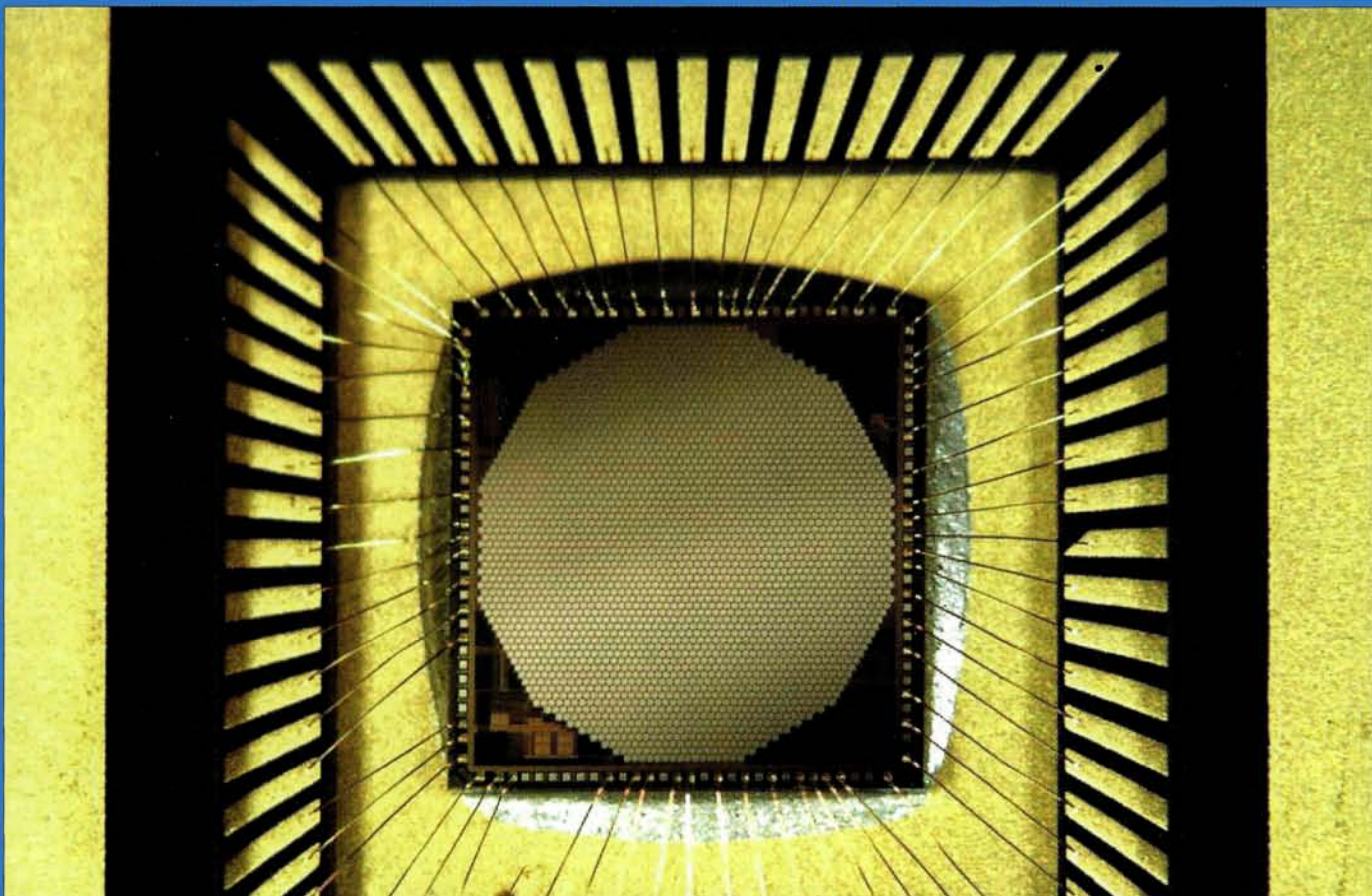
INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 44 NUMBER 6 JULY/AUGUST 2004



Pixel precision for gas detectors

NEW PARTICLES
Strangeness and charm in SELEX p6

1954-2004 CERN

ACCELERATORS
The FFAG concept comes of age p23


Save 10% on your Purchase of High & Ultra High Vacuum Products
Visit us online or Call for a Free Catalogue
MDC
VACUUM PRODUCTS CORPORATION
23842 Cabot Boulevard
Hayward, CA
U.S.A. 94545-1661
Toll-Free 1.800.443.8817
Fax 1.510.887.0626
e-mail: sales@mdcvacuum.com
Order direct from our factories and receive 10% off of our catalogue prices on MDC Flanges & Fittings, Valves, Roughing Components, Motion & Manipulation and Chambers, as well as ISI Electrical & Optical Ceramic-to-Metal Components
Limited time offer
Building-Blocks
for Vacuum Science and Technology
ISI
INSULATOR SEAL
a division of MDC Vacuum Products Corp.
6460 Parkland Drive,
Sarasota, FL
U.S.A. 34243
Toll-Free 1.800.548.9509
Fax 1.941.751.3841
e-mail: sales@insulatorseal.com
ISO 9001 : 2000
Registered Company
TÜV
www.mdcvacuum.com
www.insulatorseal.com

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

CERN Courier is distributed to member-state governments, institutes and laboratories affiliated with CERN, and to their personnel. It is published monthly, except for January and August, in English and French editions. The views expressed are not necessarily those of the CERN management.

Editor Christine Sutton
CERN, 1211 Geneva 23, Switzerland
E-mail: cern.courier@cern.ch
Fax: +41 (0) 22 785 0247
Web: cerncourier.com

Advisory board James Gillies, Rolf Landua and Maximilian Metzger

Laboratory correspondents:
Argonne National Laboratory (US): D Ayres
Brookhaven National Laboratory (US): P Yamin
Cornell University (US): D G Cassel
DESY Laboratory (Germany): Ilka Flegel, Petra Folkerts
Fermi National Accelerator Laboratory (US): Judy Jackson
GSI Darmstadt (Germany): G Siegert
INFN (Italy): Barbara Gallavotti
IHEP, Beijing (China): Tongzhou Xu
Jefferson Laboratory (US): Steven Corneliussen
JINR Dubna (Russia): B Starchenko
KEK National Laboratory (Japan): A Maki
Lawrence Berkeley Laboratory (US): Christine Celata
Los Alamos National Laboratory (US): C Hoffmann
NIKHEF Laboratory (Netherlands): Paul de Jong
Novosibirsk Institute (Russia): S Eidelman
Orsay Laboratory (France): Anne-Marie Lutz
PPARC (UK): Peter Barratt
PSI Laboratory (Switzerland): P-R Kettle
Rutherford Appleton Laboratory (UK): Jacky Hutchinson
Saclay Laboratory (France): Elisabeth Locci
IHEP, Serpukhov (Russia): Yu Ryabov
Stanford Linear Accelerator Center (US): Neil Calder
TRIUMF Laboratory (Canada): Michael Craddock

Produced for CERN by Institute of Physics Publishing Ltd
Institute of Physics Publishing Ltd, Dirac House, Temple Back, Bristol BS1 6BE, UK
Tel: +44 (0)117 929 7481; E-mail: jo.nicholas@iop.org
Web: iop.org

Publishing director Richard Roe
Publisher Jo Nicholas
Art director Andrew Giaquinto
Senior production editor Ruth Leopold
Technical illustrator Alison Tovey
Display advertisement manager Jonathan Baron
Recruitment advertisement manager Jayne Purdy
Display sales Ed Jost
Advertisement production Joanne Derrick, Katie Graham
Product manager Claire Webber

Advertising Jonathan Baron, Jayne Purdy or Ed Jost
Tel: +44 (0)117 930 1265
E-mail: sales@cerncourier.com
Fax: +44 (0)117 930 1178

General distribution Jacques Dallemagne, CERN, 1211 Geneva 23, Switzerland. E-mail: courrier-adressage@cern.ch
In certain countries, to request copies or to make address changes, contact:
China Chen Huaiwei, Institute of High-Energy Physics, PO Box 918, Beijing, People's Republic of China
Germany Gabriela Heessel or Veronika Werschner, DESY, Notkestr. 85, 22603 Hamburg 52. E-mail: desypr@desy.de
Italy Loredana Rum or Anna Pennacchietti, INFN, Casella Postale 56, 00044 Frascati, Roma
UK Mark Swaisland, CLRC, Daresbury Laboratory, Keckwick Lane, Daresbury, Warrington WA4 4AD. E-mail: m.swaisland@dl.ac.uk
US/Canada Published by *Cern Courier*, 6N246 Willow Drive, St Charles, IL 60175. Periodical postage paid in St Charles, IL. Fax: 630 377 1569. E-mail: vosses@aol.com
POSTMASTER: send address changes to: Creative Mailing Services, PO Box 1147, St Charles, IL 60174

Published by European Organization for Nuclear Research, CERN, 1211 Geneva 23, Switzerland. Tel: +41 (0) 22 767 61 11
Telefax: +41 (0) 22 767 65 55

Printed by Warners (Midlands) plc, Bourne, Lincolnshire, UK

ISSN 0304-288X

CERN COURIER

VOLUME 44 NUMBER 6 JULY/AUGUST 2004

Was this a gamma-ray burst? p12

New designs on FFAGs p23

LBNL appoints Steven Chu p33

Cover: *The gas pixel detector – electronics to read out the charge-collection anode of a micropattern gas detector have been integrated with the pixelized anode in a single chip designed and built at INFN, Pisa (p15).*

INPUT

CERN

Aymar outlines new seven-point strategy

CERN's director-general Robert Aymar presented a seven-point scientific strategy for the organization at the 128th session of the CERN Council on 18 June. Completion of the Large Hadron Collider (LHC) project, with start-up on schedule for 2007, heads the list. This is followed by the consolidation of existing infrastructure at CERN to guarantee reliable operation of the LHC. The third priority is an examination of a possible future non-LHC experimental programme.

Fourth on the list is a role for CERN in the growing coordination of research in Europe. Aymar cited as examples the Coordination of Accelerator Research in Europe (CARE) project, which could contribute to an LHC upgrade by around 2012, and the EUROTEV project through which CERN will participate in generic R&D issues related to a possible future linear collider. Both of these projects are partly financed by the European Union.

The fifth priority is the construction, starting in 2006, of a linear accelerator injector at CERN to provide more intense beams for the LHC, followed by an intensified R&D effort towards a compact linear collider, or CLIC. This novel accelerator technology under development at CERN could open the way to much higher energies than are available today. Aymar is appealing to laboratories around the world to join the project, and has so far received 18 expressions of interest.

The 128th CERN Council meeting heard about installation plans for the LHC. Tests on installing magnets in the LHC tunnel were carried out earlier this year.

The seventh and final point in the new strategic plan is to prepare a comprehensive review of CERN's long-term activity, to be available by 2010 when results from the LHC will have given a first description of the landscape of particle physics for years to come.

