserted in a tank of perchloroethylene. The solar model was verified by comparison with precise helioseismological measurements.

For more than 20 years the best estimates for the observational result and for the theoretical prediction have remained essentially constant. The discrepancy between the standard solar model prediction and the chlorine observation became widely known as “the solar neutrino problem”.

Very few people worked on solar neutrinos during 1968–1988. The chlorine experiment was the only solar neutrino experiment to provide data in these two decades. It is not easy for us to explain why this was the case; we certainly tried hard to interest others in doing different experiments and we gave many joint presentations. Each of us had one principal collaborator during this long period – Bruce Cleveland (experimental) and Roger Ulrich (solar models).

A large effort to develop a chlorine experiment in the Soviet Union was led by George Zatsepin, but it was delayed by the difficulties of creating a suitable underground site for the detector. Eventually the effort was converted into a successful gallium detector, SAGE, led by Vladimir Gavrin and Tom Bowles, which gave its first results in 1990.

Oscillations proposed

Only one year after the first (1968) chlorine results were published, Vladimir Gribov and Bruno Pontecorvo proposed that the explanation of the solar neutrino problem was that neutrinos oscillated between the state in which they were created and a state that was more difficult to detect. This explanation, which is the consensus view today, was widely disbelieved by nearly all of the particle physicists whom we talked to in those days.



Pioneering solar neutrinos – Ray Davis shows John Bahcall the tank containing 100 000 gallons of perchloroethylene. The picture was taken in the Homestake mine shortly before the experiment began operating.

In the form in which solar neutrino oscillations were originally proposed by Gribov and Pontecorvo, the process required that the mixing angles between neutrino states should be much larger than the quark mixing angles, something that most theoretical physicists believed, at that time, was unlikely. Ironically, a flood of particle theory papers explained, more or less “naturally”, the large neutrino mixing angle that was decisively demonstrated 30 years later in the SuperKamiokande atmospheric neutrino experiment.

One of the most crucial events for early solar neutrino research occurred in 1968 while we were relaxing after a swim at the CalTech pool. Gordon Garmire (now a principal scientist with the Chandra X-ray satellite) came up to Davis, introduced himself and said that he had heard about the chlorine experiment. He suggested that it might be possible to reduce significantly the background by using pulse risetime discrimination, a technique used for proportional counters in space experiments. The desired fast-rising pulses from argon-37 Auger electrons are different from the slower-rising pulses from a background gamma or cosmic ray.

Davis went back to Brookhaven and asked the local electronic experts if it would be possible to implement this technique for the very small counters that he used. The initial answer was that the available amplifiers were not fast enough to be used for this purpose with the small solar neutrino counters. However, within about a year, three first-class Brookhaven electronic engineers, Veljko Radeca, Bob Chase and Lee Rogers, were able to build electronics fast enough to be used to measure the risetime in Davis’s counters.

This “swimming-pool” improvement was crucial for the success of the chlorine experiment and the subsequent radiochemical gallium solar neutrino experiments – SAGE, GALLEX and GNO. Measurements of the risetime as well as the pulse energy greatly reduce the background for radiochemical experiments. The backgrounds can be as low as one event in three months.

In 1978, after a decade of disagreement between the Homestake neutrino experiment and standard solar model predictions, it was clear that the subject had reached an impasse and a new experiment was required. The chlorine experiment is, according to standard solar model predictions, sensitive primarily to neutrinos from a rare fusion reaction that involves boron-8 neutrinos. These are produced in only 2 of every 10^4 terminations of the basic proton-proton fusion chain. In early 1978 there was a conference of interested scientists at Brookhaven to discuss what to do next. The consensus was that we needed an experiment that was sensitive to the low-energy neutrinos from the fundamental proton-proton reaction.

The only remotely practical possibility appeared to be another radiochemical experiment, this time with gallium-71 (instead of chlorine-37) as the target. However, a gallium experiment (originally proposed by Russian theorist V A Kuzmin in 1965) was expensive – we needed about three times the world’s annual production of gallium to do a useful experiment.

Gallium push

In an effort to generate enthusiasm for a gallium experiment, we wrote another *Physical Review Letters* paper, this time with a number of interested experimental colleagues. We argued that a gallium detector was feasible and that a gallium measurement, which would be sensitive to the fundamental proton-proton neutrinos, would distinguish between broad classes of explanations for the discrepancy between prediction and observation in the chlorine-37 experiment. Over the next five or six years, the idea was reviewed a number of times in the US, always very favourably. A blue-ribbon panel headed by Glenn Seaborg enthusiastically endorsed both the experimental proposal and the theoretical justification.

To our great frustration and disappointment, the gallium experiment was never funded in the US, although many of the experimental ideas that gave rise to the Russian experiment (SAGE) and the German-French-Italian-Israeli-US experiment (GALLEX) largely originated at Brookhaven. Physicists strongly supported the experiment and said that the money should come out of an astronomy budget; astronomers said it was great physics and should be supported by the physicists. The US Department of Energy (DOE) could not get the nuclear physics and the particle physics sections to agree on who had the financial responsibility. In a desperate effort to break the deadlock, Bahcall was even the principal investigator of a largely Brookhaven proposal to the US National Science Foundation (which did not support proposals from DOE laboratories). A pilot experiment was performed with 1.3 tons of gallium by an international collaboration (Brookhaven, Pennsylvania, MPI Heidelberg, IAS Princeton and the Weizmann Institute), which developed the extraction scheme and the counters eventually used in the GALLEX full-scale experiment.

In strong contrast with what happened in the US, Moisey Markov, head of the Nuclear Physics Division of the Russian Academy of Sciences, helped to establish a neutrino laboratory within the Institute for Nuclear Research, participated in the founding of the Baksan neutrino observatory, and was instrumental in securing 60 tons of gallium free for Russian scientists for the duration of a solar neutrino experiment. ▷

The SAGE Russian-US gallium experiment went ahead under the leadership of Gavrin, Zatsepin (Institute for Nuclear Research, Russia) and Bowles (Los Alamos), while the mostly European experiment (GALLEX) was led by Till Kirsten (Max Planck Institute, Germany). Both had a strong but not primary US participation.

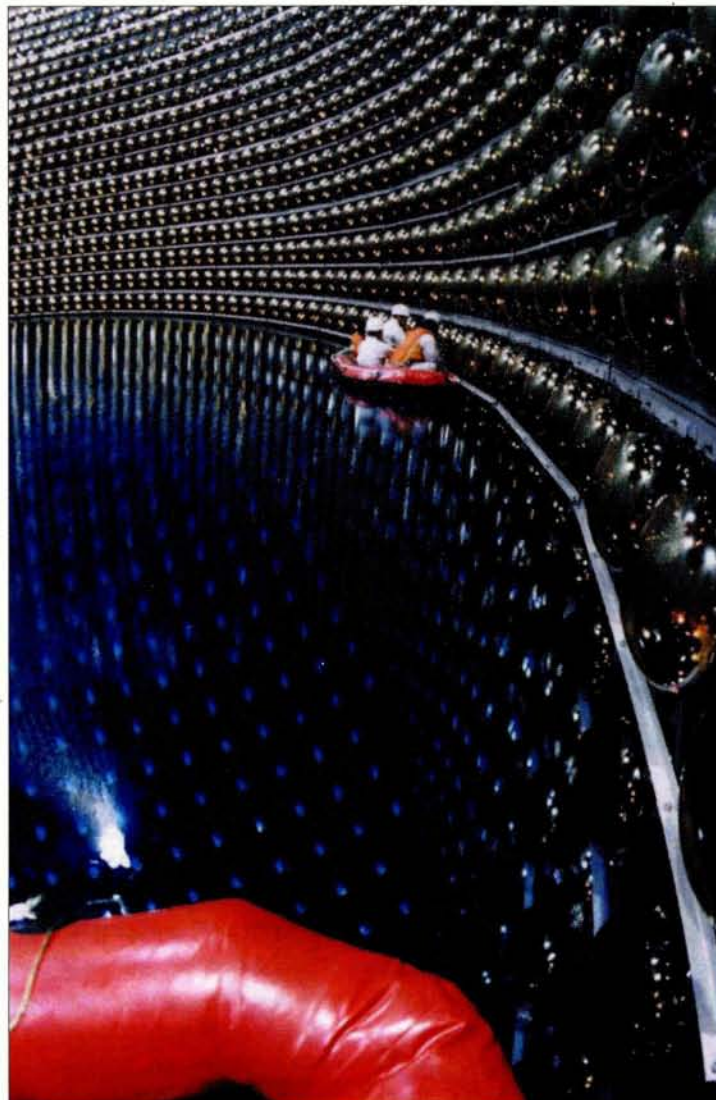
The two gallium experiments were performed during the 1990s and gave very similar results, providing the first experimental indication of the presence of proton-proton neutrinos. Both experiments were tested by measuring the neutrino rate from an intense laboratory radioactive source.

There were two dramatic developments in the solar neutrino saga, one theoretical and one experimental, before the gallium experiments produced observational results. In 1985 two Russian physicists proposed an imaginative solution to the solar neutrino problem that built on the earlier work of Gribov and Pontecorvo and, more directly, the insightful investigation by Lincoln Wolfenstein (Carnegie Mellon).

Alexei Smirnov and Stanislav Mikheyev showed that, if neutrinos have masses in a relatively wide range, then a resonance phenomenon in matter (now universally known as the MSW effect) could efficiently convert many of the electron-type neutrinos created in the interior of the Sun to more difficult to detect muon and tau neutrinos. The MSW effect can work for small or large neutrino mixing angles. Because of the elegance of the theory and the possibility of explaining the experimental results with small mixing angles (analogous to what happens in the quark sector), physicists immediately began to be more sympathetic to particle physics solutions to the solar neutrino problem. More importantly, they became enthusiasts for new solar neutrino experiments.

Big breakthrough

The next big breakthrough also came from an unanticipated direction. The Kamiokande water Cerenkov detector was developed to study proton decay in a mine in the Japanese Alps and set an important lower limit on the proton lifetime. In the late 1980s the detector



The rising sun of solar neutrinos – the SuperKamiokande underground neutrino experiment in Japan.

was converted by its Japanese founders, Masatoshi Koshiba and Yoji Totsuka, together with some US colleagues, Gene Beier and Al Mann of the University of Pennsylvania, to be sensitive to the lower energy events expected from solar neutrinos.

With incredible foresight, these experimentalists completed their revisions to make the detector sensitive to solar neutrinos in late 1986, just in time to observe the neutrinos from Supernova 1987a emitted 170 000 years earlier. (Supernova and solar neutrinos have similar energies – about 10 MeV – much less than the energies relevant for proton decay.) In 1996 a much larger water Cerenkov detector (with 50 000 tons of pure water) began operating in Japan under the leadership of Yoji Totsuka, Kenzo Nakamura, Yoichiro Suzuki (from Japan), and Jim Stone and Hank Sobel (from the US).

Remarkable results

So far, five experiments have detected solar neutrinos in approximately the numbers (within a factor of two or

three) and in the energy range (less than 15 MeV) predicted by the standard solar model. This is a remarkable achievement for solar theory, because the boron-8 neutrinos that are observed primarily in three of these experiments (chlorine, Kamiokande and its successor SuperKamiokande) depend on approximately the 25th power of the central temperature. The same set of nuclear fusion reactions that are hypothesized to produce the solar luminosity also give rise to solar neutrinos. Therefore, these experiments establish empirically that the Sun shines by nuclear fusion reactions among light elements in essentially the way described by solar models.

Nevertheless, all of the experiments disagree quantitatively with the combined predictions of the standard solar model and the standard theory of electroweak interactions (which implies that nothing much happens to the neutrinos after they are created). The disagreements are such that they appear to require some new physics that changes the energy spectrum of the neutrinos from different fusion sources.

Solar neutrino research today is very different from how it was three decades ago. The primary goal now is to understand the neu-

trino physics, which is a prerequisite for making more accurate tests of the neutrino predictions of solar models. Solar neutrino experiments today are all large international collaborations, each typically involving in the order of 100 physicists. Nearly all of the new experiments are electronic, not radiochemical, and the latest generation of experiments measure typically several thousand events per year (with reasonable energy resolution), compared with typically 25–50 per year for the radiochemical experiments (which have no energy resolution, only an energy threshold).

Solar neutrino experiments are currently being carried out in Japan (SuperKamiokande in the Japanese Alps), in Canada (SNO, which uses a kiloton of heavy water in Sudbury, Ontario), in Italy (BOREXINO, ICARUS and GNO, each sensitive to a different energy range and all operating in the Gran Sasso Underground Laboratory), in Russia (SAGE in the Caucasus region) and in the US (Homestake chlorine experiment). The SAGE, chlorine and GNO experiments are radiochemical; the others are electronic.

Since 1985 the chlorine experiment has been operated by the University of Pennsylvania under the joint leadership of Ken Lande and Davis. Lande and Paul Wildenhain have introduced major improvements to the extraction and measurement systems, making the chlorine experiment a valuable source of new precision data.

The most challenging and important frontier for solar neutrino research is to develop experiments that can measure the energies of individual low-energy neutrinos from the basic proton–proton reaction, which constitutes (we believe) more than 90% of the solar neutrino flux.

Solar neutrino research is a community activity. Hundreds of experimentalists have collaborated to carry out difficult, beautiful measurements of the elusive neutrinos. Hundreds of researchers have helped to refine the solar model predictions, measuring accurate nuclear and solar parameters and calculating input data such as opacities and equation of state.

Special mention

Three people have played special roles. Hans Bethe was the architect of the theory of nuclear fusion reactions in stars, as well as our mentor and hero. Willy Fowler was a powerful and enthusiastic supporter of each new step and his keen physical insight motivated much of what was done in solar neutrino research. Bruno Pontecorvo opened everyone's eyes with his original insights, including his early discussion of the advantages of using chlorine as a neutrino detector and his suggestion that neutrino oscillations might be important.