The current status of the LHC project was the subject of a report at the same session by Lyn Evans, the LHC project leader. The programme for installation of the LHC is currently being reviewed, following a delay in installing the distribution line for the cryogenic liquids that will cool the machine to 1.9 K. Difficulties have been solved, and the contractor has delivered a new schedule that foresees completion of the distribution line by February 2006, with two octants fully installed by the end of 2004. This compresses the overall schedule, which now requires the installation of two octants at a time to make up for the delay. However, Evans strongly reaffirmed the intention to start up the LHC in 2007, with first collisions in the summer. He also drew attention to the global collaboration that is making the LHC a reality. Most of the components from non-member states are now complete.

JLAB

Experiments pass the one-hundred mark

A decade after achieving its first beam, the US Department of Energy's Thomas Jefferson National Accelerator Facility completed data collection on its 100th and 101st experiments. The pair of experiments, named "Quark propagation through cold QCD matter" and "Q^2 dependence of nuclear transparency for incoherent ρ^0 electroproduction", ran simultaneously in Jefferson Lab's Hall B from December 2003 to early March this year.

The 100th experiment probed quantum chromodynamics (QCD), the theory of the strong interaction, with emphasis on two of the fundamental processes of QCD: hadronization and gluon emission from quarks. The experiment made use of the Continuous Electron Beam Accelerator Facility (CEBAF), essentially to knock single quarks out of hadrons. The energy that the struck quark absorbs in the collision not only knocks the quark out of the particle it was bound within but also creates new quarks and gluons. At least one of these new quarks pairs up with the original quark, while the rest join to form other multi-quark particles – the process of hadronization.

Members of the CEBAF Large Acceptance Spectrometer (CLAS) collaboration are studying this process to explore both how long it takes for the created quarks to pop into existence and combine into new particles, and exactly how these new particles are created. To this end, the experiment used five different targets composed of nuclei of various size: deuterium, carbon, iron, tin and lead. Understanding the process of hadronization inside the nucleus through such measurements may provide a clearer understanding of quark confinement.

The 101st experiment was a search for "colour transparency". According to QCD, pointlike colourless systems, such as a meson with a pointlike configuration produced in an exclusive process, should be able to travel through nuclear matter without interacting with other particles. When this happens the medium the particles are travelling through is said to be colour transparent.

In this experiment the team looked for ρ-mesons that were created when the electrons interacted with target nuclei. Some of these mesons may have acted as pointlike colourless systems; detecting them would provide a long-sought-after clear indication of the onset of colour transparency.

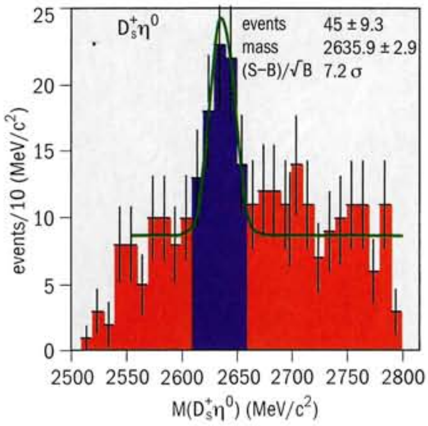
FERMILAB

SELEX finds a new charm-strange meson

A new narrow charm-strange meson – a charm quark bound with a strange antiquark – has been found by the SELEX experiment at Fermilab. The new particle is a heavier relative of similar states found in other experiments last year, and its puzzling behaviour adds another chapter to the continuing story of this intriguing family of mesons.

In spring 2003 the BaBar experiment at SLAC announced the discovery of a new charm-strange meson, the $D^+_{sJ}(2317)$, which was swiftly confirmed by CLEO at Cornell and BELLE at KEK. CLEO also found evidence for the existence of a heavier partner, with a mass slightly more than 40 MeV higher. While these mesons had been predicted theoretically, their masses were lower and their lifetimes longer than expected (*CERN Courier* June 2003 p6, July/August 2003 p8). Following these announcements, the SELEX collaboration began to re-examine its own data from fixed-target collisions at Fermilab's Tevatron.

SELEX, which had stopped data-taking in 1997, was designed to make high-statistics studies of the production of charm particles in Fermilab's charged hyperon beam. In this most recent study the collaboration analysed a sample of nearly 10^{10} interactions produced by Σ^-. In particular, the team used events containing decays of the charm-strange ground state, $D^\pm_s \rightarrow K^+K^-\pi^\pm$. To search for new excited states of the D^+_s they selected events in which it was produced together with an eta meson, identifying the eta through the two photons to which it decays, $\eta \rightarrow \gamma\gamma$. Then, when the team plotted the mass spectrum of $D^+_s\eta$ events, they found a clear peak of some 49 events, with a significance of 7.2 σ, at a mass of 2635.9 ± 2.9 MeV/c^2 (Evdokimov *et al.* 2004).



The mass distribution for the $D^+_s\eta^0$ shows a clear peak at 2635 MeV/c^2.

As a particle of this mass could also decay to D^0K^+ the team searched for this decay mode in those events in the Σ^- sample that contained the decay $D^0 \rightarrow K^-\pi^+$. The events selected in this way clearly showed the state $D^+_{sJ}(2573)$, already known, but also revealed a peak with 14 events at the slightly higher mass of 2613.5 ± 1.9 MeV/c^2. Combining the results of the two decay modes – $D^+_s\eta$ and D^0K^+ – indicates the existence of a new state, the $D^+_{sJ}(2632)$, with a mass of 2362.6 ± 1.6 MeV/c^2 and a very narrow width. Just why the new state is so narrow remains unclear, as it is massive enough to decay easily to D^0K^+. It is also surprising that this decay mode is dominated by the decay to $D^+_s\eta$. However, as the SELEX team points out, if the new state does belong to charm-strange spectroscopy in the usual way, it should have a closely spaced partner. The challenge is now on to investigate this spectroscopy thoroughly.

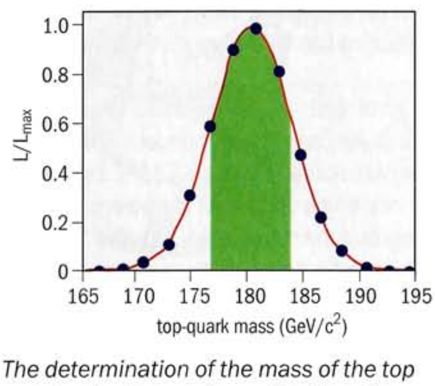
Further reading

A V Evdokimov *et al.* 2004 SELEX collaboration http://www.arxiv.org/hep-ex/0406045 (Fermilab-pub-04/087-E).

D0 sharpens its top-quark measurement

The D0 collaboration at Fermilab has applied a new technique for measuring the mass of the top quark that yields a more precise result than previously. The new result affects constraints on the mass of the Higgs boson, increasing slightly the most likely value of its mass.

In the D0 experiment pairs of top quarks and antiquarks – $t\bar{t}$ – are produced in head-on proton–antiproton collisions in the Tevatron. The t ($\bar{t}$) swiftly decays to a bottom quark, b ($\bar{b}$), and a $W^+(W^-)$ boson. In this new analysis the team has re-examined events from Run I in which one of the W particles decays into a charged lepton (electron or muon) and a neutrino, while the other decays into a quark and an antiquark. The new technique is based on ideas developed several years ago by Kunitaka Kondo at Waseda University in Japan, and independently by Richard Dalitz and Gary Goldstein at Oxford. The method gives more weight to well measured events and allows more information to be extracted from each event. Basically, the team calculates as a function of the top mass the probability that the measured variables in any event correspond to a signal. The best estimate of the mass is then given by the maximum of the product of these probabilities.



The determination of the mass of the top quark using the maximum-likelihood method in the new analysis.

The new analysis yields an improvement in statistical uncertainty for this data sample that is equivalent to collecting 2.4 times as much data. The result for M_t is 180.1 ± 5.3 GeV/c^2, which, when combined with the dilepton sample also collected by D0 in Run I, gives $M_t = 179.0 \pm 5.1$ GeV/c^2, and a new world average of 178.0 ± 4.3 GeV/c^2 (D0 collaboration 2004). The effect on constraints on the mass of the Higgs boson is to increase the most likely value from 96 to 117 GeV/c^2. This is clear of the mass range that is excluded experimentally.

The method used is now being applied to data collected in Run II, in both the D0 and CDF experiments, offering the possibility of an ultimate precision on the top-quark mass of about 2 GeV/c^2.

Further reading

D0 collaboration (V M Abazov *et al.*) 2004 *Nature* **429** 641.

KEK

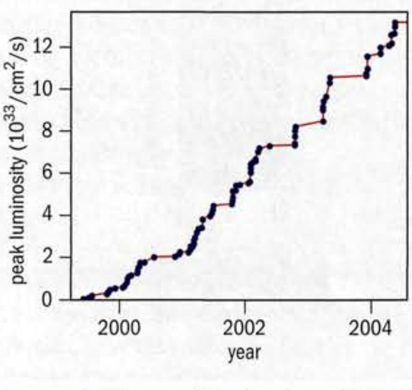
B-factory improvements deliver 1 fb^{-1} a day to Belle

With a peak luminosity that now exceeds $1.3 \times 10^{34}/cm^2/s$, KEKB, the KEK B-factory, is delivering more than 1 fb^{-1} per day to the Belle experiment. This peak luminosity is equivalent to the production of 14 B-meson – anti-B-meson pairs every second, and Belle is now accumulating approximately one million B pairs every day.

KEKB, which consists of an 8 GeV electron ring and a 3.5 GeV positron ring, started operation in 1999. Since then the performance of the facility has been steadily improved by increasing the currents of the electron and positron beams that are stored in the rings, and by using solenoidal coils wound over the entire positron ring to suppress the photoelectron cloud that was previously producing an instability. Since January this year the machine has been operating in a "continuous injection mode", where beam particle losses are compensated by injecting beam from the linac injector without interrupting data taking at Belle. This new mode of operation has successfully enabled KEKB to deliver 30% more integrated luminosity to Belle, and led to the new record of 1 fb^{-1} per day. Belle has already accumulated a total of more than 260 fb^{-1} since the beginning of the experiment.

Thanks to this huge data rate, Belle reported charge–parity (CP) violation in the B-meson system in 2001, at the same time as the BaBar experiment at SLAC, and has continued to improve the precision of $\sin 2\phi_1$ ($\sin 2\beta$), the fundamental CP violation parameter of the Standard Model. In addition, last year Belle measured a value for the CP violation parameter in $B \rightarrow \phi K_S$ decay that differs from the Standard Model prediction by 3.4 standard deviations. A more precise measurement based on more data will be reported this summer. Since a deviation from the Standard Model prediction for this parameter would be an unambiguous indication of new physics, Belle's new result is eagerly awaited by the particle-physics community.

The side-by-side electron and positron rings in the KEKB collider. (Photo courtesy of KEK.)