Over the next decade, neutrino astronomy will move beyond our cosmic neighborhood and, we hope, will detect distant sources. The most likely candidates now appear to be gamma-ray bursts. If the standard fireball picture is correct and if gamma-ray bursts produce the observed highest-energy cosmic rays, then very-high-energy (10^{15} eV) neutrinos should be observable with a km^2 detector. Experiments that are capable of detecting neutrinos from gamma-ray bursts are being developed at the South Pole (AMANDA and ICECUBE), in the Mediterranean Sea (ANTARES, NESTOR) and even in space.

Looking back on the beginnings of solar neutrino astronomy, one

lesson appears clear: if you can measure something new with reasonable accuracy, then you have a chance to discover something important. The history of astronomy shows that it is very likely that what you will discover will not be what you were looking for. It helps to be lucky.

Further information

A version of this article originally appeared as a Millennium Essay in J N Bahcall and R Davis Jr 2000 *Publications of the Astronomical Society of the Pacific* **112** 429). Copyright 2000, Astronomical Society of the Pacific, reproduced with permission of the editors.

John Bahcall's much cited Web site at "<http://www.sns.ias.edu/jnb>" has lots of background material on solar neutrinos. Of particular interest is the "solar neutrino history" menu item.

Further reading

J N Bahcall and R Davis Jr 1976 Solar Neutrinos: a scientific puzzle *Science* **191** 264.

J N Bahcall and R Davis Jr 1982 An account of the development of the solar neutrino problem *Essays in Nuclear Astrophysics* ed. C A Barnes, D D Clayton and D N Schramm (Cambridge University Press) 243. (This article is also reprinted in *Neutrino Astrophysics* by J N Bahcall (Cambridge University Press, 1989).)

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Where did the 'No-go' theorems go?

With quark-gluon calculations being extremely difficult, physicists have to use their ingenuity to get results. The most popular approach is to use powerful supercomputers to simulate a discrete space-time lattice.

A recent workshop examined progress in the field.



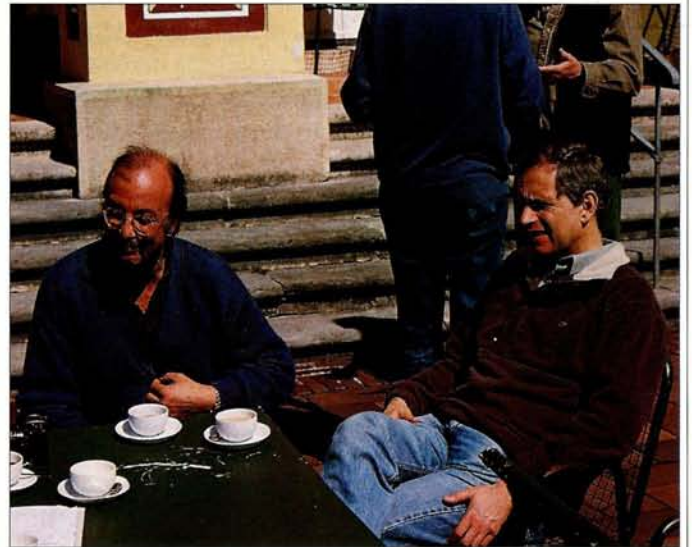
Participants of the 2000 Ringberg Workshop on Lattice Field Theory.

At the smallest possible scales, physics calculations are extremely complicated. This is the dilemma facing particle physicists.

Lattice field theories were originally proposed by 1982 Nobel laureate Ken Wilson as a means of tackling quantum chromodynamics (QCD) – the theory of strong interactions – at low energies, where calculations based on traditional perturbation theory fail.

The lattice formulation replaces the familiar continuous Minkowski space-time with a discrete Euclidean version, where space-time points are separated by a finite distance – the lattice spacing. In this way results can be obtained by simulations, but the computing power required is huge, requiring special supercomputers.

This methodology has been applied extensively to QCD: recent years have witnessed increasingly accurate calculations of many quantities, such as particle masses (including those of glueballs and hybrids) and form factors for weak decays, as well as quark masses and the strong (inter-quark) coupling constant. These results



At the workshop – Guido Martinelli (left) and Chris Sachrajda contemplate power subtractions for non-leptonic kaon decays.

provide important pointers to future progress.

The romantic Ringberg Castle, with its panoramic view of the Bavarian Tegernsee, was the scene of a recent workshop entitled Current Theoretical Problems in Lattice Field Theory, where physicists from Europe, the US and Japan discussed and assessed recent progress in this increasingly important area of research.

Obstacles removed

Despite the many successes of lattice QCD, there are stubborn areas where little progress has been made. For instance, until recently it was thought that the lattice formulation was incompatible with the concept of a single left-handed fermion (such as the Standard Model neutrino). The notion of this chirality plays a key role for the strongly and weakly interacting sectors of the Standard Model. Furthermore, weak decays like that of a kaon into two pions have been studied on the lattice with only limited success. ▽

Directions for lattice computing

Quantum physics calculations are not easy. Most students, after having worked through the solutions of the Schrödinger equation for the hydrogen atom, take the rest of quantum mechanics on trust. Likewise, quantum electrodynamics is demonstrated with a few easy examples involving colliding electrons. This tradition of difficult calculation continues, and is even accentuated, by the physics of the quarks and gluons inside subnuclear particles.

Quantum chromodynamics – the candidate theory of quarks and gluons – can only be handled using powerful computers, and even then drastic assumptions must be made to make the calculations tractable. For example, a discrete lattice (several fm) has to replace the space–time continuum. Normally only the valence quarks, which give the particle its quantum number assignment, can be taken into account (the quenched approximation), and the myriad of accompanying virtual quarks and antiquarks have to be neglected.

The benchmark of lattice QCD is the calculation of particle masses, where encouraging results are being achieved, but physicists are still far from being able to explain the observed spectrum of particle masses. Future progress in understanding subnuclear particles and their interactions advances in step with available computer power.

To point the way forward, the European Committee for Future Accelerators recently set up a panel (chaired by Chris Sachrajda of Southampton) to assess both the computing resources required for this work and the scientific opportunities that would be opened up. The panel's main conclusions were:

- The future research programme using lattice simulations is a very rich one, investigating problems of central importance for

A non-perturbative treatment of such processes is highly desirable, because they are required for our theoretical understanding of direct CP violation and the longstanding problem of explaining isospin selection rules in weak decays. However, there have been impressive theoretical advances in both of these areas, which were discussed at the Ringberg workshop.

Gian Carlo Rossi (Rome II) gave a general introduction to lattice calculations of $K \rightarrow \pi\pi$. By the early 1990s, all attempts to study this process on the lattice had been abandoned, because it was realized that the necessary physical quantity cannot be obtained from the correlation functions computed on the lattice. This Maiani–Testa No-go theorem was analysed in great detail by Chris Sachrajda (Southampton). Laurent Lellouch (Annecy) then described how the theorem can be circumvented by treating the decay in a finite volume, when the energy spectrum of the two-pion final state is not continuous, in turn violating one of the conditions for the No-go theorem to apply.

Furthermore, the transition amplitude in finite volume can be related to the physical decay rate. An implementation of this method in a real computer simulation requires lattice sizes of about 5–7 fm. This stretches the capacities of current supercomputers to the limit,

the development of our understanding of particle physics. The programme includes detailed (unquenched) computations of non-perturbative QCD effects in hadronic weak decays, studies of hadronic structure, investigations of the quark–gluon plasma, exploratory studies of the non-perturbative structure of supersymmetric gauge theories, studies of subtle aspects of hadronic spectroscopy, and much more.

- The European lattice community is large and very strong, with experience and expertise in applying numerical solutions to a wider range of physics problems. For more than 10 years it has organized itself into international collaborations when appropriate, and these will form the foundation for any future European project. Increased coordination is necessary in preparation for the 10 Tflops generation of machines.

- Future strategy must be driven by the requirements of the physics research programme. We conclude that it is both realistic and necessary to aim for machines of the order of 10 Tflops processing power by 2003. As a general guide, such machines will enable results to be obtained in unquenched simulations with similar precision to those currently found in quenched ones.

- It will be important to preserve the diversity and breadth of the physics programme, which will require a number of large machines as well as a range of smaller ones.

- The lattice community should remain alert to all technical possibilities in realizing its research programme. However, the panel concludes that it is unlikely to be possible to procure a 10 Tflops machine commercially at a reasonable price by 2003, and hence recognizes the central importance of the apeNEXT project to the future of European lattice physics.

but a calculation will certainly be feasible with the next generation of machines.

Guido Martinelli (Rome I) presented the decay from a different angle by relating it to the conceptually simpler kaon–pion transition. This strategy has been known for some time, and recent work concentrated on the final-state interactions between the two pions. The inclusion of these effects may influence theoretical predictions for measurements of direct CP violation. Given recent experimental progress in this sector (May p6), this is surely of great importance.

Many lattice theorists' hopes of being able to study the electroweak sector of the Standard Model had been frustrated by another famous No-go theorem, this time by Nielsen and Ninomiya. This states that chiral symmetry cannot be realized on the lattice, which, for instance, makes it impossible to treat neutrinos in a lattice simulation.

Recently it has been shown how the Nielsen–Ninomiya theorem could be sidestepped: a chiral fermion (such as a neutrino) can be put on the lattice provided that its discretized Dirac operator satisfies the so-called Ginsparg–Wilson relation. Several solutions to this relation have been constructed, and the most widely used are known in the trade as “Domain Wall” and “Overlap” fermions.

At Ringberg, Pilar Hernández (CERN) examined whether these solutions can be implemented efficiently in computer simulations. Obviously these more technical aspects have to be investigated before one can embark on more ambitious projects. Hernández concluded that the computational cost of both formulations is comparable, but substantially higher compared with conventional lattice fermions. In particular, her results indicate that the numerical effort needed to preserve chiral symmetry by simulating Domain Wall fermions is far greater than previously thought. This point was further explored during an open discussion session led by Karl Jansen (CERN) and Tassos Vladikas (Rome II). A conclusion was that conventional lattice fermions appear quite sufficient to address many – if not all – of the problems in applied lattice QCD.

As well as calculating hard results, the preservation of chiral symmetry on the lattice has also been exploited in the study of more formal aspects of quantum field theories. Oliver Bär (DESY) presented recent work on global anomalies, which can now be analysed in a rigorous, non-perturbative way using the lattice framework. SU(2) gauge theory coupled to one massless, left-handed neutrino thereby leads to the lattice analogue of the famous Witten anomaly. Further work on anomalies was presented by Hiroshi Suzuki (Trieste), while Yigal Shamir (Tel Aviv) reviewed a different approach to lattice chiral gauge theories based on gauge fixing.

Among other topics discussed at Ringberg was the issue of non-perturbative renormalization, with contributions from Roberto

Petronzio (Rome II), Steve Sharpe (Seattle) and Rainer Sommer (Zeuthen). The problem is to relate quantities (for example form factors and decay constants) computed on the lattice to their continuum counterparts via non-perturbatively defined renormalization factors. Such a procedure avoids the use of lattice perturbation theory, which is known to converge only very slowly.

The successful implementation of non-perturbative renormalization for a large class of operators removes a major uncertainty in lattice calculations. Furthermore, talks by Antonio Grassi, Roberto Frezzotti (both Milan) and Stefan Sint (Rome II) discussed recent work on QCD with an additional mass term which is expected to protect against quark zero modes. It is hoped that this will help in the simulation of smaller quark masses.

Many other contributions, for example two-dimensional models, Nahm dualities and the bosonization of lattice fermions, could also lead to further progress. However, the variety of topics discussed at the workshop underlines that lattice field theory is a very active research area with many innovative ideas. Progress in understanding how nature works on the smallest possible scale depends on such theoretical and conceptual advances as well as sheer computer power.

The Ringberg meeting was organized by Martin Lüscher (CERN), Erhard Seiler and Peter Weisz (MPI Munich).

Hartmut Wittig, CERN.

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Towards the ultimate the X-r



An international team using the superconducting TTF at DESY, Hamburg, has set a new record for the shortest wavelength of radiation ever achieved with a free electron laser. (DESY.)

On 22 February an international team working at the superconducting TESLA Test Facility (TTF) at DESY, Hamburg, set a new record for the shortest wavelength of radiation ever achieved with a free electron laser (FEL). The collaboration, involving around 140 scientists from 38 institutes in 9 countries, succeeded in generating ultraviolet radiation with a wavelength of 109 nm. The previous best using this type of self-amplified spontaneous emission (SASE) FEL was 530 nm (by a group at Argonne). Within a few weeks the group pushed the wavelength down to 80 nm and tuned the FEL to various wavelengths up to 180 nm, thus demonstrating for the first time the free wavelength tunability of SASE FELs over a large range.

To achieve this decisive step towards a new range of laser wavelengths, the TESLA team used the electron beam from the superconducting test linac of the TTF, set up for the development and

With their ultrashort wavelengths, X-rays are excellent for... the DESY laboratory has developed a technique

testing of new superconducting niobium cavities for DESY's planned 33 km TESLA electron-positron linear collider (May 1999 p11).

Having demonstrated that SASE is working at such small wavelengths, the collaboration is now extending the short TTF into a 300 m device that could operate in the soft X-ray range around 6 nm. This user facility should be available for experiments by 2003.

The ultimate goal is to produce X-rays with a wavelength of 0.1 nm. Since these short wavelengths require an electron beam of much higher energy, this X-ray laser facility is planned to be included as an integral part of the proposed TESLA linear collider.

Synchrotron radiation

Since its discovery in the mid-1940s, synchrotron radiation has evolved into an invaluable tool for experiments in a range of fields – from surface physics, materials sciences and chemistry, to geophysics, molecular biology and medicine. Nowadays, third-generation synchrotron radiation sources are producing nearly every wavelength from infrared to hard X-rays. However, one thing has so far remained a dream: beams of coherent high-intensity X-rays – a high-intensity X-ray laser.

How to reach this "ultimate" X-ray source has been the subject of many efforts both theoretically and experimentally in the last 20 years. During the past 6–8 years a consensus has developed that fourth-generation sources, implying a higher degree of coherence, higher power, brilliance and ultrashort pulses, possibly at very short wavelengths, such as the hard X-ray region, would probably involve a linear accelerator driving a FEL.

This shift from storage rings to linear devices is because the quality of the electron beam – short bunch lengths and small beam emittance – is limited at storage rings but is crucially important for the FEL process. Especially when aiming at X-ray wavelengths with a SASE FEL, the limitations of storage rings become noticeable.

Free electron lasers

The main ingredients of a FEL are a high-energy electron beam with very high brightness and a periodic transverse magnetic field, such as that produced by an undulator magnet. As the electron bunches

Next generation X-ray source: Free electron laser

...ent probes of fine structure. An international team at
...e for attaining wavelengths of less than 100 nm.

As they zigzag through the magnetic field, they emit synchrotron radiation around their direction of motion. For small undulations the radiation is quasimonochromatic. For every undulator period the radiation phase moves ahead of the electrons by a distance equal to this specific resonant wavelength, keeping each electron in phase with the radiation field.

Depending on the relative phase between radiation and electron oscillation, electrons experience either a retardation or an acceleration with respect to the mean electron velocity.

If the electron beam is of sufficient quality and the undulator long enough, the longitudinal density of the electron bunch becomes modulated, with "microbunching" at the resonant wavelength. This electron density modulation reduces phase cancellation in the emission process, increasing the intensity of the emitted light. This light interacts again with the electron beam and again enhances the bunch density modulation, thereby further increasing the intensity. The net result is an exponential increase in radiated power – ultimately about six orders of magnitude more brilliant than conventional undulator radiation.

No mirrors

Like conventional lasers, most present FELs use an optical cavity formed by mirrors to store the light from many successive electron bunches. Many of these FELs work in the infrared range, and some even reach ultraviolet wavelengths. However, extending them towards the X-ray regime is difficult, owing to the lack of good reflecting surfaces at wavelengths below 150 nm.

An alternative path to shorter wavelengths was found with the development of SASE FELs. These achieve lasing in the single pass of a high-brightness electron bunch through a very long undulator by the SASE process, without any mirrors.

The concept of SASE FELs was introduced in the early 1980s (Kondratenko and Saldin 1980) and further explored in 1984 (Bonifacio *et al.* 1984), soon leading to first experimental tests (Scharlemann *et al.* 1986). During 1997–8 a Los Alamos/UCLA experiment at Los Alamos (Hogan *et al.* 1998) produced a gain of 3×10^5 for the first time and established the proof-of-principle of



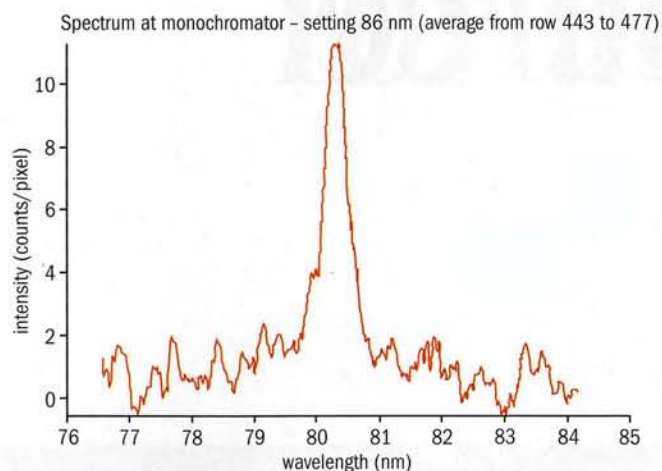
The undulator used in DESY's TTF free electron laser is a 15 m magnetic structure comprising three 4.5 m modules, each made up of 652 permanent magnets. To ensure that the electron beam does not deviate from a straight line by more than 50 μm , the magnets have to be fitted together to an accuracy of just a few microns. In addition, the undulator is set up in a special air-conditioned room where the temperature is held constant with a precision of 0.1° in order to avoid expansion of undulator components.

SASE theory at a wavelength of 12 μm . Recently, SASE at 530 nm was demonstrated at Argonne (Milton *et al.* submitted).

Testbed

The TTF was set up at DESY in 1993, with major contributions from the US, Italy and France, to provide a testbed for the TESLA linear collider project, especially the superconducting niobium cavities for particle acceleration. In 1994 work began on the test accelerator to extend it into a 300 m FEL comprising all of the basic elements that will subsequently be employed in full-size TESLA X-ray lasers.

In a first phase, now brought to laser operation, the TTF was equipped with a 15 m undulator, a bunch compressor (reducing the bunch length, thus increasing the bunch peak current) and a radiofrequency photocathode electron gun. ▷



X-ray laser radiation at 80 nm wavelengths.

There are essentially two technical challenges to be met by an X-ray FEL. First, it is crucial to generate and accelerate a low emittance and high-peak-current electron beam. This can be achieved using a high-brightness radiofrequency photocathode gun as an electron source. The electron gun currently used at the TTF-FEL is a joint contribution of Fermilab, INFN/Milan, Rochester, the Max Born Institute in Berlin and DESY.

It has meanwhile demonstrated that such a particle source can drive a facility 24 h a day for weeks and even months. Because the radiofrequency gun performance is so critical for further development, DESY is building up a standalone gun test facility at its institute in Zeuthen near Berlin.

The peak current inside the bunches produced by the low-emittance gun is still not high enough to reach laser saturation within an undulator of reasonable length. The solution is to compress the bunches longitudinally to increase the peak current. This can be achieved using a "bunch compressor chicane" - a sequence of deflecting magnets.

The principle is not new, but aiming at a few kiloamperes of peak current means achieving bunch lengths of less than 0.1 mm, which is a challenge. Accelerating the beam off the crest of the radiofrequency waveform in the linac creates an energy-phase correlation that can be used to shorten the bunch. When passing the chicane, electrons with different momenta travel different path lengths. The TTF-FEL currently uses a bunch compressor at 140 MeV, which compresses the bunch length below 0.5 mm rms.

The second important technical challenge is to keep the electron beam (focused to a transverse beam size of about 0.1 mm) in essentially complete overlap with the photon beam as it passes through the undulator. This sets new standards for undulator alignment procedures and beam orbit control.

Interleaved operation

Combining the machine expertise at a high-energy physics facility with operation of a radiation source continues a long and fruitful tradition at DESY. Technically, both X-ray SASE FELs and linear colliders depend fundamentally on the generation of low-emittance, short electron bunches and on accelerating long bunch trains with-

out loss of this quality. This is best achieved with a superconducting linac, combining high accelerating gradients and low wakefield effects with long bunch trains at high duty cycle, owing to low power losses.

For power cost reasons, a superconducting linear collider has a radiofrequency-on-time fraction of only 1%. Consequently there is room for further radiofrequency pulses to accelerate an interleaved electron beam for FEL operation. In this way the most expensive component of an X-ray laser - the linac - is shared with the high-energy physics community.

All TTF findings are consistent with existing models for SASE FELs. So far, a laser gain of more than 1000 has been observed, while laser saturation is expected well beyond 10^6 . Thus the next steps will be focused on achieving even higher laser gain by improving orbit control and electron beam quality. Operation with long trains of several thousand electron bunches will also be tested.

Having accomplished the proof-of-principle experiment (Andruszkow *et al.*), the TESLA collaboration will then upgrade the superconducting linac to 1000 MeV (Åberg *et al.* 1995), bringing the FEL wavelength down to 6 nm. The new user facility should be ready for experiments by 2003. As for the TESLA Linear Collider with Integrated X-ray Lasers, a conceptual design was published in 1997 (Brinkman *et al.* 1997) and a Technical Design Report, including schedule and costs, will be presented in 2001 for evaluation by the German Science Council (Wissenschaftsrat), the German Federal Government's scientific advisory board. As a first step towards formal planning permission, an agreement was signed in 1998 by the relevant German federal states.

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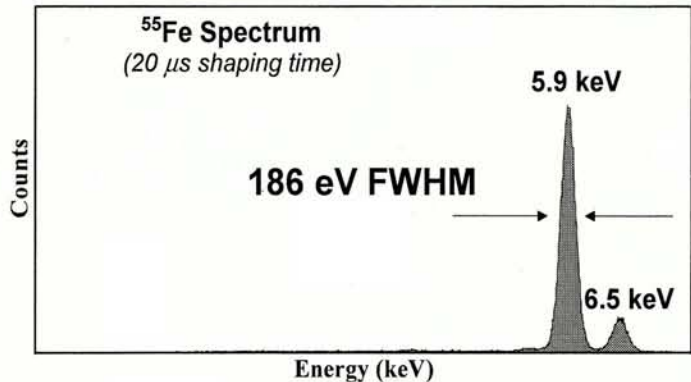
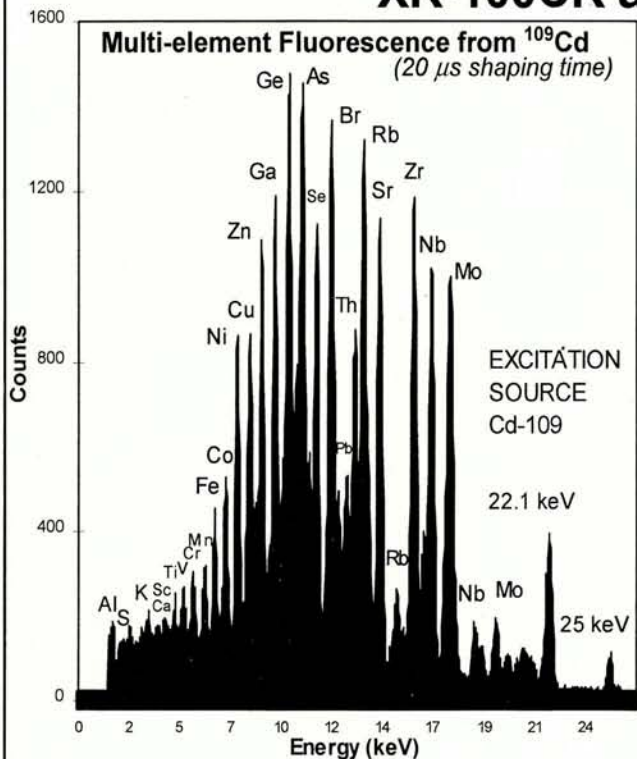
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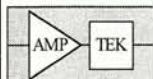
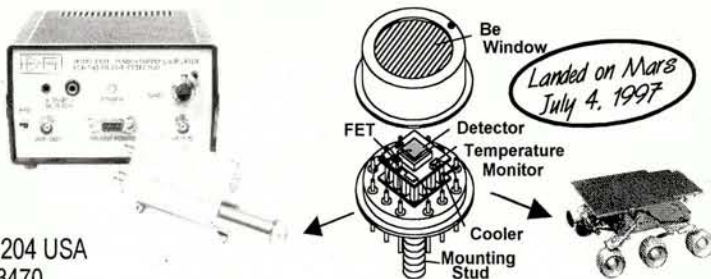
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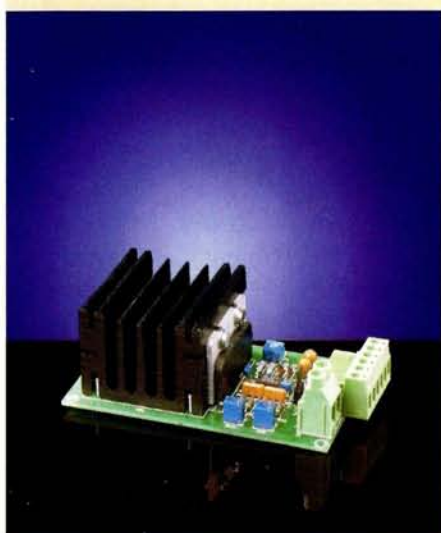
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Berkeley Lab's ALS generates femtosecond synchrotron radiation

A team at Berkeley's Advanced Light Source has shown how a laser time-slicing technique provides a path to experiments with ultrafast time resolution.

A Lawrence Berkeley National Laboratory team has succeeded in generating 300 fs pulses of synchrotron radiation at the ALS synchrotron radiation machine. The team's members come from the Materials Sciences Division (MSD), the Center for Beam Physics in the Accelerator and Fusion Research Division and the Advanced Light Source (ALS).

Although this proof-of-principle experiment made use of visible light on a borrowed beamline, the laser "time-slicing" technique at the heart of the demonstration will soon be applied in a new bend-magnet beamline that was designed specially for the production of femtosecond pulses of X-rays to study long-range and local order in condensed matter with ultrafast time resolution. An undulator beamline based on the same technique has been proposed that will dramatically increase the flux and brightness.

The use of X-rays to study the course of solid-state phase transitions, the kinetic pathways of chemical reactions and the efficiency and function of biological processes on the fundamental timescale of a molecular vibration (about 100 fs) is an emerging field of research.

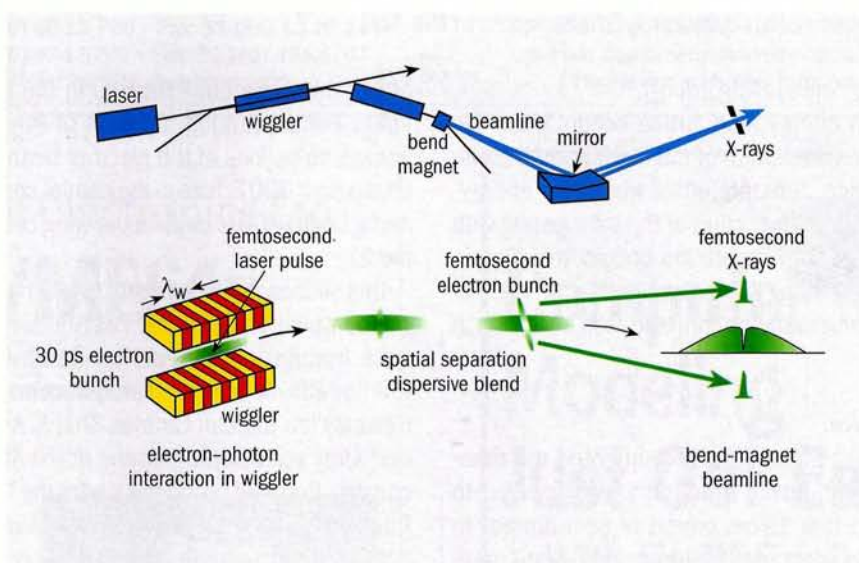


Fig. 1: Schematic showing how the laser bunch-slicing technique was used to produce femtosecond pulses of synchrotron radiation at Berkeley's Advanced Light Source. Left: laser/electron beam interaction in resonantly tuned wiggler. Centre: separation of accelerated femtosecond electron slice in a dispersive bend magnet. Right: generation of femtosecond synchrotron radiation in a bend-magnet beamline.