The trend of the peak luminosity at KEKB. It exceeded $1 \times 10^{34}/cm^2/s$ in May 2003, marking a new era for particle colliders.

Latest K2K results support neutrino oscillations

K2K, the KEK to Kamioka long-baseline neutrino-oscillation experiment, has announced results based on data collected from the start-up in 1998 through to February 2004. During this time the experiment, which uses the underground Super-Kamiokande detector to record the interactions of a beam of neutrinos generated about 250 km away at KEK, in Tsukuba, has observed 108 beam-induced neutrino interactions.

In the absence of neutrino oscillations, in which one type of neutrino can change to another, the expected number of such events would be $150.9^{+11.6}_{-10.0}$. The observations therefore show a deficit consistent with the oscillation effects previously reported by Super-Kamiokande using data from naturally produced (atmospheric) neutrinos (*CERN Courier* September 1998 p1). K2K also reported the first significant evidence for the energy dependence of the oscillation effect. Taking into account measurements of the beam obtained from "near" detectors on the KEK site, the probability that the observed data are consistent with the hypothesis of no oscillations, and hence massless neutrinos, is negligible at 10^{-4}.

The Super-Kamiokande detector suffered a major accident in November 2001 when many of its 11 200 photomultiplier tubes were destroyed. Rebuilding began during 2002 so that operation of the K2K experiment could restart in January 2003, albeit with a reduced detector (*CERN Courier* May 2002 p7). The K2K collaboration expects to increase the number of observed events in a run starting in October 2004 and ending before the anticipated shutdown of the KEK proton accelerator in 2005. These additional data will include special studies to refine plans for the next-generation experiment, T2K (Tokai to Kamioka), at the new J-PARC accelerator facility under construction in Tokaimura, Japan. A new scintillating bar detector system – SciBar – was installed in the K2K "near" detector and commissioned in September 2003. Scibar is intended in part as an in-service prototype for a critical detector element in the T2K experiment.

POWER CONVERTERS

BRUKER

Principles :

Current or voltage stabilized from % to the sub ppm level

Technologies :

- **Linear, Switch Mode primary or secondary,**
- **Hard, or resonant, Buck,**
- **Boost, 4-quadrant operation**

Limits :

- **1A up to 25kA**
- **3V to 50kV**
- **0.1kVA to 3MVA**

Control :

- **Local manual and/or computer control**
- **Interfaces: RS232, RS422, RS485, IEEE488/GPIB,**
- **CANbus, Profibus DP, Interbus S, Ethernet**
- **Adaptation to EPICS**
- **DAC and ADC 16 to 20 bit resolution and linearity**

Applications :

- **Electromagnets and coils**
- **Superconducting magnets or short samples**
- **Resistive or capacitive loads**
- **Klystrons, IOTs, RF transmitters**

5V/300A for supraconducting magnets with 10 extra shims

80V/600A, 50kW
linear technology
< 5ppm stability
IEE488

60V/3500A, 210kW
Thyristor controlled (SEM®)
10^{-4}, Profibus

For more informations www.bruker.fr

BRUKER BIOSPIN S.A. • France
34 rue de l'industrie • F-67166 Wissembourg Cedex
Tél. +33 (0)3 88 73 68 00 • Fax. +33 (0)3 88 73 68 79
power@bruker.fr

BRUKER BIOSPIN

CERN COURIER ARCHIVE: 1963

To celebrate the 50th anniversary of CERN, we look back at some of the items in the early issues of *CERN Courier*

ECFA

Physics using future high-energy accelerators

At the first meeting of the European Committee for Future Accelerators (ECFA), held last January [1963] at CERN, Prof L Van Hove presented a paper with the rather impressive title of "The physics that could be done with future high-energy accelerators as it appears in January 1963". This is a revised version of that talk.

The first thing to be said in an article of this kind is that it is not really possible to discuss the kind of physics experiments that may be done with high-energy accelerators in the future, simply because it is impossible to predict what new discoveries are likely to be made. All that can be done is to consider what experiments physicists would like to do with such machines, assuming nothing unexpected happens between now and the date they come into operation...

The physics of leptons

In the field of leptons, that is electrons, muons and neutrinos, as well as their interactions, which are the electromagnetic and the weak interactions, the last two years have not given any unexpected surprises. The discovery of the second neutrino, fundamental as it is, was not really a surprise but the confirmation of a bold theoretical prediction that a number of people had made on the basis of previously known facts. This lack of surprise is an indication that our understanding of this part of physics is much better, so that useful, realistic theoretical discussions are possible before experiments are done.

The most important task for a future programme of lepton physics is the search for deviations from the presently accepted theories of quantum electrodynamics and weak interactions. Both kinds of study are in progress now and will continue for quite a while. The extension of this sort of work will carry us necessarily to increasing momentum transfers, especially in electrodynamics. It will be necessary to do electron collisions (electron–electron and electron–proton) and muon–proton collisions at increasing energies and angles in order to explore the higher momentum transfers, which unfortunately have very small cross-sections.

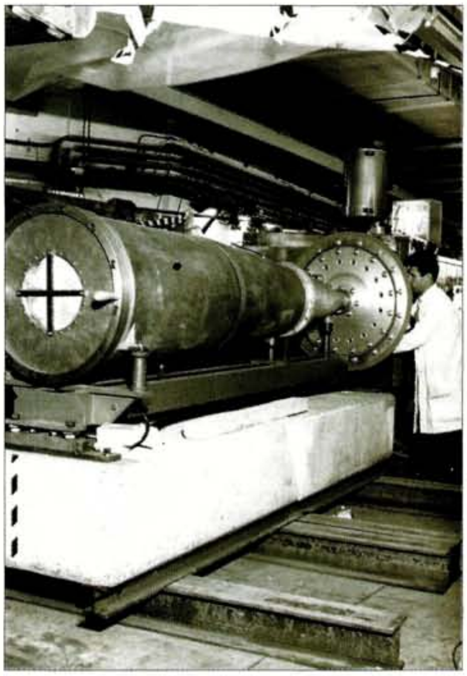
The same general course will probably be followed with neutrino physics. Electron–nucleon scattering will be replaced by neutrino–nucleon collisions, and the main difficulty will be with the small cross-sections. Neutrino physics again has a possible fundamental discovery on the programme: the intermediate boson, which, if it exists, would fit well within the framework of current thinking. This type of work will no doubt be going on next year, the year after, and probably still in 1968 or 1970, although in the meantime unexpected things may come in addition – perhaps related to the strange particles, the weak decays of which are so puzzling.

The search for deviations from accepted theoretical views may give the answer to an outstanding question first asked long ago. This is the puzzle of the two electrons, the difference between electron and muon. It is not clear whether higher energy is necessarily needed in this case. Maybe the measurement of the mass of the neutretto, the neutrino of the muon, will produce a crucial advance. However, it may also be that to obtain new information on the electron–muon puzzle, neutrino energies of several hundred GeV would be required, which would be very expensive.

• Taken from *CERN Courier* April 1963 pp48–51.

THE PS

Last month on the PS at CERN



During the whole of March [1963] work continued at the Proton Synchrotron on the numerous jobs arranged for the shut-down period. Of particular importance was the installation of the fast-ejection system, which will enable the beam of accelerated protons to be extracted from the machine, and the final setting-up apparatus for the forthcoming experiments with neutrinos...

The magnetic (or neutrino) horn was one of the first pieces of new equipment to be placed in position near the synchrotron during the shut-down. Seen in the picture above is Roger Gerst, working on the pulsed beam-transport system. This conducts the protons ejected from the accelerator to the target in the throat of the horn, where they produce pions.

• Taken from *CERN Courier* April 1963 p46 and p50.

EDITOR'S NOTE

ECFA, the European Committee for Future Accelerators, held its first ever meeting at CERN in 1963, and in the public session Léon Van Hove, then leader of the Theory Division, gave his view of the future, including his thoughts on neutrinos, which are extracted here. Van Hove became director-general of CERN from 1976–1980 and experiments with high-energy neutrinos became an important part of CERN's physics programme. Neutrinos remain a hot topic, and there are now ingenious new ideas for creating intense beams (see p30).

Electron and Ion Guns / Systems
UHV Components, Vacuum Chambers

UHV Electron Guns/Systems

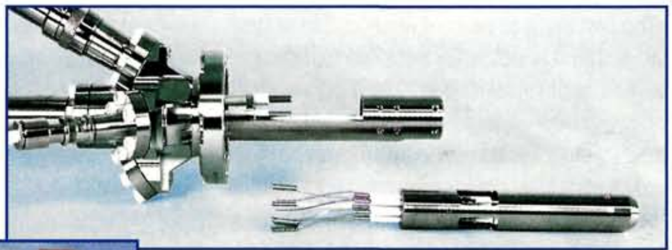
UHV Ion Guns/Systems

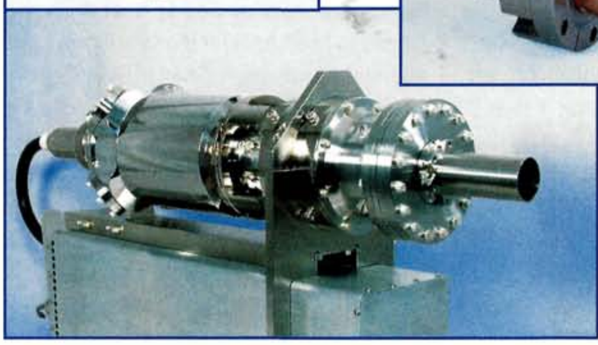
Beam energies: <1 eV to 100 keV.
Beam currents: femtoamps to amperes
Energy sweeping, deflection, rastering, fast pulsing, emission current control, computer control, arc-resistant electronics, remote control, and multiple cathode options (ThO_2, LaB_6, Ta disc, W, BaO),

Applications: Surface physics, vacuum physics, charge neutralization, cathodoluminescence, phosphor testing, RHEED, ESD, IPES, SIMS, semiconductor processing,Custom.

Components: Multi-CF Fittings, Compact UHV Chambers, Instrument Chambers, Modular Components, Cathodes, Cathode cartridges, Faraday cups, Phosphor Screens, eV Parts (rods, cylinders, spacers, plates, tubes, brackets, insulators, balls, brackets, fasteners; alumina & stainless steel)

CF Fittings not seen before!