Ahmed H Zewail of Caltech was awarded the 1999 Nobel Prize for Chemistry for demonstrating how rapid laser techniques can reveal how atoms move during chemical reactions. Pump-probe methods in which a pump pulse stimulates the process followed by a probe pulse to examine it at intervals thereafter constitute a common way of following the dynamics of ultrafast processes with infrared and visible lasers. However, there is a dearth of ultrafast X-ray sources to provide structural data on this time-scale. The pulse length of synchrotron radiation, for example, is limited by the

bunch length of the electron beam – about 30 ps at the ALS.

Ultrashort pulses

A solution to the bunch-length problem was described four years ago by Alexander Zholents and Max Zolotarev of the Center for Beam Physics. In short, a high-power femtosecond laser synchronized with the electron bunches passes collinearly with an electron bunch through an insertion device (undulator or wiggler) as in a free electron laser. The high electric field of the shorter laser pulse modulates a portion of the longer electron bunch, with some

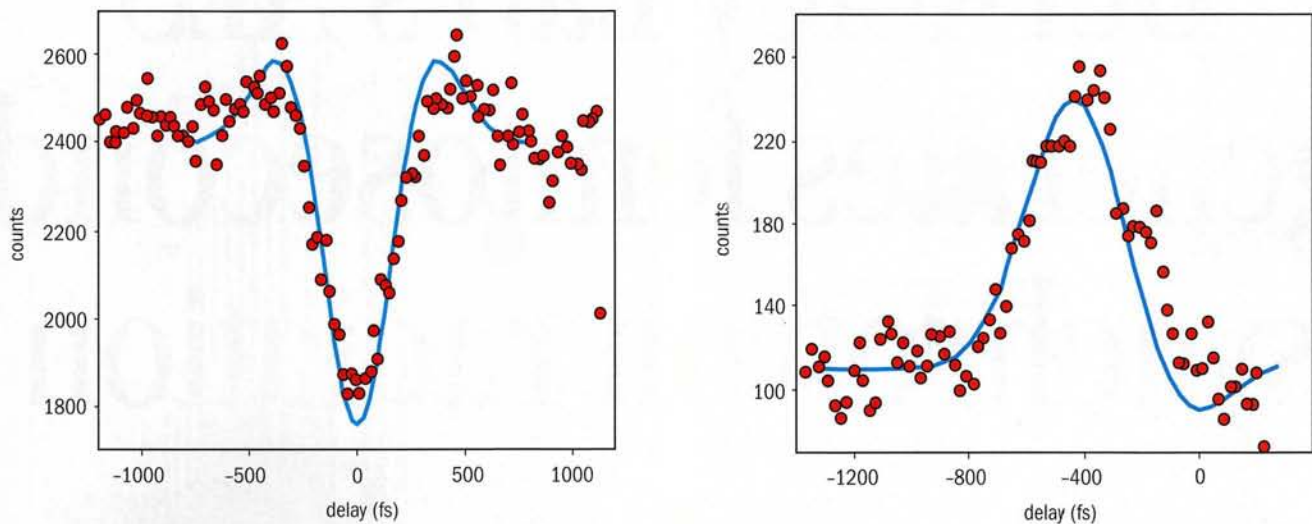


Fig. 2: Cross-correlation between a delayed laser pulse and the synchrotron radiation shows that (left) light from the central core of the electron bunch has a dark femtosecond hole and (right) light from a horizontal wing of the electron bunch has a bright femtosecond peak. The solid lines are from a model calculation of the spatial and temporal distribution of the energy-modulated electron bunch following propagation through 1.5 arc-sectors at the ALS.

electrons gaining energy and some losing energy.

The condition for optimum energy modulation occurs when the laser wavelength matches the wavelength of the fundamental emission from the insertion device. Subsequently, when the energy-modulated electron bunch reaches a section of the storage ring with a non-zero dispersion, a transverse separation occurs, resulting in slices of the bunch roughly as long as the laser pulse. A collimator or aperture selects the synchrotron radiation from the displaced bunch slices.

Femtosecond time structure

The team led by MSD's Robert Schoenlein implemented the time-slicing scheme by using a high-power titanium sapphire laser to modulate the electron beam in a 16 cm period wiggler already in straight section 5 of the 12-fold symmetric storage ring. Bend magnets between the wiggler and the beamline provide horizontal dispersion and the synchrotron radiation, and a test chamber on an existing bend-magnet beamline in the curved sector after straight section 6 records the femtosecond pulses (figure 1).

Schoenlein's group verified the femtosecond time structure by imaging visible light from the beamline onto a nonlinear optical crystal along with a delayed 50 fs cross-correlation pulse from the laser system and then counting photons at the sum frequency as a function of delay between the modulating and the cross-correlation laser pulses. An

An adjustable knife edge located in the beamline at an intermediate image plane provided a means to select radiation from different transverse regions of the electron beam.

adjustable knife edge located in the beamline at an intermediate image plane provided a means of selecting radiation from different transverse regions of the electron beam. In this way the team measured a dark 300 fs hole in the central cone of the synchrotron radiation and a bright 300 fs peak in the wing of the synchrotron radiation (figure 2).

This success was the result of a synergistic collaboration between two complementary groups at Berkeley working at the ultrafast science frontier – the Center for Beam Physics, headed by Swapan Chattopadhyay and the Femtosecond Spectroscopy Group, led by Berkeley lab director Charles Shank. As part of a growing femtosecond X-ray science programme at the ALS, new beamlines are under construction and proposed under the leadership of Schoenlein and Roger Falcone of the University of California, Berkeley. A bend-magnet beamline, with an anticipated completion date of June 2000, has a performance goal of 100 fs pulses at a repetition rate of 5 kHz with a flux of about 10^5 photons/s/0.1% bandwidth and a brightness of about 10^8 photons/s/mm²/mrad²/0.1% bandwidth for photon energies up to 10 keV. A proposed undulator beamline would increase the flux and brightness by factors of about 100 and 10 000 respectively. An in-vacuum device, the planned undulator has a 5 mm gap, almost a factor of three smaller than the current smallest magnetic gap (14 mm) and nearly a factor of two smaller than the narrowest vacuum chamber (9 mm) in the ring. A vertical rather than horizontal dispersion would also be used. A complete mini-beta lattice with large vertical dispersion bumps is being designed to accommodate these features.

Further reading

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Arthur L. Robinson, ALS, Berkeley Laboratory.

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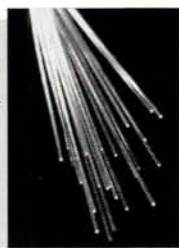
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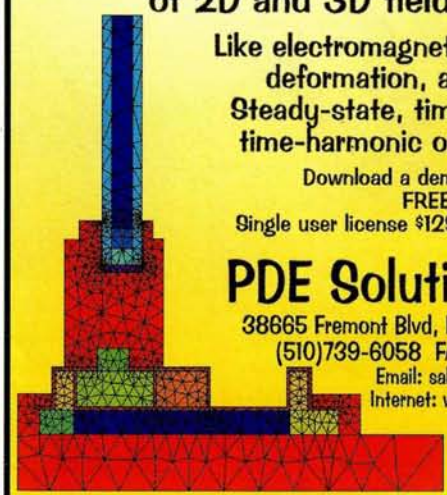
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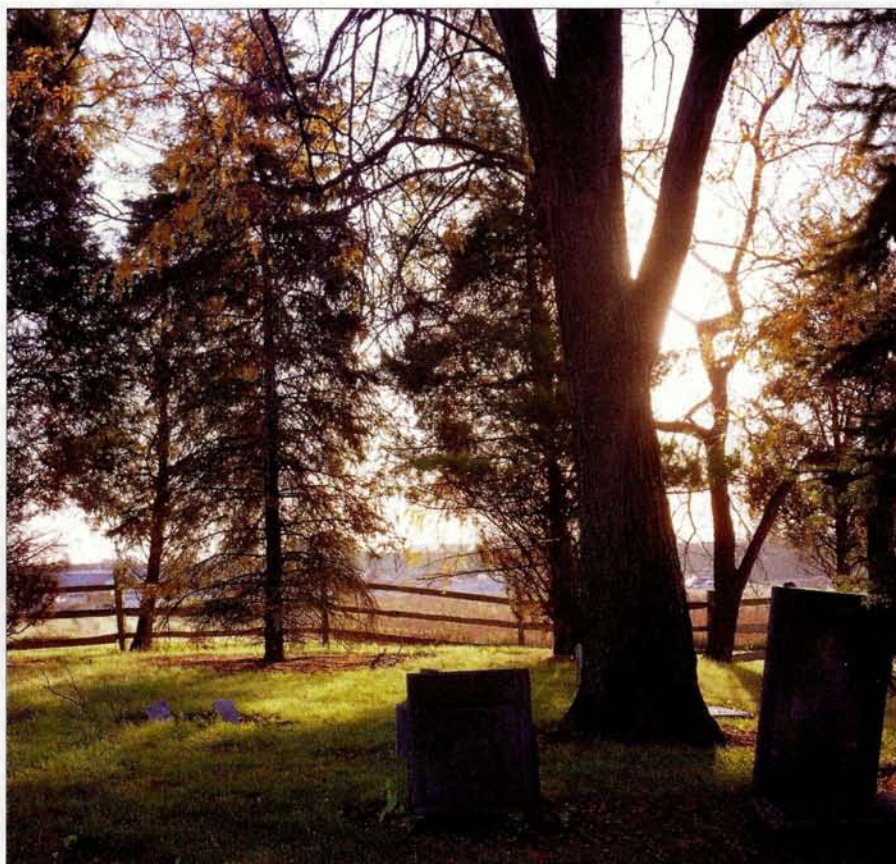
On 19 April director of the Joint Institute for Nuclear Research (JINR) **Vladimir Kadyshevsky** (right) received Germany's distinguished Verdienstkreuz award from Ambassador of the Federal Republic of Germany to the Russian Federation **Ernst-Jorg von Studnitz**. The award was in recognition of Kadyshevsky's meritorious contribution to the successful and dynamic development of the co-operation between German physicists and their JINR colleagues. During the past 10 years, new research projects involving scientists from DESY (Hamburg), GSI (Darmstadt) and the Jülich Research Centre have been successfully realized, along with the joint research programmes involving physicists from the former East Germany, and with significant scientific results.



Marie-Noelle Fontaine recently retired after many years of sterling service in CERN's Theory Division Secretariat. Among those at her leaving party was 1999 Nobel prizewinner **Martin Veltman**.



Family photograph at a CERN visit of permanent representatives in Geneva of CERN member and non-member states on 5 May.



On 28 April the ashes of Fermilab founder Robert Wilson were buried in Pioneer Cemetery, a 19th-century burial ground on the Fermilab site. Among the graves in the Pioneer Cemetery, the headstones of which date from 1839, is that of General Thompson Mead, a veteran of the War of 1812, who established a homestead in Batavia. The cemetery became part of the Fermilab site when the federal government acquired the land for the National Accelerator Laboratory in 1967. Robert Wilson died on 16 January (March p13).

MEETINGS

The Strings 2000 Conference will be held at the University of Michigan, Ann Arbor, on 10–15 July. The conference is part of the ongoing series of major annual string theory meetings and will focus on the latest topics in string theory and M theory. Further information is available at "<http://feynman.physics.lsa.umich.edu/strings2000/>".

The 2000 meeting of the Division of Particles and Fields (DPF2000) will be held on 9–12 August on the Columbus campus of Ohio State University. The meeting will cover the latest experimental results and new theoretical ideas that set the stage for physics in the new millennium. The deadline for the reduced registration fee is 8 July, and 1 June for abstract submission. The two primary sources of housing (Holiday Inn on the Lane and North Campus Dormitories) are within a short walk of all conference venues. Deadlines for guaranteed hotel and dormitory rates are 8 and 24 July respectively. For more details on the conference, including the programme, registration, submission of abstracts, and housing, visit "<http://www.dpf2000.org>".

The Cairo International Conference on High Energy Physics (CICHEP2001) will be held on 9–14 January 2001 and is organized by the Department of Physics, Faculty of Science, Ain Shams University, Cairo, Egypt. The purpose of the conference is to bring together scientists from universities and research institutes around the world to discuss current developments and new trends, results and perspectives. Topics include the status of the standard model; the phenomenology of the minimal supersymmetric standard model; experimental searches for supersymmetry; supersymmetry and supergravity theory; neutrino physics; string theory, dualities and M-theory; and the early universe and cosmology. Further information is available at "<http://www.ectp.org>".

ON PEOPLE

Jacques Marteau of Lyon's Institute for Nuclear Physics receives a Lyon young researcher award for his work on neutrino–nucleus interactions, which has led to new directions in the analysis of results from the detection of atmospheric neutrinos.



CERN LHC project director **Lyn Evans** (left) and director-general **Luciano Maiani** (centre) at the famous round table at the Budker Institute, Novosibirsk, with laboratory director **Alexander Skrinisky**. The Budker Institute is heavily involved in preparations for CERN's LHC collider, supplying magnets for beamlines and other equipment, and carrying out synchrotron radiation studies for development work on the LHC vacuum chamber.



The "Live from CERN" Webcast "Antimatter: the Mirror of the Universe" took place on 10 May. Top: CERN physicist **Alvaro de Rujula** explains the role of antimatter, with co-presenter **Paola Catapano**. Bottom: with the help of a tabletop simulation, CERN physicist **Rolf Landua** (right) explains to co-presenter **Mick Storr** how antimatter is produced.



Princess Maha Chakri Sirindhorn of Thailand at CERN, with **Tiziano Camporesi** (left), spokesman of the Delphi experiment at CERN's LEP electron-positron collider, and research director **Claude Détraz**.



At a recent workshop at GANIL, Caen, France, to discuss the dynamics and thermodynamics of heavy-ion collisions – GANIL director **Daniel Guerreau** (left) with CERN research director and former GANIL director **Claude Détraz**. While heavy-ion work at CERN has focused on the plasma-gas transition of nuclear matter (April p13), that at GANIL is more concerned with the gas-liquid transition.

COURSES

The University of Siegen, Germany, has introduced a new graduate course in physics. The course aims at a master degree after two years of physics studies and a PhD in natural science after an additional three years. A bachelor degree or equivalent is required. All lectures are given in English. Grants for excellent students are anticipated. The master thesis is expected to specialize in imaging techniques in medical physics, biophysics, material science or structural biology. More information is available at "<http://besch2.physik.uni-siegen.de/~imaging/>".

John Clive Ward 1924–2000

John Ward rose into world prominence with two succinct papers published in the *Physical Review* in 1950, both featuring his famous "Ward Identity": differentiating an electron propagator introduces an effective vertex interaction into that line. In the first paper, using his identity, Ward showed that soft photon-photon scattering will vanish and thus a separate four-photon renormalization constant is not required. In the sequel he proved that the electron wave-function renormalization constant had to equal that of the electron-photon vertex, a result that had previously been conjectured by Dyson. In the following year he thereby established the full renormalizability of quantum electrodynamics and avoided dealing with overlapping infinities by his clever use of the identity.

Such gauge identities and their generalization to finite photon momentum transfer today play a routine role in constraining the renormalization of gauge theories and in relating Green functions that differ by an extra vector gauge boson.

In the early 1960s with Salam, Ward laid the groundwork for today's "standard model" of elementary particles. Their 1964 paper in *Physics Letters* points out the $SU(2) \times U(1)$ gauge group, also found by Glashow, and

describes the mixing of the neutral vector gauge bosons with the famous weak mixing angle, although the mechanism of spontaneous breaking is missing.

They also made significant progress in elucidating non-leptonic weak interactions by realizing that the $\Delta I = 1/2$ rule can be understood via the occurrence of a vacuum expectation value for the neutral K meson.

Ward published a number of papers on higher symmetries and grand unification, although they lacked the impact of his earlier work. For his significant contributions to quantum electrodynamics, he was elected Fellow of the Royal Society in 1965. He was awarded the Guthrie Medal of the UK Institute of Physics in 1980 and the Royal Society's Hughes Medal in 1983. He spent many years in the US (at Princeton, Carnegie Institute and Johns Hopkins) before emigrating to Australia in 1967, where he became Professor of Physics at Macquarie University. There he was instrumental in reshaping the structure of the undergraduate degree.

R Delbourgo, University of Tasmania.



John Ward
1924–2000.

Giuliano Preparata 1942–2000

Italian theoretician Giuliano Preparata died in Frascati on 24 April after a relatively short battle against cancer. Born in Padua, he studied in Rome. After graduating in 1964 he joined Raoul Gatto's group in Florence. Later he was in the US at Princeton, Harvard and Rockefeller universities. In those years he produced excellent work on symmetries, current algebra and on the field theory approach to particle physics. After returning to Rome, he was soon called to CERN as a staff member. He was later Professor of Theoretical Physics at Bari and Milan.

Preparata was a theorist of great talent, with tremendous drive and a strong personality. His most recognized contribution to particle physics is the extension of the Wilson short-distance operator expansion to the whole of the light cone, developed in collaboration with Richard Brandt in around 1970. This

remains a basic theoretical tool for the understanding of inclusive electron-positron annihilation and deep inelastic lepton scattering. However, his interests were already very wide and, in the same years, he produced a well known, seminal paper on nonlinear quantum optics with Rodolfo Bonifacio.

With time he progressively became critical of many steps in the construction of the Standard Model and of some parts of its foundations, such as QCD. His interests were then increasingly concentrated on different subjects, often with non-conventional approaches and opinions, such as nuclear physics, superconductivity, cold fusion and quantum gravity. He worked until the end with great energy. He was at CERN for the last time in January, when Remo Ruffini gave a presentation on their work on a possible mechanism for the production of gamma-ray bursts.

Lloyd Smith 1922–2000

Lloyd Smith, pioneer accelerator theorist and distinguished physicist, died on 1 May at his home in Berkeley, California. He was a major contributor to the design of most of the large US accelerators from the 1940s to the 1970s.

Born in Chicago in 1922, Smith completed his BA at Illinois, Urbana Champaign, in three years, and, after starting his PhD at Illinois, he moved with his advisor to Ohio State, where his thesis involved work with the Van de Graaff generator. At this time it was common practice to check accelerator operation by sighting on the beam. While working at the Illinois cyclotron, Smith suffered eye damage caused by neutrons from nuclear reactions of the beam with background gas. In 1949 he had the first successful surgery for neutron-induced cataracts, a procedure later used to help victims of the atomic bomb at Hiroshima.

Following his PhD, Smith spent a year at Chicago and joined the then Lawrence Radiation Laboratory to work on the design of the Bevatron. In 1950, during the anti-Communist years, when the state required loyalty oaths, Smith and his wife, a member of the Berkeley Campus faculty, left California.

He went to the Carnegie Institute of Technology, where he helped to design a 450 MeV synchrocyclotron. He returned to the Rad Lab in 1952, where he remained until his retirement in 1994, except for leaves in 1955–56 at Brookhaven, 1959–60 at CERN, and 1968–70 at Fermilab – all crucial accelerator years for those laboratories.

Smith was a leading theorist in all accelerator projects taken on by the Berkeley Laboratory during the 1950s to the 1970s. He was a major figure in the design of the 88" Cyclotron and the HILAC, the Positron Electron Project at SLAC, the Electron Ring Accelerator and the Experimental Superconducting Accelerator Ring. He was head of the theory group for the 200 BeV study, which preceded the Fermilab accelerator. He made major contributions to the theory of proton linacs and spiral-ridged cyclotrons, and he was an acknowledged expert on linear accelerators.

Smith also made fundamental contributions to the effort to develop nuclear fusion. In the late 1950s he worked on the theory of various "magnetic bottle" configurations to confine plasmas, including mirror machines.



October 1949 – Berkeley accelerator pioneers admire a model of the planned Bevatron. Left to right: Lloyd Smith, Edwin McMillan, E O Lawrence, Edward Lofgren, William Brobeck and Duane Sewell.

From 1976 he was the head of the Heavy Ion Fusion theory group at the Berkeley Lab, where he made fundamental contributions in the areas of intense beam transverse and longitudinal stability. At this time (1986) he also completed a study of the nonlinear effects of undulators on beam dynamics in storage rings, a most complete and rigorous work and a widely used reference in undulator and light source design.

Smith, a retiring, brilliant man with an incisive and witty sense of humour, made a broad and significant impact on accelerator theory. *Christine Celata.*

Klaus Halbach 1924–2000

Klaus Halbach, a long-time staff physicist with the Lawrence Berkeley National Laboratory and an international expert in magnetic systems for particle accelerators, passed away on 11 May following a long battle with prostate cancer. He was 75.

A native of Germany who received his PhD in physics at Basel in Switzerland, Halbach came to the US in 1957 to work at Stanford with nuclear magnetic resonance pioneer Felix Bloch. Following a short return to Switzerland to start a plasma physics group, he joined the plasma physics group at Berkeley in 1960. His work with plasma physics led him into accelerator design and he was a major contributor to the Omnitron, a synchrotron that would have accelerated nuclei from hydrogen to uranium. Though never built, the Omnitron's design laid the groundwork for the Bevalac.

Halbach made his reputation with his work on magnetic systems for particle accelerators. He and Ron Holsinger, a Berkeley engineer and later Halbach's son-in-law, created the

famous POISSON computer codes for magnetic system design, still in use after more than 30 years. Halbach went on to become one of the world's premier designers and developers of permanent magnets for use as insertion devices – wigglers and undulators – in synchrotron light sources and free electron lasers. He also designed magnets for the Berkeley Advanced Light Source storage ring.

In addition to his critical contributions to the Advanced Light Source, Halbach served as a consultant to many other projects around the world, including the Advanced Photon Source at Argonne and the Stanford Synchrotron Radiation Laboratory. All of the premier radiation sources within these machines depend on the permanent magnet technology now known as the Halbach Array. He was also a major contributor to the designs of high-resolution spectrometers at Jülich and LAMPF, Los Alamos.

Although he officially retired in 1991, Halbach continued to work on magnet design.



Klaus Halbach 1924–2000.

He made contributions to such diverse projects as magnets for a miniature cyclotron that could be used for medical radioisotope production, magnets and low-friction magnetic bearings for an electromechanical battery, and the design of miniature permanent magnet NMR spectrometers for future Mars lander missions.

Halbach trained numerous students in his field and shared his knowledge with generous delight. His contributions and his enthusiasm will be sorely missed.

Lynn Yarris, Public Information Department, Lawrence Berkeley National Laboratory.

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Exhibit:

November 28-30

Materials Development
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Tel 724-779-3003
Fax 724-779-8313
E-mail: info@mrs.org

Abstract Deadlines — In fairness to all potential authors, late abstracts will not be accepted.

June 5, 2000: for abstracts sent via fax or mail • June 19, 2000: for abstracts sent via the MRS Web site

2000 MRS FALL MEETING SYMPOSIA

Cluster 1: Nano-Microstructured Materials

- A: Nanotubes and Related Materials
- B: Structure and Mechanical Properties of Nanophase Materials—Theory and Computer Simulations vs Experiment
- C: Anisotropic Nanoparticles—Synthesis, Characterization, and Applications
- D: Nonlithographic and Lithographic Methods for Nanofabrication—From Ultralarge-Scale Integration to Photonics to Molecular Electronics
- E: Microphonics—Materials, Physics, and Applications
- F: Nano- and Microcrystalline Semiconductor Materials and Structures

Cluster 2: Semiconductors

- G: GaN and Related Alloys
- H: Silicon Carbide—Materials, Processing, and Devices
- I: Semiconductor Spintronics—Physics, Materials, and Applications
- J: Semiconductor Quantum Dots

Cluster 3: Metals

- K: Quasicrystals
- L: Supercooled Liquid, Bulk Glassy, and Nanocrystalline States of Alloys
- M: Thermal Barrier Coatings
- N: High-Temperature Ordered Intermetallic Alloys IX

Cluster 4: Materials Processing and Analysis

- O: Ion Beam Synthesis and Processing of Advanced Materials
- P: Growth, Evolution, and Properties of Surfaces, Thin Films, and Self-Organized Structures
- Q: Fundamentals of Nanoindentation and Nanotribology II
- R: Microstructural Processes in Irradiated Materials
- S: Applied Magnetic Field Effects on Materials Behavior
- T: Dynamics in Small Confining Systems VI
- U: Ultrafast Nonlinear Optical Phenomena
- V: Low-Vacuum SEM/SEM in Materials Science: Wet SEM—The Liquid Frontier of Microscopy

Cluster 5: Defects, Mechanics, and Length Scales

- W: The Limits of Strength in Theory and Practice
- Y: Influences of Interface and Dislocation Behavior on Microstructure Evolution
- Z: Multiscale Materials Modeling
- AA: Structure-Property Relationships of Oxide Surfaces and Interfaces

Cluster 6: Device and Functional Materials

- BB: Characterization and Modeling of Domain Microstructures in Materials
- CC: Ferroelectric Thin Films IX
- DD: Materials Issues for Tunable RF and Microwave Devices II
- EE: Materials Science of Microelectromechanical System (MEMS) Devices III

Cluster 7: Inorganic Materials

- FF: Materials Science of High-Performance Concrete
- GG: Solid-State Chemistry of Inorganic Materials
- HH: Advanced Catalytic Materials - 2000
- II: High-Temperature Superconductors—Crystal Chemistry, Processing, and Properties

Cluster 8: Organic and Biomaterials

- JJ: Organic Electronic and Photonic Materials and Devices
- KK: Filled and Nanocomposite Polymer Materials
- LL: Orthopaedic/Dental Biomaterials
- MM: Cardiovascular Biomaterials
- NN: Biomaterials for Drug Delivery
- OO: Neurologic Biomaterials

Cluster 9: General

- X: Frontiers of Materials Research

2000 MRS FALL MEETING ACTIVITIES

SYMPOSIUM TUTORIAL PROGRAM

Available only to meeting registrants, the tutorials will concentrate on new, rapidly breaking areas of research.

EXHIBIT

Over 225 international exhibitors will display a full spectrum of equipment, instrumentation, products, software, publications, and services.

PUBLICATIONS DESK

A full display of over 630 books, plus videotapes and electronic databases, will be available at the MRS Publications Desk.

SYMPOSIUM ASSISTANT OPPORTUNITIES

Graduate students planning to attend the 2000 MRS Fall Meeting may apply for a Symposium Assistant (audio-visual aide) position.

EMPLOYMENT CENTER

An Employment Center for MRS members and meeting attendees will be open Tuesday through Thursday.

The 2000 MRS Fall Meeting will serve as a key forum for discussion of interdisciplinary leading-edge materials research from around the world. Various meeting formats—oral, poster, round-table, forum and workshop sessions—are offered to maximize participation.

RECRUITMENT

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**DEUTSCHES ELEKTRONEN-
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The Theory Group of DESY Hamburg invites applications for a permanent position which becomes available in the year 2000:

DESY Staff Position in Theoretical Particle Physics

Applicants should have experience in lattice gauge field theories. The salary follows the BAT contract rules of the Federal Republic of Germany. DESY especially encourages women to apply.

Handicapped applicants will be given preference in case of equal qualification.

Interested theorists are asked to send their application, including the List of Publications and the Curriculum Vitae, to DESY until September 30, 2000 (Code-No. 43/00).