Excellence in Electron and Ion Optics

KIMBALL PHYSICS INC. KPI

311 KIMBALL HILL ROAD, WILTON, NH 03086-9742 USA

www.kimballphysics.com

Toll Free: 1 888 KIM-PHYS (1 888 546-7497)
e-mail: info@kimphys.com
Tel. 1 603 878-1616 Fax: 1 603 878-3700

PHYSICSWATCH

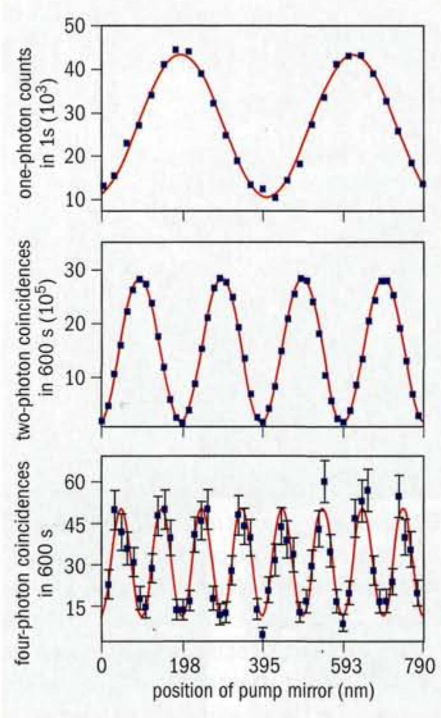
Compiled by Steve Reucroft and John Swain

Entangled photons show interference and bilocation

Most standard books on quantum mechanics discuss interference in the two-slit experiment and argue that if you turned down the intensity of the source sufficiently you would find that photons basically interfere with themselves, and not with each other. Paul Dirac himself wrote that "interference between two different photons never occurs". However, it now seems that this is not quite true, and that entangled photons can produce interference patterns that beat the diffraction limit expected for single photons.

Philip Walther of the University of Vienna and colleagues have shown that linear optics can be used to entangle N photons and get them to act as if they were just one entity with a wavelength N times smaller (Walther *et al.* 2004). Similar work has also come out of the University of Toronto from M W Mitchell and co-workers (Mitchell *et al.* 2004). So far, $N = 4$ is the biggest N that they have managed, but there is no obvious limit to how many photons can be entangled. This technology might even find commercial applications ranging from high-density optical storage to quantum computing.

Two entangled photons can be far away from each other and still yield correlated results for measurements that naively would seem to violate some combination of reality and locality – the famous Einstein–Podolsky–Rosen effect. A more exotic scenario, and one that has recently been measured, is when a photon hits a beam splitter and turns into what are effectively two versions of itself in two different places, which display the same sort of correlations between its two manifestations. Björn Hessmo and colleagues at the Royal Institute of Technology in Kista, Sweden, have managed to make delicate phase measurements of the two photons, which were really just one photon going two ways (Hessmo *et al.* 2004). They find that once again the bizarre predictions of quantum mechanics really do hold in our universe.



An experimental demonstration of pure one-, two- and four-photon interference from the experiment by M W Mitchell and colleagues.

Further reading

B Hessmo *et al.* 2004 *Phys. Rev. Lett.* **92** 180401.

M W Mitchell *et al.* 2004 *Nature* **429** 161.

P Walther *et al.* 2004 *Nature* **429** 158.

Website calculates doomsday scenario

Have you ever wondered what would happen if a big rock or lump of ice from space hit Earth? Now, thanks to Robert Marcus, an undergraduate student at the University of Arizona in Tucson and his colleagues, you can calculate the effects yourself. Just go to the website they have set up (see below) and enter the parameters that describe the impact of your worst nightmare and how close it is to you, and you can find out just how much you would suffer.

Further reading

http://www.lpl.arizona.edu/impacteffects.

When Beer's law fails

It's common knowledge, expressed more formally in Beer's law, that a pulse of light in a medium dies off exponentially with distance as it is absorbed. But theory predicts this is not quite true. The idea, which dates back almost a century, is quite simple and based on the fact that a sharp pulse of white light has many frequencies. These all go at somewhat different speeds in a medium, and among the various frequencies will be some that can propagate a long way with little loss. This gives rise to "precursors" – signals that get ahead of the main pulse and die away very slowly, falling only with the square root of the distance. Now, Seung-Ho Choi and Ulf Österberg of Dartmouth University, New Hampshire, have observed the first clear example of this effect in laser pulses 540 fs long propagating through 700 mm of water. The work is of interest for many fields including optical imaging of the human body and long-range underwater communications.

Further reading

S-H Choi and U Österberg 2004 *Phys. Rev. Lett.* **92** 193903.

A rotating black-hole accelerator?

The past few years have seen a great deal of counterintuitive features in the kinematics around rotating black holes, and now a new effect could help explain the origin of the highest energy cosmic rays. Bahram Mashhoon and Carmen Chicone of the University of Missouri found that near a rotating black hole particles beyond a critical speed of $c/\sqrt{2}$ can experience huge accelerations perpendicular to the axis of rotation, which could be sufficient to produce particles carrying enough energy to be near the Greisen–Zatzepin–Kuzmin cut-off, above which no cosmic rays should be able to arrive from far away. New data expected from the Pierre Auger Observatory are eagerly awaited to see if there is any association of the highest energy cosmic rays with "microquasars" – X-ray binary systems that include black holes, which have been observed to emit high-energy jets of material.

Further reading

http://xxx.lanl.gov/abs/astro-ph/0406005.

Compiled by Marc Türler

X-ray constraints on dark energy

The existence and nature of dark energy has been probed using images of galaxy clusters obtained by NASA's Chandra X-ray Observatory. These results are completely independent from the previous supernova results and confirm the effect of dark energy on the acceleration of the universe.

The first evidence for dark energy came in 1998 with the observation that distant type Ia supernovae are dimmer than expected. This suggested that the expansion of the universe is not decelerating under its own gravity but accelerating through the effect of some mysterious dark energy (*CERN Courier* September 2003 p23). The first results of the Wilkinson Microwave Anisotropy Probe (WMAP) confirmed in 2003 that dark energy is the main contributor to the matter-energy content of the universe (*CERN Courier* April 2003 p11). Along with additional observational constraints, a cosmological "concordance model" could be derived in which 4% of the present universe is made of baryons, 20–25% is non-baryonic dark matter of unknown nature, and dark energy accounts for the remaining 70–75%.

The new study led by Steve Allen of the Institute of Astronomy at Cambridge University is based on the X-ray emission of hot gas in 26 galaxy clusters (*CERN Courier* July/August 2003 p13). Using X-ray measurements from Chandra, the authors derive for each cluster the mass ratio of the hot gas to dark matter. Under the assumption that this gas fraction should be constant with redshift, they then adjust the distance scale to give a best fit to the data. This work suggests the existence of dark energy with a significance of $>3\sigma$ (Allen *et al.* 2004). It thus offers the first clear confirmation of the results from type Ia supernovae by detecting the effect of dark energy on distance measurements for a different class of astronomical objects.

Galaxy-cluster images from NASA's Chandra X-ray Observatory are providing a new method for detecting and probing dark energy. This image is an optical (blue) and X-ray (red) composite of the galaxy-cluster Abell 2029. The giant elliptical galaxy at the centre is surrounded by smaller galaxies forming the cluster. Their combined gravity traps the X-ray emitting gas heated to about 100 million degrees. (Optical: NOAO/Kitt Peak/J Uson, D Dale; X-ray: NASA/CXC/IoA/S Allen et al.*)*

This study also suggests that the dark-energy density does not change quickly with time and may even be constant, consistent with Albert Einstein's "cosmological constant" concept. The best estimation of equation-of-state parameter "w", which describes the nature of dark energy, is, however, found to be slightly below −1. This implies that the universe might end in a "Big Rip", where dark energy increases until galaxies, stars, planets and eventually atoms are torn apart (*CERN Courier* May 2003 p13).

However, it is important not to over-interpret the data by forgetting that they rely on some prior assumptions. For example, another recent study, also based on the X-ray emission of galaxy clusters, yielded the opposite result by showing that the redshift dependence of the number counts of galaxy clusters is nearly an order of magnitude below the expectations of the "concordance model", while being in remarkable agreement with those of a matter-dominated universe (Vauclair *et al.* 2003). Such a classical Einstein-de-Sitter universe could even account for the WMAP results if the Hubble constant has the rather low value of 46 km/s/Mpc (Blanchard *et al.* 2003). The controversy over the existence and moreover the nature of dark energy is clearly not yet over.

Further reading

S W Allen *et al.* 2004 http://arxiv.org/abs/astro-ph/0405340.

A Blanchard *et al.* 2003 *Astron. Astrophys.* **412** 35.

S C Vauclair *et al.* 2003 *Astron. Astrophys.* **412** L37.

Picture of the month

Is this the remnant of a gamma-ray burst? If the answer is yes, then it would be the first one to be discovered in our Milky Way galaxy. This composite image of the supernova remnant W49B shows bright infrared rings (red and green) on both sides of a glowing bar of intense X-ray radiation (blue). The infrared rings are likely to have been expelled during the short life of a massive star. A few thousand years ago, when the star exhausted its nuclear fuel, its core collapsed to form a black hole. Much of the surrounding gas was pulled into the black hole, but some of it was probably flung away in oppositely directed jets, as witnessed by the remaining bar-shaped region of X-ray emitting gas. Those jets travelling near the speed of light could have produced a gamma-ray burst that might be observed, in a few billion years, by an observer in a remote galaxy located along the jet axis. (Credit: NASA/CXC/SSC/J Keohane *et al.*; Infrared: Caltech/Palomar/J Keohane *et al.*)

Cryogenic operations come in from the cold

A recent meeting at Jefferson Lab has inaugurated a new biennial workshop on reducing operating costs and increasing stability and reliability in a new generation of refrigeration plants for superconducting accelerators. **Steven Corneliussen** reports.

The 2 and 4 K cold boxes inside the Central Helium Liquefier for the CEBAF facility at Jefferson Lab. (Photo: Jefferson Lab.)

The 2 K cold box for the new Spallation Neutron Source facility at Oak Ridge is inspected prior to shipment. (D Arenius.)

Accelerators and light sources rely increasingly on superconducting magnets, superconducting accelerating structures and other very-low-temperature equipment. At the same time there has also been progress in understanding the design, operation and optimization of the refrigeration plants needed to provide the cooling. To speed the evolution of this understanding and to foster its practical application, cryogenics engineers have instituted a new biennial meeting. The first Workshop on Cryogenics Operations was held on 30 March – 2 April at the US Department of Energy's Thomas Jefferson National Accelerator Facility (Jefferson Lab) in Newport News, Virginia, with participants attending from Europe and America.

A cryogenics plant's operating expenses include manpower, electricity, helium refrigerant gas and liquid nitrogen. At Jefferson Lab, for example, the 2 K plant supporting the Continuous Electron Beam Accelerator Facility (CEBAF) and a free-electron laser user-facility requires several staff and \$3.5 million (€2.8 million) per year for electricity, plus another \$850 000 (€690 000) for liquid nitrogen and \$400 000 (€325 000) for helium.

Recent cryogenics upgrades at Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) illustrate how such operating costs can be controlled and how system reliability can be raised. RHIC's system maintains the superconducting magnets in two collider rings at or below 4.6 K. At the workshop Ahmed Sidi-Yekhlef from the RHIC project described how a new approach to process control, coupled with hardware modifications, yielded a power reduction of about 20% (1.8 MW) while boosting system reliability, stability and flexibility, with less human intervention. In RHIC's new process control system the refrigerant charge pressure of the cryogenic system is continuously varied automatically to match the imposed cryogenic load of the superconducting magnets. The lower system charge pressures reduce the mechanical loading and wear on the refrigerator's main helium gas compressors, which are electrically driven. The result is savings in electrical power, maintenance and repairs.