**Deutsches Elektronen-Synchrotron DESY
Notkestraße 85, D-22607 Hamburg/Germany**

Additional information may be obtained from Prof. P.M. Zerwas, tel. 040.8998.2416/2413 or via e-mail peter.zerwas@desy.de.



**DEUTSCHES ELEKTRONEN-
SYNCHROTRON DESY**

The Theory Group of DESY Hamburg invites applications for two positions which become available in the year 2000:

DESY Staff Position in Theoretical Particle Physics and DESY Junior Staff Position in Theoretical Particle Physics

Applicants should have experience in areas of physics beyond the Standard Model. These staff positions are permanent (Code-No. 45/00) and limited to three years (Code-No. 44/00) with possible extension, respectively. Salaries follow the BAT contract rules of the Federal Republic of Germany. DESY especially encourages women to apply.

Handicapped applicants will be given preference in case of equal qualification.

Interested theorists are asked to send their application, including the List of Publications and the Curriculum Vitae, to DESY until September 30, 2000.

**Deutsches Elektronen-Synchrotron DESY
Notkestraße 85, D-22607 Hamburg/Germany**

Additional information may be obtained from Prof. P.M. Zerwas, tel. 040.8998.2416/2413 or via e-mail peter.zerwas@desy.de.

TEXAS A&M UNIVERSITY

POSTDOCTORAL POSITION IN EXPERIMENTAL HIGH ENERGY PHYSICS

The experimental high energy physics group at Texas A&M University has a postdoctoral position available starting in fall 2000 to work on the CDF experiment at Fermilab. Data taking with a fully commissioned detector is expected to begin in March 2001. The Texas A&M University responsibilities on CDF include commissioning of the Silicon Vertex Detector (SVX-II) data acquisition system and development of muon reconstruction and tau identification code in C++ for Run II. In addition, our group leads physics analyses searching for Supersymmetry. Candidates must possess a Ph.D. in particle Physics and have a demonstrated ability pertinent to the above activities. Salary will be commensurate with the candidate's experience.

Applications (resume, list of publications) and three letters of recommendation should be sent via e-mail (preferably as a post-script file) to kamon@physics.tamu.edu, followed by a paper copy Dr. Teruki Kamon, Department of Physics, Texas A&M University, College Station, TX 77843-4242. The deadline for a Fall 2000 appointment is July 31, 2000.

Texas A&M University is an Affirmative Action/Equal Opportunity Employer, committed to excellence through diversity. Texas A&M University particularly invites applications from minorities, women, veterans and persons with disabilities.

UNIVERSITY of GLASGOW

DEPARTMENT OF PHYSICS AND ASTRONOMY

RESEARCH ASSOCIATES IN PARTICLE PHYSICS

£16,286 - £24,479

Two new positions are available, initially from Oct 1 2000 for up to two years with the possibility of extension. We are looking for outstanding applicants with experience in Experimental Particle Physics who have, or are about to obtain, a PhD. The posts are based in Glasgow but will involve periods of work in Geneva and at RAL for the LHCb post.

The first is on the ATLAS experiment preparations for physics at the Large Hadron Collider. The Glasgow group is involved in forward semiconductor tracker silicon module construction and testing, and in establishing advanced computing resource requirements and simulation studies in preparation for physics analysis. The second position is to work with the Glasgow group on the LHCb experiment. We have made major contributions to the Research and Development of particle identification using the RICH detector. We plan a continuing programme of physics simulation, software development together with photon detector development and implementing the mechanics and alignment of the upstream RICH in LHCb.

For further particulars see our website at <http://ppewww.ph.gla.ac.uk/rafpds.html> or E-mail: d.saxon@physics.gla.ac.uk Applications, including CV, publications list, and the names and addresses of two referees, should be sent by 27 July 2000, to Prof. D H Saxon, Kelvin Building, University of Glasgow, Glasgow G12 8QQ, Scotland.

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**UNIVERSITY OF COPENHAGEN
NIELS BOHR INSTITUTE FOR
ASTRONOMY, PHYSICS, AND GEOPHYSICS**

Postdoctoral position in Experimental Particle Physics

A postdoctoral position is available from October 1, 2000 with the Experimental Particle Physics group at the Niels Bohr Institute, University of Copenhagen. The position is for two years with a possibility of prolongation, however, not exceeding five years.

The particle physics group is located at the Niels Bohr Institute, and its experiments ALEPH and ATLAS are performed at CERN and HERA-B at DESY.

It is expected that the appointed candidate will participate in the HERA-B activities. More specific she/he should contribute to the physics analysis and the group's second level trigger involvement. The position also demands participation in the university teaching program. The candidate will be based in Copenhagen.

Salary is set by agreement between the Ministry of Finance and AC (The Danish Confederation of Professional Associations). The annual salary depends on seniority, and the scale ends at a yearly salary of DKK 313.808 after contributions to the pension scheme and including a seniority independent yearly increment of DKK 39.746.

Deadline for applications is August 28, 2000, at noon.

Further information can be obtained from Professor Jørn Dines Hansen (dines@nbi.dk). If you consider applying for the position, please read the full text of the advertisement on the Internet address <http://www.ku.dk/led/stillinger/>.

Applications should be sent to:

**Professor Jørn Dines Hansen
The Niels Bohr Institute
Blegdamsvej 17, DK-2100 Copenhagen
Denmark.**

**EXPERIMENTAL PARTICLE
OR NUCLEAR PHYSICS
Argonne National Laboratory**

Resumes are invited for three experimental postdoctoral positions in the HEP Division at Argonne National Laboratory to start in summer or fall 2000. Well-qualified candidates will also be considered for higher level appointments. Argonne's projects in experimental physics include CDF, ZEUS, Soudan 2, STAR, MINOS and ATLAS. Resumes are especially sought for work on the STAR detector at RHIC and on the MINOS detector.

For STAR, the major research focus will be the determination of the gluon spin distribution in the proton within the RHIC spin program. Argonne physicists are collaborating on the construction of the STAR endcap electromagnetic calorimeter, which will play a vital role in measuring the gluon spin. Argonne will focus on the construction and testing of a scintillator strip shower maximum detector. Participation in ongoing experimental programs involving spin is also expected. MINOS will make the definitive exploration of neutrino oscillations and mass in the region suggested by atmospheric neutrino observations. Argonne has major responsibilities for the construction of scintillator modules and readout electronics, as well as planning for the physics exploitation of the detector. The experiment will begin taking data in 2003. Work will be centered primarily at Argonne, but with visits to FNAL and the Soudan Mine.

Candidates should have obtained a Ph.D. in experimental nuclear or high energy physics. Applicants are requested to send a list of publications, curriculum vitae, and the names of 4 references to: **Susan Walker, Box HEP-210675-40, Employment and Placement, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439. Fax: 630-252-9388. TDD: 630-252-7722.**

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- UNIX and Real-Time Operating Systems such as VxWorks, LynxOS or ChorusOS
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Swiss or part of the European Community, please send your resume to:

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Tel: +41.22.879.51.00
E-mail: ces@ces.ch

ASSOCIATE DIRECTOR

(Position #AR0001)

Accelerator Division Associate Director, Jefferson Lab

The Thomas Jefferson National Accelerator Facility (Jefferson Lab) is seeking qualified candidates for the position of Accelerator Division Associate Director. The successful candidate must have broad expertise in a relevant scientific or technological discipline, and have made internationally recognized contributions to their field. Candidates must furthermore have demonstrated managerial skills suited to leading a world class scientific organization.

Jefferson Lab, located in Newport News, Virginia, is a Department of Energy laboratory operated by the Southeastern Universities Research Association. Jefferson Lab operates a major experimental facility, the Continuous Electron Beam Accelerator (CEBAF), for the medium energy nuclear physics community. This 6 GeV high duty cycle (cw) accelerator is based on a large-scale application of superconducting rf technology. The CEBAF experimental program, involving over 1600 users worldwide, began in 1994. Jefferson Lab designed and now operates the world's highest average power (kilowatt-level) tunable, infrared free electron laser (FEL) as a user facility for the scientific, industrial and defense communities. The Laboratory is currently undertaking the design and delivery of the superconducting linac and cryogenic systems for the Spallation Neutron Source being built at Oak Ridge National Laboratory.

The Accelerator Division Associate Director, who leads a scientific and technical staff of over 300 persons, is responsible for the operation and upgrades of both CEBAF and the FEL. Design activities for upgrading CEBAF to 12 GeV, and significantly extending the FEL power and wavelength range are presently underway. The responsibilities of the Accelerator Division Associate Director include promoting Jefferson Lab within the broader scientific community; developing productive collaborations with other institutions; and maintaining an appropriate balance between ongoing activities and new initiatives to assure that the laboratory remains at the forefront of its core technologies. Serving on the Director's Council, the Associate Director is an integral member of the laboratory's senior management, responsible for establishing the laboratory's future programs and direction.

Minimum qualifications include a PhD or equivalent in a relevant scientific/technological field and extensive applicable experience, including substantial managerial experience in a large organization.

Our search will continue until an appropriate candidate is selected. For prompt consideration, applications should be sent by October 1, 2000 to: Jefferson Lab, Attn: Employment Manager, 12000 Jefferson Ave., Newport News, VA 23606. For further information on this position, applicants may contact Dr. Charles Sinclair, Search Committee Chair, at 757-269-7679 or e-mail sinclair@jlab.org.

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Thomas Jefferson National Accelerator Facility



Universität Hamburg

Fachbereich Physik, II. Institut für Experimentalphysik
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The Physics Department at the University of Hamburg invites applications for the tenure position of a Full Professor (C4 Professur)

Bjørn Wiik Professorship in Accelerator Physics

named in honour of the late distinguished particle and accelerator physicist B. H. Wiik. We seek candidates with a strong commitment to both research and teaching and with an international reputation in the physics of high energy particle accelerators and/or synchrotron radiation sources. The successful candidate is expected to assume a leading role in the research and development related to the proposed superconducting linear electron-positron collider TESLA and the integrated X ray Free Electron Laser as well as in the R&D work at the TESLA Test Facility and the associated vacuum-ultraviolet FEL facility. A close cooperation with the accelerator physics group at DESY is considered essential. The present tradition at Hamburg to deeply involve graduate (diploma and PhD) students in the research activities related to these ambitious projects shall be continued and expanded. Applications from highly qualified persons of German or non-German nationality are equally welcome.

The teaching obligations at Hamburg University amount to 8 semester week hours and comprise teaching of undergraduate and graduate students as well as supervision of diploma thesis work. In the framework of opening the university to foreign students, the lectures and exercises can be held in English, especially for students in higher semesters. Good knowledge of the German language is desirable but not a condition.

Candidates should submit a letter of application outlining their qualifications and interests with a resume and publications list. The material submitted should provide evidence of the ability to carry out an independent research program and of teaching skills.

The University of Hamburg is an equal opportunity/affirmative action employer and welcomes applications from qualified women.

In case of equal qualifications preference will be given to handicapped persons.

Applications should be sent by **August 30, 2000** to **Präsident der Universität Hamburg, Referat Personal & Organisation -332.11/12-, Kennziffer 1696/4, Moorweidenstrasse 18, D-20148 Hamburg.**

E-mail information: peter.schmueser@desy.de

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE Accelerator Physicist/RF Engineer

We have an opening for an accelerator physicist/RF engineer to join our R+D activities on linear colliders. Our group is currently involved in international collaborations with DESY (TESLA) and CERN (CLIC). The successful candidate will be expected to contribute to these programmes which involve the construction of accelerator components.

In addition to a sound knowledge of beam theory and experience with computer simulation codes, the successful candidate should be familiar with accelerator related technologies. In particular, previous experience with radio-frequency cavities (room temperature and/or superconducting), microwave measurement techniques and beam instrumentation is required.

The candidate will be expected to assume the responsibility of project leadership in the construction of accelerators or accelerator components.

Candidates should have several years of experience in the field of accelerators and should have obtained an Engineering Diploma (level Grande Ecole) or a Ph.D. in physics or electrical engineering. A good command of the English language is essential. Salary will be dependent on experience. Recruitment will initially be on a fixed-term basis.

Please write with CV to: **Service du Personnel, Laboratoire de l'Accélérateur Linéaire, B.P. 34, 91898 Orsay cedex, France.**

Informal enquiries can be addressed to Dr. T. Garvey
(Tel: 33 01 64 46 89 61; e-mail garvey@lal.in2p3.fr)

Laboratori Nazionali di Frascati dell'INFN European Union "Improving" Programme Marie Curie Individual Fellowships

We invite applications for postdoctoral fellowships "category 30" (one to two years) in theoretical, experimental physics (high energy physics, astroparticle physics, nuclear physics, synchrotron radiation and gravitational wave detection), and accelerator physics at the Laboratori Nazionali di Frascati of INFN (Istituto Nazionale di Fisica Nucleare).

The 1 GeV e+e- machine DAPHNE (Phi factory) to study CP violation and hypernuclear physics is currently under commissioning.

More detailed information can be obtained from: A. Antonelli, tel. +39 06 9403 2787, e-mail: antonella.antonelli@lnf.infn.it and from our web site: www.lnf.infn.it/lnfadmin/job/Euf.html.

Applicants must be nationals of a European Union member state (excluding Italy) or an associated state, or have been residing in the EU for at least the last five years, age under 35 and have a PhD degree (or equivalent level of education) or 4 years' full-time research activities at post-graduate level. Furthermore the candidate should not have carried out research activities in Italy for more than 12 months in the last two years. More information can be obtained visiting the EU web site www.cordis.lu/improving.

Fellows will be employed under the EU's general conditions governing Marie Curie Individual fellowships and will receive an allowance in Euro per month to cover subsistence and mobility expenses, tax and social security contributions and cost of attending conferences, travel expenses, etc... Total monthly subsistence allowance will be of about 3800 Euro (plus a mobility allowance of 400 Euro per month).

Candidates should send a letter of application (where the activity of interest must be specified), a C.V. and two letters of recommendation, **by July 31st**, to:

Marie Curie Individual Fellowships, Dr.ssa A. Antonelli
LNF - INFN - Via E. Fermi 40 - 00044 - Frascati, Italy
Tel. +39 06 9403 2373 or 2787 - Fax +39 06 9403 2475
e-mail: antonella.antonelli@lnf.infn.it

Selected candidates will be asked to apply to the next round of EU selection which has the closing date of September 13th, 2000.

Computer/Information Systems

C++/DATABASE DEVELOPER

Argonne National Laboratory, one of the United States' premier research and development organizations, seeks a self-motivated team player to develop core software that will support data analysis for the ATLAS high energy physics experiment.

The analytical problem-solver must be proficient in C++ and UNIX. Candidates must also be familiar with object-oriented design patterns and with database systems. Solid written/verbal communication and interpersonal skills are needed, as well as insight into emerging technologies. Desirable skills include proficiency with other programing and scripting languages (Java, FORTRAN, Python).

Knowledge and skills for this position would be best acquired through a PhD in Computer Science, High Energy Physics, or Nuclear Physics or through a Master's or Bachelor's Degree in Computer Science with appropriate experience.

Argonne provides an excellent compensation/benefits package. For consideration, please send a detailed resume, salary history, and the names/addresses of four references to Susan Walker, Box HEP-210529-60, Employment and Placement, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439. Fax: 630-252-9388. TDD: 630-252-7722. Argonne is an Equal Opportunity/Affirmative Action Employer.

For additional information, please refer to Argonne's Home Page on the internet <http://www.anl.gov/welcome.html>.



UNIVERSITY OF VICTORIA/TRIUMF

POSTDOCTORAL RESEARCH ASSOCIATE POSITIONS IN EXPERIMENTAL HIGH ENERGY PHYSICS

The University of Victoria and the TRIUMF Laboratory each have a vacancy for a Research Associate position in Experimental Particle Physics to work on analysis and software development for the OPAL and ATLAS experiments. The positions have a term of two years with a possible one year extension and are available immediately.

The High Energy Physics group at Victoria closely collaborates with the ATLAS group at the TRIUMF Laboratory designing, constructing and testing liquid argon hadronic calorimetry for the endcap region of the ATLAS detector. The successful candidates are expected to take a leading role in developing object oriented reconstruction software for hadronic calorimetry. The candidates are also expected to take an active interest in the test beam R&D program and physics simulations.

The TRIUMF Laboratory is responsible for the construction of one complete endcap hadronic calorimeter. The development of a software group at TRIUMF and Victoria to exploit the hardware is our highest priority. The University of Victoria is exploring the use of a LINUX cluster and a new IBM SP high performance computer to develop a Canadian centre for ATLAS analysis. Victoria is taking a leading role in developing an OO version of the test beam reconstruction software. The Victoria group is a member of the OPAL collaboration with active interests in triple gauge couplings and tau physics. Research Associates employed by Victoria will have the opportunity to contribute to OPAL physics analysis.

Candidates should indicate on their application which institute they would prefer to be employed by - the University of Victoria, Victoria BC, or TRIUMF, Vancouver, BC. The candidate will be located at the institute where they are employed.

Candidates should have a recent Ph.D. in particle physics and experience with UNIX and LINUX operating systems. Familiarity with the C++ programming language would be an asset. Further inquiries can be made to Prof. M. Lefebvre (lefebvre@uvic.ca), Dr. C. Oram (oram@triumf.ca) and Dr. R. Sobie (rsobie@uvic.ca).

Interested candidates should, prior to 31 August 2000, send a curriculum vitae and arrange for two letters of recommendation to be sent to:

Prof. Richard Keeler

Department of Physics and Astronomy, University of Victoria,
P.O. Box 3055 Stn CSC, Victoria, BC CANADA V8W 3P6

e-mail: rkeeler@uvic.ca

Telephone: (250) 721-6156

Fax: (250) 721-7752

Applications will be accepted after the deadline until the positions are filled. In accordance with Canadian immigration regulations, priority will be given to Canadian citizens and permanent residents. All qualified individuals are encouraged to apply.

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SYSTEMS & ENGINEERING OPPORTUNITIES

Synchrotron Radiation Facility Daresbury Laboratory, Warrington

Daresbury Laboratory is responsible for the operation and continuing development of the SRS national research facility in Cheshire which is guaranteed to operate for another 7 years. This facility provides state of the art experimental facilities for a large community of academic and industrial scientists exploiting the unique properties of light emitted from a 2 GeV electron storage ring. Scientists and engineers at Daresbury will also play a key role in the design of the new synchrotron facility to be constructed at Rutherford Appleton Laboratory, Oxfordshire. The new synchrotron project is a joint venture between the UK and French Government and the Wellcome Trust. The following systems and engineering opportunities exist at Daresbury to support the advanced accelerators, beamlines and experimental programmes on the SRS and to contribute to the design of the new synchrotron.

Electrical Engineering Group Leader : Reference VND023/00

You will take overall responsibility for safe and efficient electrical engineering and power converter operations on the SRS facility which includes three high energy electron accelerators driving an experimental facility of 12 beamlines and 30 experimental stations. As a Chartered Engineer with an honours degree in electrical engineering, and with a proven track record of achievement, you will have the experience and maturity to manage a substantial team of technical staff and the innovative ability to make a major contribution to the development of power converters for accelerator based research facilities. The starting salary will be between £30,000 and £38,000 depending on experience.

Electronics and Controls Group Positions

The following three positions are in the Electronics and Controls Group which provides design, development and operational support to the SRS and develops new projects. The SRS control system is currently undergoing a major development to replace the original controls based on three mini computers with a new system using PC clients and embedded servers. There are also ongoing developments in distributed control system design, digital control of power converters and signal processing of beam position detectors.

Controls Systems Engineer : Reference VND026/00

You will be working on the hardware and software design of embedded control systems in all parts of the accelerator and experimental complex. Some experience in system design and programming is essential although applications from recent graduates will be considered. Previous experience with some or all of OS9, Visual Basic, 'C', and Unix systems will be advantageous. The starting salary will be between £19,000 and £24,000 depending on experience.

Systems Manager : Reference VND027/00

Under the supervision of a Senior Systems Engineer, you will be responsible for the administration, maintenance and support of all the installed control system computers. This work will include provision of software solutions to specific applications problems and the management and development of databases used to record historical information on control system configuration and parameters. The starting salary will be between £19,000 and £24,000 depending on experience.

Software Engineer : Reference VND028/00

You will be working on major new codes to exploit modernisation of the integrated facility control system and the provision of new application packages to support the accelerator physics and operations team in maintaining the international competitiveness of the SRS. The starting salary will be between £19,000 and £24,000 depending on experience.

Further technical information on these positions is available from P.D.Quinn@dl.ac.uk (Electrical Engineering) and M.T.Heron@dl.ac.uk (Controls and Systems).

Progression within each salary range is dependent upon performance. A non-contributory pension scheme, flexible working hours and a generous leave allowance are also offered.

Application forms can be obtained from: Human Resources Division, Daresbury Laboratory, Daresbury, Warrington, Cheshire, WA4 4AD. Telephone (01925) 603864 or email recruit@dl.ac.uk, quoting the appropriate reference. More information about CLRC is available from CCLRC's World Wide Web pages at <http://www.cclrc.ac.uk>

All applications must be returned by 21 July 2000

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Postdoctoral Physicist

The HyperCP Group of the Physics Division at the Lawrence Berkeley National Laboratory has a postdoctoral physicist position available. The primary goal of HyperCP is to study CP symmetry in strange-baryon decays. The Berkeley group played a significant role in wire chambers, readout electronics, data acquisition, and is currently focusing on data analysis that poses outstanding computing challenges due to the very large data samples and delicate analyses. The group is also involved in KamLAND, a long-baseline neutrino oscillation experiment in Japan that will begin data taking in 2001.

A Ph.D. in particle physics and demonstrated strong potential for outstanding achievement as an independent researcher. The primary responsibility of this position will be physics analysis on HyperCP as well as some level of participation on KamLAND.

This is a two-year term appointment with the possibility of renewal. Applications, including CV, list of publications, description of skills, and three letters of recommendation should be sent via e-mail to gensciemployment@lbl.gov or mail to Lawrence Berkeley National Laboratory, 1 Cyclotron Road, MS 50-4037, Berkeley, CA 94720. Please reference Job# PH/012282/JCERN. E-mail inquiries to KRPrintup@lbl.gov.

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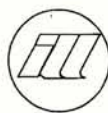
Your profile

You have a background of several years in experimental nuclear or particle physics, preferably with experience in fundamental neutron experiments and very low energy neutron beams/sources.

For further information please contact Dr. M. Daum, phone ++41 56 310 3668, e-mail: manfred.daum@psi.ch

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These positions represent an excellent opportunity for young postdoctoral scientist to develop their expertise, broaden their experience and interact with leading scientists from around the world. More experienced scientists on detachment may also be considered. The successful candidates will be highly motivated scientists having a PhD. They will be expected to carry out their own research programme, assist ILL users in conducting experiments and participate in the operation and development of particular instruments.

The vacancies exist in the following groups :

Ref. 00/27 : Time-of-Flight and High Resolution Group (TOF/HR)

Applicants should have a PhD in chemistry or physics. They must have an interest in instrumentation and have a sound practical knowledge of computing. The successful candidate will initially take joint charge of two very high resolution instruments, the back-scattering spectrometers IN10 and IN16.

Further information: Dr. A.J. Dianoux, Head of TOF/HR Group, tel: (33) 4.76.20.72.06; e-mail: dianoux@ill.fr Deadline for application: 31.08.2000.

Ref. 00/17 : Nuclear and Particle Physics Group (NPP)

At the Lohengrin spectrometer (PN1), a program was started to investigate very neutron rich nuclei produced in nuclear fission. Dedicated measurements comprise gamma ray spectroscopy of isotopes far from stability with the aim to determine ground state lifetimes, search for microsecond isomers and investigation of gamma and conversion electron transitions following beta decay. The successful candidate will share responsibility for the instrument PN1. He/she will participate in spectroscopic work on this instrument and collaborate in the project for measurements with the European MINIBALL set up. He/she will also join a project to design and build a dedicated germanium cluster array on the spectrometer.

Further information: Dr. H. Börner, Head of NPP Group : tel: (33) 4.76.20.73 94; e-mail: borner@ill.fr Deadline for application: 31.07.2000.

For these posts, the successful candidates will be offered fixed-term contract, the duration of which will under no circumstances exceed five (5) years. In addition to a competitive salary, certain benefits (reimbursement of removal expenses, adaptation allowance, etc.) may be offered.

Applications with curriculum vitae, list of publications and the names of two academic referees should be sent (quoting the appropriate reference) to the Head of the relevant Group.

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PARTICLE ACCELERATOR PHYSICISTS (TWO POSTS)

Daresbury Laboratory, Warrington

Opportunities exist for two physicists to join the small team who design, build and operate advanced high-energy particle accelerators, based at CLRC Daresbury Laboratory in North Cheshire.

At present the accelerator physics team supports the operation of the SRS, the UK national light source facility based on a 2 GeV electron storage ring, but it has in addition provided the design capability for feasibility studies on a more advanced replacement source that has now been funded. Recently support for the new UK initiative in accelerator research and development for electron linear colliders has also been initiated, intended to put the UK in a position to make a significant contribution to a future international high energy physics facility. You will be expected to make a major contribution in one of these new exciting areas. The comprehensive design phase of the new light source will commence shortly and you would be involved in a range of activities from particle beam dynamics through to component specification. Alternatively design work on advanced damping rings and collider simulation code development are possible, requiring close working with particle physicists and the various international design teams. As well as playing a major role in these activities you would also have the opportunity to participate practically in the ongoing support of the SRS.

We are looking for highly motivated scientists with an independent outlook, but who must be able to work in a team. You would be joining a laboratory with an international reputation to maintain, a challenge implying a determined commitment to work and a willingness to take on a variety of tasks, both experimental and theoretical. Previous accelerator experience, although welcome, is not essential, as full training in accelerator physics will be available. Career development opportunities will be available in this core professional activity of the CLRC.

You should have a good honours degree in physics or a closely related subject, or an equivalent qualification. Postdoctoral scientists are also encouraged to apply, as are final year undergraduates. A willingness to travel is essential and to participate in a large multinational collaboration is desirable.

Additional information is available from Mike Poole (m.w.poole@dl.ac.uk; (0)1925-603256) or Susan Smith (s.l.smith@dl.ac.uk; (0)1925-603260); also from <http://accelerator.dl.ac.uk/Ap/>

The salary ranges are between £14,850 and £21,850 and £18,620 and £26,600; salary on appointment is awarded according to relevant experience. A non-contributory pension scheme, flexible working hours and a generous leave allowance are also offered.

Application forms can be obtained from: Human Resources Division, Daresbury Laboratory, Daresbury, Warrington, Cheshire, WA4 4AD. Telephone (0)1925 603864 or email recruit@dl.ac.uk, quoting reference VND029/00. More information about CLRC is available from CCLRC's World Wide Web pages at <http://www.cclrc.ac.uk>



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**COUNCIL FOR THE CENTRAL LABORATORY
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RESEARCH ASSOCIATE Experimental High Energy Physics

The Department of Physics at Stanford University is inviting applications for a postdoctoral research associate to participate in a long baseline neutrino experiment, MINOS, utilizing a beam from Fermilab and a detector at Soudan in northern Minnesota.

The MINOS experiment is designed to be sensitive to $\nu_{\mu} \rightarrow \nu_e$ and $\nu_{\mu} \rightarrow \nu_{\tau}$ oscillations down to $\sin^2 2\theta = 0.01$ and to Δm^2 values below 10^{-3} eV^2 . Thus the experiment will be able to cover the full Super-K suggested region of oscillation parameter space. The neutrino beam will be produced by the protons extracted from the Fermilab Main Injector, a recently constructed 120 GeV proton synchrotron. The far detector will be a multi-kiloton magnetic iron/scintillator spectrometer in the Soudan mine in Minnesota, some 730 km away. The existing Soudan 2 detector will also form part of the experimental apparatus. This experiment was endorsed in 1995 by HEPAP as an important element of the future US high energy physics program. This endorsement has been reaffirmed by several subsequent reviews. The project has been baselined in the fall of 1998, and the conventional construction is well underway both at Fermilab and at Soudan. The installation of the detector in the Soudan mine should start in the spring of 2001 and the data taking before the end of 2003.