The workshop participants took special note of how cryogenics operations of this kind of increasing sophistication are being applied to coming generations of machines. As discussed at the meeting, the first stage of the refrigeration system for the Large ▷

Hadron Collider is now installed and ready for cooling tests in 2005 (see *CERN Courier* May 2004 p15). Presentations and discussions during the workshop also described progress with the cryogenics systems at ISAC-II, the superconducting-linac-based upgrade of the radioactive beam facility at TRIUMF in British Columbia, and at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory in Tennessee.

The SNS will serve as the next-generation neutron-scattering facility for the US, providing the most intense pulsed neutron beams in the world for scientific research and industrial development. With a total cost of $1.4 billion (€1.1 billion), construction of the SNS began in 1999 and will be completed in 2006. At the heart of the new facility is a superconducting accelerator cooled by a 2400 W, 2.1 K helium cryogenic system, with a shield load of 8300 W at 38 K. The system was designed and built in partnership with Jefferson Lab for unattended operation with greater than 99% reliability. At the workshop, Dana Arenius of Jefferson Lab and Donald Richied of SNS reported on how the design phase had focused on this new optimization approach, which uses automatic pressure-reduction control to match the variations in the facility's cryomodule load. The efficiency of the plant is maintained with lower operating costs while extending the service lifetimes of major components. Comparable technology for unattended operation has been proven in operation at Michigan State University's National Superconducting Cyclotron Laboratory.

Arenius chaired the workshop, and there were substantial contributions from Ganni Rao, also from Jefferson Lab. Because the laboratory expects to participate in future projects much as it has in the construction of the SNS, the Accelerator Division has been especially motivated to initiate and stimulate critical thinking concerning cryogenics optimization. Raymond L Orbach, who directs the US Department of Energy's Office of Science, recently announced a prioritized list of more than two dozen major future scientific facilities and upgrades for the next 20 years (see *CERN Courier* January/February 2004 p13). High-field superconducting magnets or superconducting microwave technology will figure in around a third of these, including the Rare-Isotope Accelerator and the Linac Coherent Light Source, for which the prospects for cryogenics operation were discussed during the meeting.

John Weisend of SLAC will chair the second Workshop on Cryogenics Operations, to be held in 2006, probably with Japanese participation, and CERN is contemplating hosting in 2008. The workshop complements the biennial Cryogenic Engineering Conference, which occurs in odd-numbered years and focuses on the broad field of breakthroughs in cryogenic technology and cryogenic industrial products.

Steven Corneliussen, *Thomas Jefferson Laboratory.*

A marriage of pixels and proportional counters

Different technologies come together in the gas pixel detector, a device that for the first time brings very high resolving power to gas detectors, as **Ronaldo Bellazzini** explains.

Over the past decade micropattern gas detectors (MPGDs) have become increasingly important, not only in high-energy physics but also in other applications where high spatial resolution is required together with operation at high rates. MPGDs are position-sensitive proportional counters, descendents of the multiwire chambers that amplify and collect charge released as ionizing particles pass through a volume of gas. The difference with MPGDs is that the electrodes that sense the avalanche of charge are constructed using microelectronics, thin-film or advanced printed circuit board (PCB) techniques. With such methods, feature sizes of just a few microns can be achieved, leading to detectors that have excellent spatial resolution and fast charge collection.

One attractive class of MPGD is the gas electron multiplier (GEM) detector, which can fully decouple the charge-amplification structure from the read-out structure. The GEM concept uses a thin sheet of metalized plastic pierced by a regular array of tiny, closely spaced holes. When a voltage is applied across the device, the high electric field at the holes causes an avalanche of charge, which can be collected by a read-out electrode (*CERN Courier* December 1998 p19). In this way, the charge amplification and read-out can be independently optimized. For example, by organizing the read-out plane in a multipixel pattern it is possible to obtain true 2D imaging capability (see figure 1). The high granularity of the pixelated read-out plane preserves the intrinsic resolving power of the device and its high rate capability, which are otherwise unavoidably lost if a conventional projective read-out approach is used – for example, with a read-out on *x* and *y* axes (Bellazzini and Spandre 2003).

However, when the pixel size is small (less than 100 μm) and the number of pixels is large (more than 1000), it is virtually impossible to bring the signal charge from individual pixels in the GEM read-out to a chain of external read-out electronics, even if advanced, fine-line, multilayer PCB technology is used. The fan-out connecting the segmented anodes that collect the charge to the front-end electronics is the real bottleneck: technological constraints limit the number of independent electronics channels that can be brought to the peripheral electronics. Furthermore, the cross-talk between adjacent channels and the noise that is caused by the high-input capacitance to the pre-amplifiers become significant. ▷

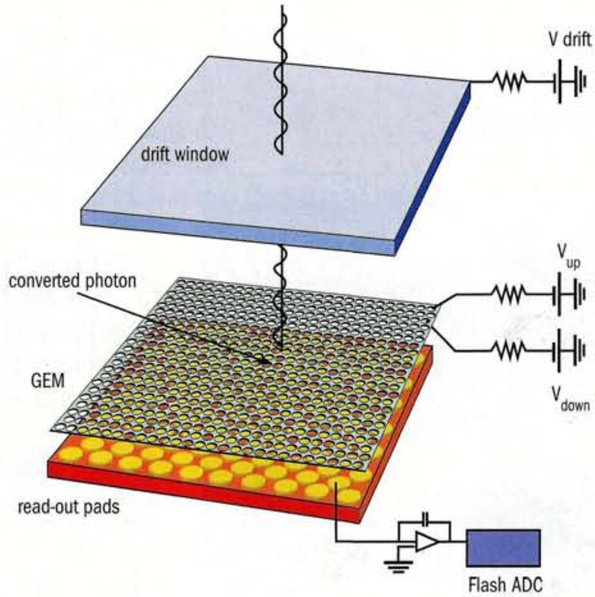


Fig. 1. The basic structure of a gas pixel detector for an X-ray application. The X-ray photon is absorbed in the drift plane and the photoelectron track drifts to the gas electron multiplier (GEM). The high electric field at the holes in the GEM provides the charge amplification. The pixelized anode, which is also the read-out plane, is grounded, while the lower and upper sides of the GEM and the drift plane are at successively higher voltages.

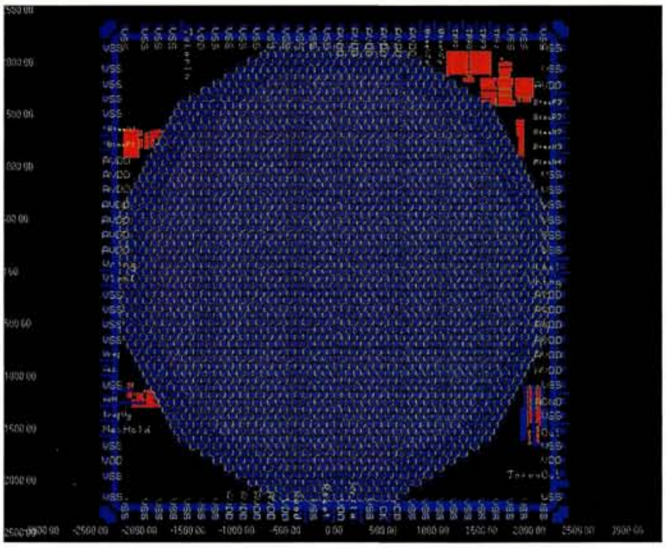
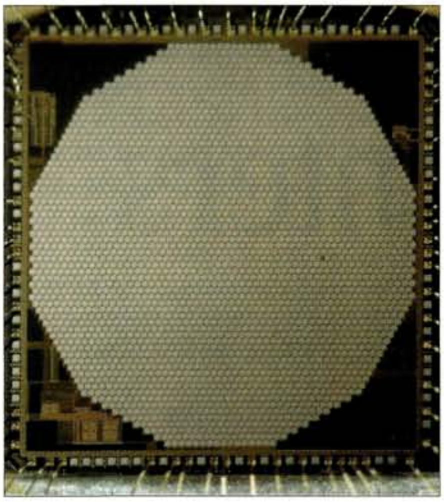
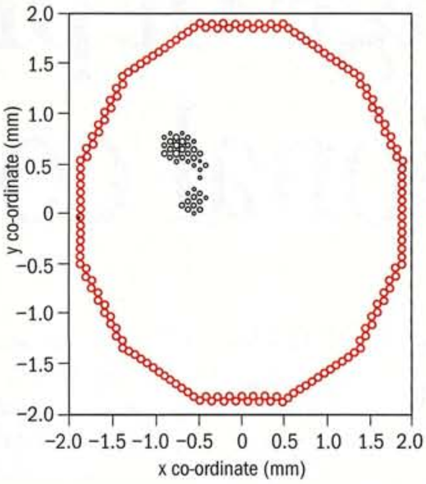
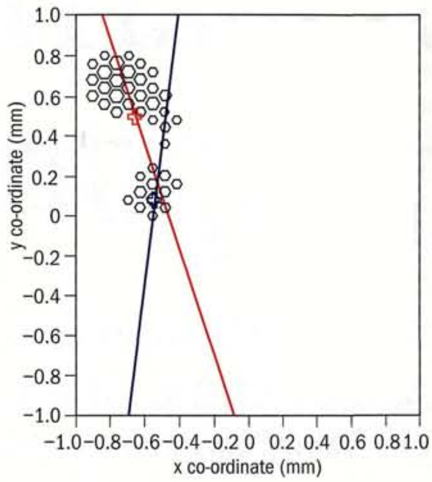
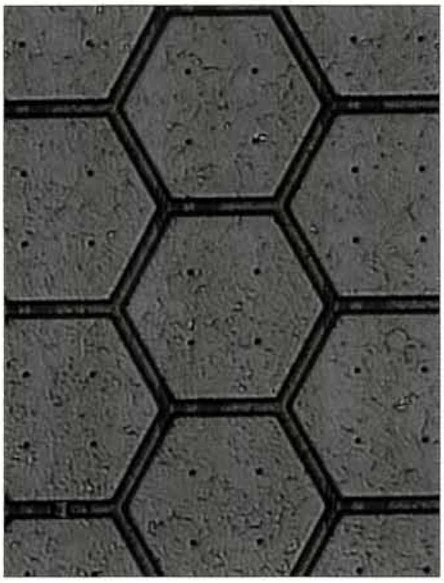


Fig. 2. Layout of an ASIC designed to include the full read-out electronics for each pixel, as seen from above. The active pixels are pink, while the guard ring and I/O (in/out) pads are blue.