It is anticipated that the majority of the successful applicant's time will be spent in residence at Stanford, working mainly on MINOS simulations and design and construction of the detectors and neutrino beam elements. It is expected that the successful applicant will spend some time at Soudan during the installation and commissioning phase of the experiment. The initial appointment will be for three years with the possibility of an extension.

Interested applicants are requested to send three letters of reference and a resumé to:

**Professor Stanley Wojcicki, Stanford University,
Physics Department, Stanford, CA 94305-4060**

The applications will be accepted until September 1, 2000 or until the position is filled.

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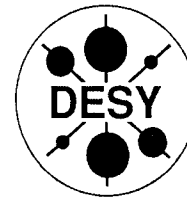
Laboratori Nazionali di Legnaro (Padova), Laboratori Nazionali del Gran Sasso (L'Aquila), Laboratori Nazionali del Sud (Catania) e Laboratori Nazionali di Frascati (Roma).

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Informations, requests for application forms, and applications should be addressed to Istituto Nazionale de Fisica Nucleare, Direzione Affari del Personale, Ufficio Borse di Studio - Casella Postale 56 - 00044 Frascati (Roma) Italia.

ISTITUTO NAZIONALE DI FISICA NUCLEARE
IL PRESIDENTE
(Prof. Enzo Iarocci)



Postdoc Position@NIC (DESY-Zeuthen)

The Group „Particle Physics“ of the John von Neumann Institute for Computing (NIC) at DESY-Zeuthen has an opening for a Postdoctoral Position (BAT IIa-O) in Theoretical Particle Physics.

The main interests of the NIC research group are in the non-perturbative aspects of quantum field theories, mainly Quantum-Chromodynamics on the lattice. The group has access to massively parallel supercomputers (APE, CRAY) and is involved in large scale numerical simulations. There is a close collaboration with the theory group at DESY-Zeuthen and the lattice gauge theory groups at the universities in Berlin.

The applicant should have a background in quantum field theory and have experience in lattice gauge theory, ideally also with numerical simulations. The successful candidate is expected to join the activities of the NIC research group and participate in the APE-project.

The position, starting 1.10.2000, is for two years with a possible extension. DESY welcomes in particular the application of qualified women. Handicapped applicants will be given preference to other applicants with the same qualifications. Candidates are invited to send their application including a curriculum vitae, list of publications as well as three letters of reference to

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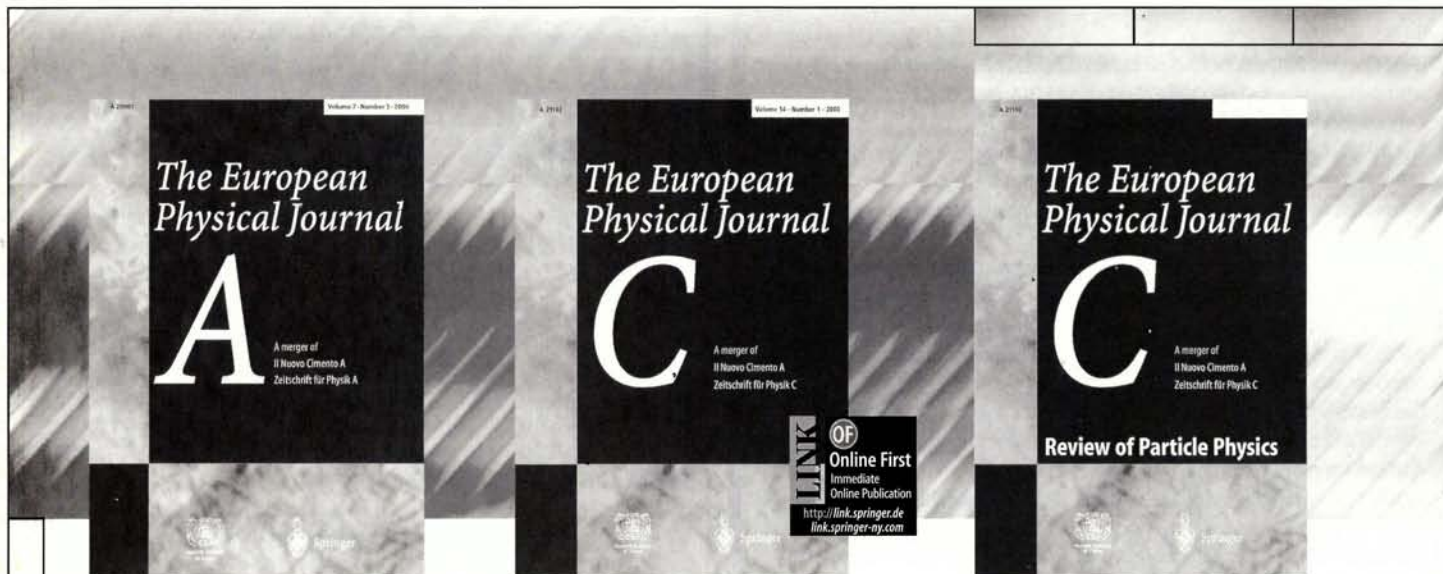
Personalabteilung, Notkestraße 85, D-22607 Hamburg

by 31 July 2000. For further information please contact K. Jansen, e-mail Karl.Jansen@cern.ch, Tel.: 0041-22-767-2421.

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Strange Beauty: Murray Gell-Mann and the Revolution in 20th Century Physics by

George Johnson (published by Knopf in the US: 0679437649, and by Jonathan Cape in the UK: 0224044273).

Murray Gell-Mann befriended me in Paris towards the end of my National Science Foundation postdoctoral junket and lured me to Pasadena. It was the year of the Eightfold Way, smack in the middle of Gell-Mann's two-decade reign as emperor of elementary particles. His brilliance was so intense that lesser folk, such as myself and my sidekick Sidney Coleman, had to ration our time with him. Not only did Gell-Mann devise the lion's share of today's particle lore, but on first acquaintance you would soon learn, through his painfully in-your-face erudition, that he knew far more than you about almost everything, from archaeology, birds and cacti to Yoruban myth and zymology. He once drew a false etymology of avocado, but his errors were so rare as to be cherished.

This book is a brave attempt to interweave two stories. One is the history of particle physics according to Gell-Mann, from the development of quantum field theory to the fall of the Superconducting Super-Collider (which he lamented) and the coincidental rise of string theory (which he championed). The other is a must-read account of the life of a truly fascinating character.

Explaining particle physics to the lay reader is a labour of Hercules. Johnson strives magnificently but doesn't always succeed. After a long explication of strangeness, he drops the ball by asserting that the Xi hyperon has strangeness +2. His exposition of the quark hypothesis is better: how they were invented and named by Gell-Mann; thought of independently by George Zweig, who called them "aces", had his paper rejected and soon left physics; how Gell-Mann vacillated for years between the interpretation of quarks as helpful mathematical fictions or as real and observable particles (they are neither); how quarks acquired their "colours", the change of which from patriotic to primary is given undue significance; and how they have become a crucial part of today's Standard Model of particle physics.

However, bloopers like "the briefer a particle's life span, the higher its energy", "in quantum theory every particle can be represented by a differently shaped wave", "neutrons and antineutrons [have] different



Murray Gell-Mann – erudition.

spins" and the allegation that mesons are fermions will annoy physicist readers and mislead others. To explain the meaning of parity violation, Johnson asks how a radio message sent to Martians could tell them which side is the left. Two simple answers are given, but they are said to cheat or to "violate the spirit of the game". Just what game is this?

Johnson portrays Gell-Mann's family origins in Galicia and Austria, and his father's difficult accommodation of life in the US, partly via his introduction of the curious hyphen. We see Gell-Mann evolve from an arrogantly precocious know-it-all, to a preppy pretender at Yale, to an aspiring then renowned theoretical physicist and, most recently, to a wealthy and charming curmudgeon with homes in Aspen, Santa Fe and Manhattan.

We follow his triumphant path through the reductionist subatomic world and his recent return to a childhood fascination with the richer world of "complex adaptive systems" consisting of such marvels as birds, jaguars and (says Johnson) the relationship between biographer and biographee. Along the way we learn how Gell-Mann wooed and wed two remarkable women, reared two difficult children and was almost jailed for receiving smuggled antiquities.

This tale of quarks and quirks is engagingly told, although Johnson often resorts to jarringly undocumented quotations. He has Gell-Mann saying: "But I do know everything"

to his classmates, "Where are the dotted eighth's?" at a concert, "I would rather starve" to his father's suggestion that he become an engineer, "The cross-sections are just details" to Dyson, "[Electromagnetism] doesn't do dirty little jobs for people" to Fermi, and so on. Was Johnson there at the time, like Edmund Morris's imaginary avatar who follows Reagan about in *Dutch*?

Much is made of the family's rejection of their heritage: neither father nor son wished to be regarded as Jews. Gell-Mann once attributed his name to the confluence of two Scottish rivers. I recall another incident when, as we were wandering about Hollywood, Stanley Mandelstam read the Hebrew sign on a butcher's shop and Gell-Mann immediately corrected his pronunciation of kosher. "I didn't know you were Jewish," said poor Stanley, to Murray's pained "What? Me Jewish?" (Here I adopt Johnson's conceit.) Why does Gell-Mann do this? Why does he refer to Israel as Palestine, and Jerusalem as the citadel of the Jebusites?

Another recurrent motif is Gell-Mann's sometimes extreme difficulty in putting thoughts to paper. He was almost unable to complete his one book *The Quark and the Jaguar*, and he never did write up his Nobel lecture. However, Johnson errs when he relates Gell-Mann's reluctance to disseminate his discovery of the Eightfold Way. The original version, a well circulated and often cited CalTech report, was created in just a few days.

In summary, I rather like this book. It explains why Gell-Mann is universally regarded as a great scientist, but only occasionally as a pompous prig. It describes his warmth and generosity toward his colleagues (Francis Low, Harald Fritzsch, John Schwarz and Yuval Ne'eman, among many others) and his problems with others (he alienated Zweig, belittled Julian Schwinger, detested Bram Pais, and his friendship with Dick Feynman turned sour). Most of all this book gives a new twist to the classic tale of a poor immigrant's son from the Bronx making it big in the US.

Sheldon Lee Glashow.

This review first appeared in the June issue of the American Journal of Physics. Reprinted with permission. Sheldon Lee Glashow, who shared the Nobel Prize for Physics in 1979, has been Higgins Professor of Physics at Harvard since 1979. He is joining the faculty of Boston University as the first Arthur G B Metcalf Professor of Science.

Lie Algebras in Particle Physics by Howard Georgi (2nd edn) Perseus 0 7382 023 9.

It is fortunate that Howard Georgi has decided to publish a revised and updated version of his famous book *Lie Algebras in Particle Physics*, the previous edition having appeared in 1982. In this case it may have been a non-trivial problem to decide whether significant changes to the text are pertinent, because, as the author himself points out in the preface to the second edition, "this has been an extremely successful book". Indeed, many generations of graduate students have learned from it the basic algebraic tools in SU and other such Lie algebras, which are at the core of the Standard Model and all of its conjectured extensions.

Besides a healthy evolution from old-fashioned typewriter fonts to modern LaTeX layout, the present edition includes numerous improvements in the presentation, as well as new material. Perhaps the most important piece of new material is an enlarged introductory chapter on finite group theory. This makes the book a little longer, but much more self-

contained, because a lot of the group-theory jargon – such as conjugacy classes, characters and the role of the permutation group and Young tableaux – is introduced in a simple form, where the student can see the nuts and bolts explicitly.

Finite groups appear in many physics problems, so their absence from the first edition was somewhat unfortunate. On the other hand, in its present form the book can be used as a rather complete group-theory textbook for particle physics students.

One of the distinctive reasons for the book's success had been the introduction of "physics-flavoured" chapters in which the algebraic techniques were put to work in simple yet important topics in high-energy physics. It is those physics chapters that have undergone comparatively major rewriting.

Keeping the essential outline of the first edition, one notes many changes in wording and emphasis, which reflects the author's desire to suppress anecdotal information – such as the hadron tables of chapter XVII in the first edition, while at the same time

making room for more useful theoretical applications. One good example is the description of algebraic constraints on the Higgs mechanism in various common unification models.

To summarize, the book's contents have been improved while the basic philosophy – introducing the mathematical tools in a way as concrete and "calculational" as possible – is kept almost intact. Prof. Georgi has managed to maintain a fresh and direct "lecture notes" style – something that students and teachers will surely value.

J L F Barbon, CERN.

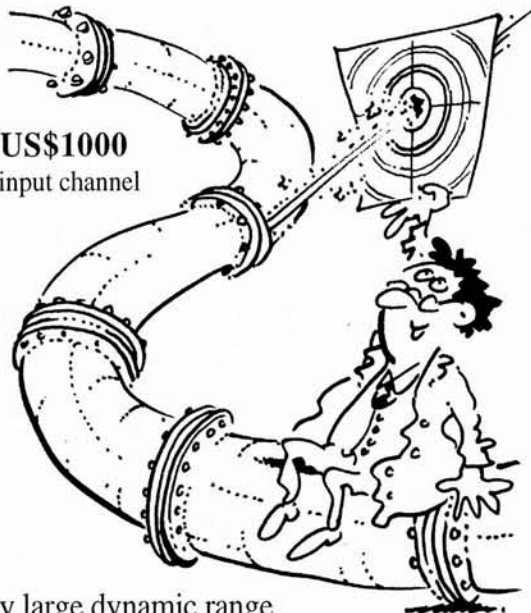
Statistical Motels for Nuclear Decay: from Evaporation to Vaporization by J Cole, Institut des Sciences Nucleaires, Grenoble, France. Institute of Physics Publishing, Bristol and Philadelphia 0750305126 (illus. hbk 368pp £80/\$130).

This book covers statistical models applied to the decay of atomic nuclei with emphasis on highly excited nuclei, which are usually produced using heavy ion collisions.

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