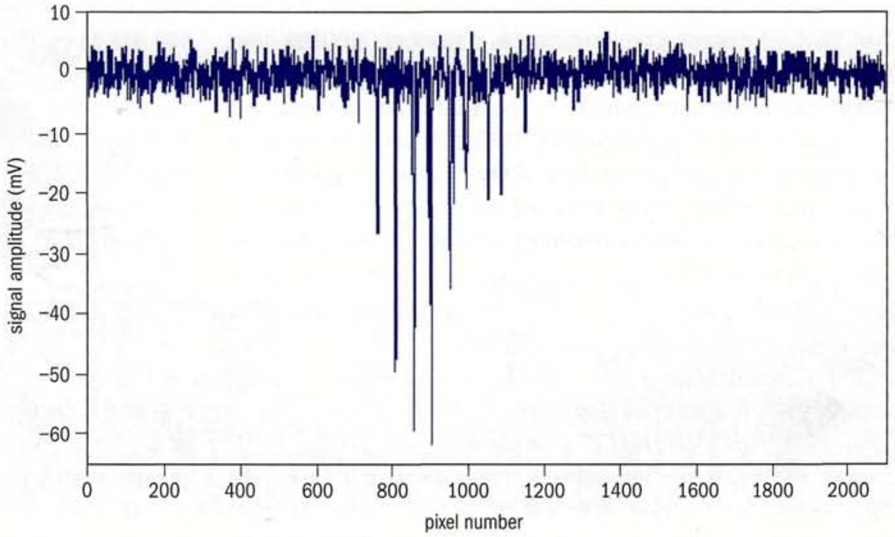


Fig. 3a. (Top, left.) The ASIC chip bonded to its ceramic package. Fig. 3b. (Bottom, left.) A close-up of the chip's honeycomb pixel matrix. Fig. 4a. (Top, centre.) The reconstructed track of a 5 keV photoelectron. Fig. 4b. (Top, right.) Track direction reconstruction algorithm: red line, first step; blue line, second step. Fig. 5. (Bottom, right.) The raw data for the event in figure 4.

The solution is that, rather than take the signal from the pixel to the read-out electronics, the electronics chain has to be brought to the individual pixel. This concept has been developed recently at INFN Pisa, where deep, submicron VLSI technology was used to build an application-specific integrated circuit (ASIC) to perform both charge collection and read-out. The top metal layer of the ASIC consists of a CMOS array of 2101 active pixels with an 80 μm pitch, which is used directly as the charge-collecting anode of a GEM. Each charge-collecting pad of the array is connected to a full electronics chain (pre-amplifier, shaping amplifier, sample-and-hold, multiplexer) built immediately below the pad using the five remaining active layers of the VLSI structure. With this approach, gas detectors have for the first time reached the level of integration and resolution typical of solid-state pixel detectors (Bellazzini *et al.* 2004).

The ASIC was created using 0.35 μm, 3.3 V CMOS technology. Figure 2 shows the device layout as seen from the top metal layer. The active matrix, in pink, is surrounded by a passive guard ring of 3–4 pixels, which are set to the same potential as the active pixels. Figure 3 shows the actual chip bonded to its ceramic package.

To build the complete detector, a single GEM MPGD with an active gas volume of less than 1 cm^3 is assembled directly over the chip containing the ASIC, which forms both the charge-collecting anode and the pixelized read-out of the MPGD, so that the detector and the read-out electronics become a single unit. This enables the full electronics chain and the detector to be completely integrated without the need for complicated bump bonding.

In the prototype there is a drift region (absorption gap) of 6 mm above the GEM foil, while a 1 mm spacer defines the collection gap between the lower surface of the GEM and the pixel matrix of the read-out chip. The GEM has a standard thickness of 50 μm and holes of 50 μm diameter at 90 μm pitch on a triangular pattern. The entrance window is made from 25 μm thick Mylar foil, aluminized on one side. Typical applied voltages are 1000 V (drift electrode), −500 V (top of GEM) and −100 V (bottom of GEM) – the collecting electrodes being around 0 V. In these conditions the detector operates at a typical gain of 1000.

Thanks to the very low pixel capacitance at the preamplifier input, a noise level of 1.8 mV was measured, which corresponds to around 100 electrons. This means that with the gas gain of 1000, the detector has significant sensitivity to a single primary electron.

The first application of this new MPGD concept is for an X-ray polarimeter, for use in astronomy, operating in the low-energy band (1–10 keV). Information on the degree and angle of polarization of astronomical sources can be derived from the angular distribution of the initial part of the photoelectron tracks when they are projected onto a finely segmented 2D imaging detector (*CERN Courier* September 2001 p23).

The algorithm for the reconstruction of the photoelectron path begins with the evaluation of the first moment (M_1) of the charge distribution on the read-out pixels, and the maximization of the second moment (M_2) of the charge distribution to define the principal axis of the track. In a further step, the asymmetry of the charge release along the principal axis (third moment, M_3) is computed and the conversion point is derived by moving along this axis in the direction of negative M_3, where the released charge is smaller by a length of around M_2. The reconstruction of the direction of emission is then carried out by taking into account only the pixels in a region weighted according to the distance from the estimated conversion point.

The morphology of a real track obtained by illuminating the device with a low-energy radioactive source (5.9 keV X-ray from ^{55}Fe) is shown in figure 4. The small cluster owing to the Auger electron and the initial part of the track can be distinguished from the larger Bragg peak. The plot of the raw signals of all of the channels for the same event shows the optimal signal-to-noise ratio obtained using this detector (figure 5). Around 50 000 electrons from the gas-amplified primary photoelectrons are divided between 53 pixels.

The final design for our X-ray polarimeter application (Costa *et al.* 2001) will have 16–32 K channels with a pixel size of 60–70 μm and an active area of around 1 cm^2. However, many other applications can be foreseen, depending on various factors, such as the size of the pixels and the die, the electronics shaping time, the analogue versus digital read-out, counting versus integrating mode and gas filling. Such developments would surely open new directions in gas proportional detectors, and bring the field to the same level of integration as that of solid-state detectors.

Further reading

R Bellazzini and G Spandre 2003 *Nuclear Instruments and Methods in Physics Research A* **513** 231.
R Bellazzini *et al.* 2004 http://www.arxiv.org/physics/0403019.
E Costa *et al.* 2001 *Nature* **411** 662.

Ronaldo Bellazzini, *INFN Pisa*.

From bent crystals to nanostructures

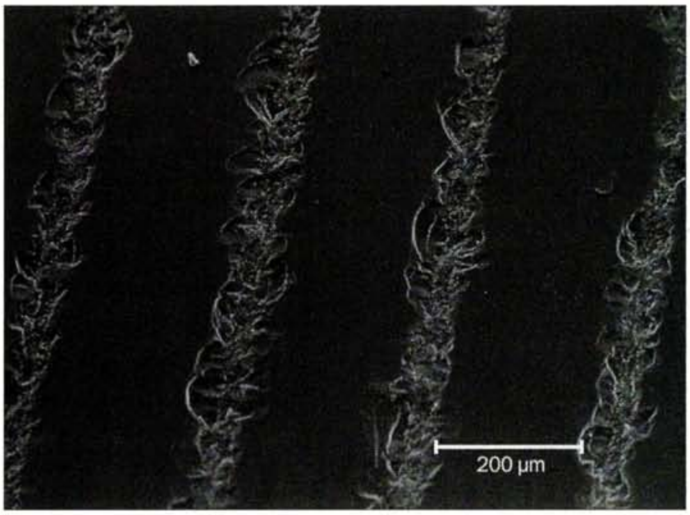
A recent workshop in Frascati highlighted some of the exciting possibilities for future developments in channelling particle beams in ordered structures.

Research on the physical phenomena induced when high-energy beams of charged and neutral particles interact with ordered matter, such as crystal lattices and nanostructures, has seen considerable progress in recent years, from both theoretical and experimental points of view. When charged particles, especially those moving at relativistic speeds, pass through a crystal they feel a strong coherent electric field due to the nuclear charges. Particles can be channelled by the arrangement of atoms in crystals, and specially bent crystals are used in accelerator laboratories to steer high-energy beams.

On 23–26 March this year, INFN's Laboratori Nazionali di Frascati (LNF) hosted the International Workshop on Relativistic Channelling and Related Coherent Phenomena. Several successful meetings in this field have previously taken place, notably at Maratea in 1986, Protvino (Serpukhov) in 1991 and Aarhus in 1995. This year's workshop was held at the home of the DAFNE-LIGHT synchrotron radiation facility, which is particularly suitable for experimental work at infrared wavelengths and in X-ray diffraction. The LNF has also been supported by the European Union (EU) as one of the major research infrastructures in Europe to give free access to researchers during the period 2000–2004, and the EU has recently approved a new access to research infrastructure programme at the LNF for 2004–2008.

The main purpose of the workshop was to assess the current state of the art of this fast-growing field and to stimulate research collaboration among the different groups involved, with the aim of prompting the organization and presentation of joint projects in the near future. The success of the workshop can be shown by the number of participants, with around 40 specialists attending from 12 different countries, including Japan, the US and most of the former USSR, and by the high quality of the technical presentations.

Erik Uggerhoj from Aarhus launched a new initiative towards research on strong field effects in ordered matter at multi-TeV energies, entering the territory far above the critical Schwinger field. This could lead to a new multi-TeV electron (positron) beam facility at CERN's Large Hadron Collider (LHC), providing new opportunities for fixed-target physics and applications. Such research at the LHC



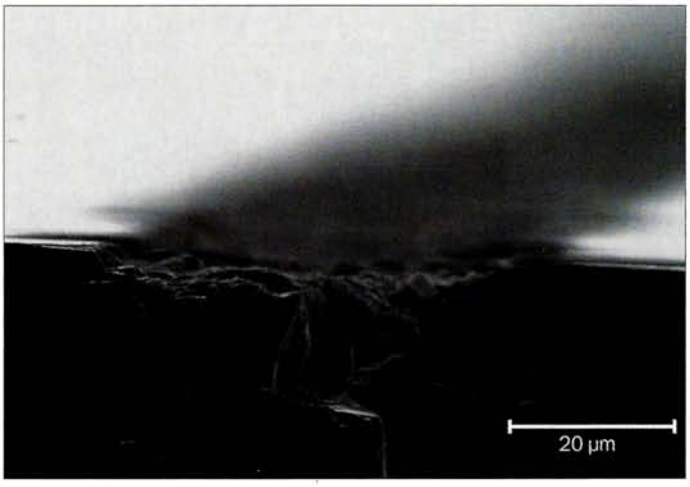


Fig. 1. Top: a scanning electron microscope image of a silicon crystal undulator, showing 50 µm grooves on the undulator surface spaced by 200 µm. Bottom: side view of the same sample. Micromachining produces periodic deformations that propagate in the bulk of the crystal.

would require crystal-assisted extraction of a parasitic beam, a technique based on strong crystal fields. Simulations at the workshop showed that a tiny crystal installed into the collimation system could enhance the efficiency of the LHC collimation by an order of magnitude. The channelling for collimation purposes can then easily be turned into an instrument for beam extraction when needed. ▷

A team from Brookhaven National Laboratory reported on crystal collimation experiments with beams of gold ions at the Relativistic Heavy Ion Collider, which were performed jointly with the Institute for High Energy Physics (IHEP) in Protvino. Channelling efficiencies of about 30% were measured, in good agreement with Monte Carlo simulation. This is a significant step forward, but more work is needed to incorporate a strong crystal field into an accelerator lattice and to benefit from it fully.

Channelling in "bent" crystals is routinely used in experiments at Protvino, where many crystals are installed at six locations around the main ring. Some channelling crystals have been used for extraction for more than 10 years without replacement. Extraction efficiencies of 85% for a 70 GeV beam of 10^{12} protons have been measured for 2 mm crystals, in excellent agreement with predictions.

In addition to the well known use of bent crystals and focusing crystals demonstrated at IHEP more than a decade ago, crystal undulators are now being introduced to experiments, as Yuri Chesnokov of IHEP reported. Channelling undulators offer sub-millimetre periods and fields of the order of 1000 tesla. Figure 1 (p19) shows scanning electron microscope images of an undulator surface that was produced by micromachining a silicon crystal at IHEP. The images, obtained by a team from LNF in collaboration with CNR-IFN (Rome), reveal the undulator's 50 μm grooves spaced by 200 μm, which produce periodic deformations that propagate in the bulk of the crystal. Samples of this kind, which have been characterized with X-rays and tested with protons, are now ready for the positron beam tests planned for the Beam Test Facility at the LNF, as well as at IHEP and at the Super Proton Synchrotron at CERN.

Positron sources are another application of strong coherent fields. Teams from KEK and Yerevan presented the progress and new ideas in this direction, and a number of talks reported on the theories of coherent radiation and electron–positron pair production in ordered matter.

Nanostructures also offer a new line of research for particle interactions with ordered matter. Several talks were devoted to particle channelling in nanotubes, radiation in periodic nanostructures and the growth of aligned nanostructured arrays. Possibilities for experiments with channelling nanostructures were outlined by teams from LNF and IHEP, where such activities are already underway.

Further reading

The proceedings will be published as a special issue of *Nuclear Instruments and Methods B*, which is scheduled to appear in December 2004. For further information about the workshop, see www.lnf.infn.it/conference/rc2004.

Stefano Bellucci, *INFN, Frascati, and* **Valery Biryukov**, *IHEP, Protvino.*

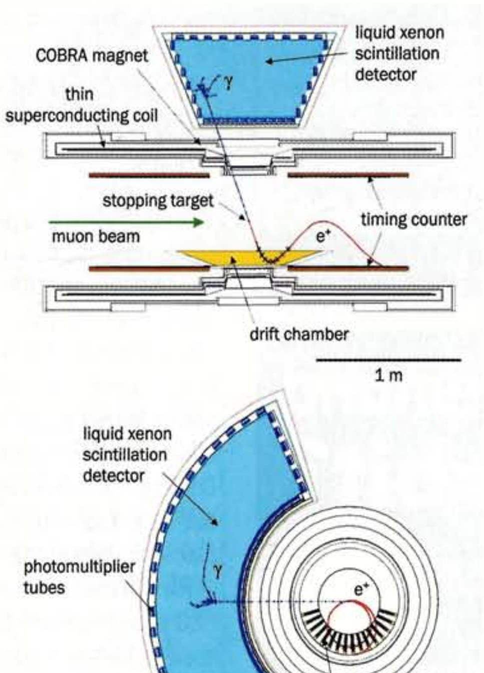
MEG goes in search of the forbidden

The 30th anniversary of the proton accelerator complex at PSI heralds the start of a new generation of particle-physics experiments, with the search for the decay of the muon to a positron and a photon.

This year marks 30 years of successful operation of the 590 MeV proton accelerator complex at Switzerland's national user laboratory, the Paul Scherrer Institut (PSI) in Villigen. Originally designed for proton currents of 100 μA, the ring cyclotron is now routinely producing beam currents of close to 2 mA. This megawatt beam is the progenitor of the world's most intense direct current (DC) pion and muon beams and makes possible the measurement of rare decays and the search for "classical" forbidden decays. If found, the latter would signal new physics and allow access to these phenomena in a regime complementary to that possible with high-energy colliders.

PSI has a long tradition in this field, especially in searches for lepton-flavour violation (LFV); some of the most competitive limits in the charged lepton sector stem from the laboratory's high-intensity muon beams. Notable examples of such searches are for $\mu \rightarrow 3e$, $\mu \rightarrow e$ conversion and muonium (μ^+e^-) $\rightarrow$ anti-muonium (μ^-e^+) conversion. Although all of the results so far are still limits, the next generation of charged LFV searches may promise more. Recent results from the neutrino sector – for example at Super-Kamiokande, SNO (*CERN Courier* June 2002 p5/November 2003 p5) and KamLAND (*CERN Courier* March 2003 p7) – demonstrate flavour-changing processes in the realm of neutral leptons, which are associated with non-zero neutrino mass. There is also a continued interest in the results from the Muon g-2 Collaboration at Brookhaven (*CERN Courier* January/February 2004 p6).

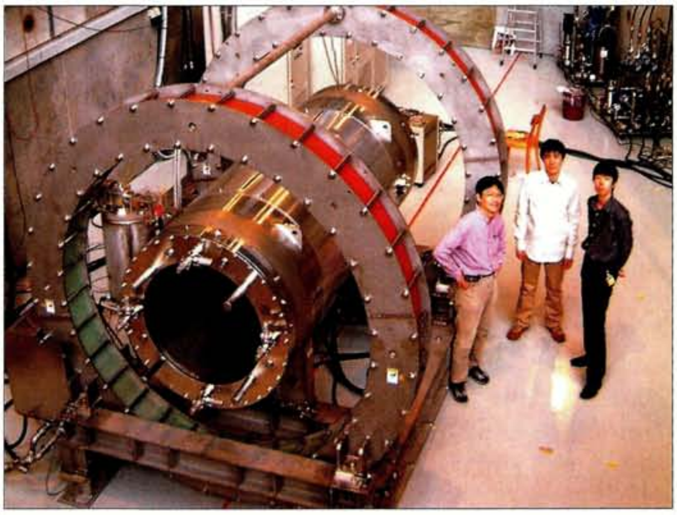
While in simple extensions to the Standard Model the interesting rates are prohibitively small, in supersymmetric extensions (SUSY) and especially in grand-unified theories (SUSY–GUT) – which turn out to be particularly favourable to LFV – the branching ratios are predicted to lie only one to two orders of magnitude lower than the present experimental bounds. In particular, compared with other LFV processes, such as $\mu \rightarrow 3e$, $\mu \rightarrow e$ conversion in a nucleus and $\tau \rightarrow e\gamma$, the decay process $\mu \rightarrow e\gamma$ is expected to have a higher sensitivity to supersymmetric unification. A new generation of LFV searches is therefore now in preparation, notably the MEG experiment ($\mu^+ \rightarrow e^+\gamma$ search) at PSI and MECO ($\mu \rightarrow e$ conversion search) at Brookhaven.



The main components of the MEG detector: the Constant Bending Radius (COBRA) positron spectrometer with drift-chamber tracking devices and scintillation timing-counter hodoscopes, and the 0.8 m^3 liquid xenon photon calorimeter.

The MEG collaboration, comprised of some 50 members from 11 institutes in Italy, Japan, Russia and Switzerland, is currently commissioning the initial part of the beam line, as well as the first detector components, which have already arrived at PSI. The ambitious goal of this experiment is to achieve a single-event sensitivity for the decay $\mu^+ \rightarrow e^+\gamma$ that will be more than two orders of magnitude lower than the current best limit on the branching ratio $\mu^+ \rightarrow e^+\gamma \leq 1.2 \times 10^{-11}$, achieved by the MEGA collaboration at the Los Alamos Meson Physics Facility (LAMPF).

For the MEG detector to be able to distinguish the coincident back-to-back $\mu^+ \rightarrow e^+\gamma$ events at a high rate from the main combinatorial background of normal and radiative muon decays, a high-current DC duty-cycle machine, such as the Ring Cyclotron at PSI, combined with the highest intensity surface muon beam is a prerequisite. On the detection side, two main components – an 800 litre liquid xenon (LXe) photon calorimeter using scintillation light together with a gradient-field, thin-coil superconducting positron spectrometer – make possible the required ▷



Members of the University of Tokyo with the COBRA magnet in the experimental zone at PSI, after a successful full-excitation test that proved a journey from Japan across three oceans and a trip up the Rhine to Basle could be mastered. The two large compensation coils visible at either end serve to reduce the stray magnetic field at the position of the liquid xenon calorimeter.

energy/momentum, spatial and timing resolutions.

The gradient magnetic field of the COBRA (Constant Bending-Radius) spectrometer allows the decay positrons to execute spiral paths of constant projected bending radius and increasing axial pitch, which depend entirely on the particle's total momentum while being independent of its emission angle. This allows a background of lower energy Michel positrons to be swept away more effectively from the fiducial tracking volume of the azimuthally spaced, staggered-cell drift chambers. Timing information and hence trigger information for events is provided by a set of fast, double-layered, orthogonally placed timing-counter arrays, positioned at either end of the magnet.

The LXe photon calorimeter, which is viewed from all sides by some 800 photomultiplier tubes (PMTs) immersed in the cryogenic fluid, allows a homogeneous measurement of the energy, spatial and timing co-ordinates of the photon. A milestone in the development of the calorimeter was recently achieved with beam tests in Japan and at PSI. A large prototype detector with about one-tenth of the volume and 228 PMTs has yielded a preliminary value of better than 4.5% full width at half maximum for the energy resolution at 55 MeV, as well as a position-dependent spatial resolution, σ, of 2–4 mm, demonstrating that the required resolutions can be achieved.

The R&D phase for MEG is now slowly drawing to a close and the production phase is beginning to gain impetus. Initial engineering runs are planned during 2005, with full detector assembly expected for the end of 2005. Data taking will start in 2006, almost 60 years after the first attempt by E P Hincks and Bruno Pontecorvo to see what was then known as a "meson" decay to an electron and photon, using cosmic rays. Naturally, we hope not to measure "zero"!

Further reading

http://meg.web.psi.ch.

Peter-Raymond Kettle, *PSI.*

The rebirth of the FFAG

After 50 years in waiting, fixed-field alternating-gradient accelerators are at last being built – for a wide variety of applications. **Michael Craddock** reports on the current status.

The attendees at the FFAG 2004 Workshop, which was held in April at TRIUMF in Vancouver, including alternating-gradient pioneer Ernest Courant (fourth from the left) and FFAG pioneer Andy Sessler (fifth from the left).

Fixed-field alternating-gradient (FFAG) accelerators, which were intensively studied in the 1950s and 1960s but never progressed beyond the model stage, have in recent years become the focus of renewed attention. Two proton machines have already been built and three more, plus an electron FFAG and a muon phase rotator, are under construction. A variety of designs are also under study for the acceleration of protons, heavy ions, electrons and muons, with applications as diverse as cancer therapy, industrial irradiation, driving subcritical reactors, boosting high-energy proton intensity and neutrino production. These advances have been underpinned by a series of international workshops, the first being held at CERN in 2000, with subsequent meetings at KEK (twice), LBNL, BNL and TRIUMF. The next workshop will again be held at KEK, in October 2004.

With their fixed magnetic fields, modulated radiofrequency (RF) and pulsed beams, FFAGs operate just like synchrocyclotrons – in fact they bear the same relation to classic synchrocyclotrons as isochronous ring cyclotrons (such as at PSI, IUCF, RIKEN and so on) do to the classic Lawrence cyclotron: the central region has been removed and the magnet broken into radial or spiral sectors to provide edge and strong focusing.

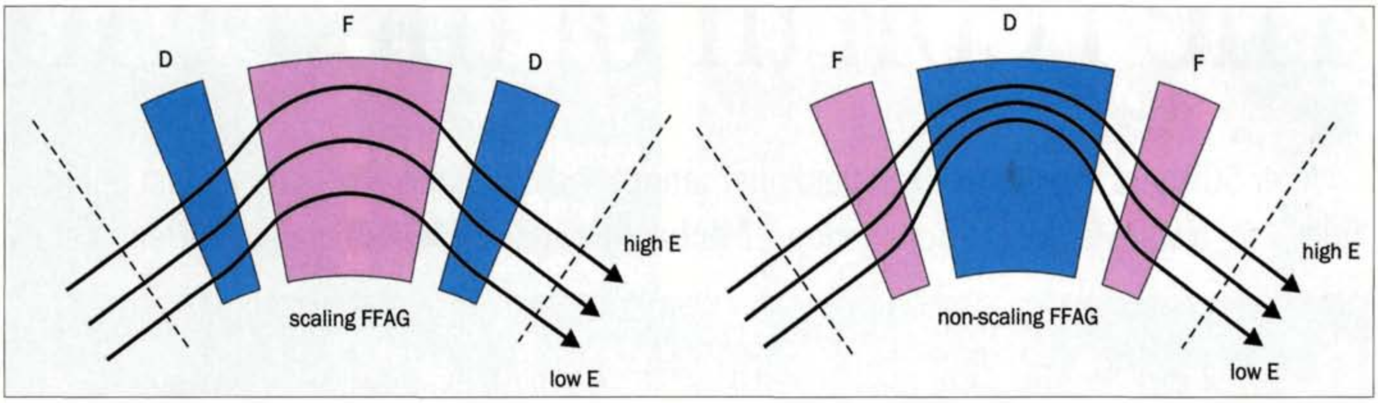
The fixed magnetic field leads to a spiral orbit, so the vacuum chamber and magnets tend to be larger than for a synchrotron, but the repetition rate (and hence beam intensity) can be much higher, as it is set purely by RF considerations. High repetition rate and large momentum acceptance are the two features where FFAGs offer advantages over synchrotrons, and it is applications needing one or both of these features that have driven the current surge of interest.

Following the discovery of alternating gradient (AG) focusing in 1952, FFAGs were proposed independently by Tihiro Ohkawa in Japan, Keith Symon in the US and Andrei Kolomensky in the USSR. The most intensive studies were carried out by Symon, Donald Kerst and others at MURA (the Mid-western Universities Research Association) in Wisconsin, and culminated in the construction and successful testing of electron models of radial-sector and spiral-sector designs. But the proposals for proton FFAGs were not funded at that time, nor in the 1980s when 1.5 GeV machines were proposed by the Argonne and Jülich laboratories as spallation neutron sources.

Scaling FFAGs

In order to avoid the slow crossing of betatron resonances associated with conventional low energy-gain per turn, all the FFAGs constructed so far have been based on the "scaling" principle. This means that the orbit shape, optics and betatron tunes are kept fixed, independent of energy, just as in synchrotrons. One implication of this is that the magnets must be built with constant field index (logarithmic gradient). In the case of spiral-sector designs it also implies a constant spiral angle. The need for both strong gradient and high spiral angle (to achieve adequate focusing) makes the spiral magnet design very challenging.

For radial-sector designs the focusing (F) and defocusing (D) gradient magnets must have equal and opposite fields (but different lengths) to give enhanced "magnetic flutter" (rms field variation) and strong edge as well as AG focusing. The two proton FFAGs ▷



The orbit shape is invariant in scaling FFAG cells, but varies with energy (E) in non-scaling ones (F = focusing, D = defocusing).

recently built by Yoshiharu Mori's group at KEK are of this type. The 1 MeV POP (proof of principle) FFAG has eight sectors, each consisting of a "DFD" radial-sector triplet. It came into operation in 2000 (*CERN Courier* October 2000 p11) and measurements on the beam have provided valuable confirmation of its predicted behaviour.

The larger 150 MeV FFAG at KEK is a prototype for proton therapy and neutron production. It has 12 sectors, also DFD, with the orbit radius increasing from 4.4 to 5.3 m. Beam from the 12 MeV cyclotron injector has been accelerated to full energy and the extraction system is currently being commissioned.

A key technical innovation by Mori's KEK group has been the use of Finemet metallic alloy for rapid modulation of the RF frequency at repetition rates higher than are practical with ferrite (250 Hz in the larger machine, with a 1.5 to 4.6 MHz sweep). This material has two advantageous properties: high permeability, permitting short cavities and a high effective accelerating field; and lossiness, making the quality factor very low ($Q \sim 1$) and so allowing acceleration over a wide frequency range without any need for active tuning.

A 150 MeV FFAG of the same design is also being installed at the Kyoto University reactor, in collaboration with Mitsubishi, to test accelerator-driven sub-critical reactor operation. Two further FFAGs act as injector (a 2.5 MeV betatron with eight spiral sectors) and booster (20 MeV with eight radial sectors). Initially the repetition rate will be 120 Hz, yielding a 1 μA beam, and then later 1 kHz, providing 100 μA.

For heavy-ion therapy the National Institute of Radiological Sciences at Chiba in Japan, home of the Heavy Ion Medical Accelerator (HIMAC), has designed a three-stage FFAG, comprising rings operating at 6, 100 and 400 MeV/u. The largest, with 12 radial sectors, has a circumference of 70 m. The complex is designed to operate at 200 Hz and provide a beam of 2×10^9 C^+ions/s. Mitsubishi is also designing heavy-ion FFAGs for therapy, but of spiral-sector design. In this case a 12-sector booster (3.5–4.0 m radius) would accelerate C^+ ions to 62 MeV/u, or protons to 230 MeV. The 16-sector main ring (6.6–7.2 m radius) would take the C^+ to 400 MeV/u.

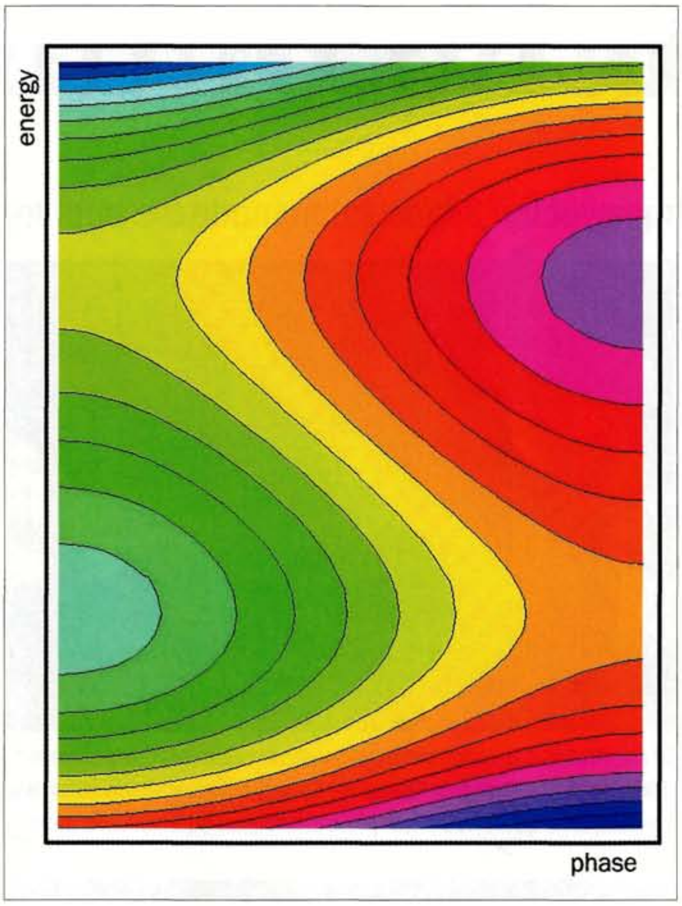
Another Mitsubishi project is the construction of a 1 MeV electron FFAG betatron as a scaled-down prototype for industrial irradiation, CT scanning and radiation therapy. This machine, appropriately named "Laptop", has five spiral sectors, an overall diameter of 10 cm and a magnet weighing all of 2.8 kg!

The 12-sector 150 MeV proton FFAG recently built at KEK.

Muon FFAGs

FFAGs are also of interest for muons at both low and high energies. PRISM (Phase-Rotated Intense Slow Muon Source), based on a 10-cell "DFD" radial-sector FFAG of 6.5 m radius, is under construction at RCNP Osaka for eventual installation at J-PARC. It will collect 5 ns wide bunches of muons at 68 MeV/c ± 30% and use a sawtooth RF field to rotate them in phase space, reducing the momentum spread to ± 3%. With a repetition rate of 100–1000 Hz the muon intensity will be 10^{11}–10^{12}/s, making possible ultra-sensitive studies of rare muon decays. It is also planned to use PRISM for ionization cooling of muons. Another proposal for ionization cooling comes from Al Garren at UCLA and Harold Kirk and Stephen Kahn at Brookhaven, who suggest using a small 12-sector gas-filled FFAG with superconducting magnets (96 cm radius) for cooling muons of 250 MeV/c ± 30%.

The KEK group's most ambitious plan is to build a neutrino factory at J-PARC based on a sequence of four muon FFAGs with top energies of 1, 3, 10 and 20 GeV. The largest would have a radius of 200 m (with a total orbit spread of 50 cm) and consist of 120 cells, each containing a superconducting DFD triplet. Most of the cells would also contain RF cavities to provide an overall energy gain of around 1 GeV per turn, restricting the losses through muon decay to 50% overall. The use of low-frequency RF (24 MHz) keeps the buckets wide enough to contain the phase drift occurring as the



In the longitudinal phase space of a non-scaling muon FFAG, bunches move from low energy to high energy along the S-shaped yellow band between the buckets.

orbit expands. A major advantage of FFAGs over linacs – either single or recirculating – is that their large acceptance obviates the need for muon cooling or phase rotation. There also turn out to be significant cost savings.

Non-scaling FFAGs

The rapid acceleration that is essential for muons allows betatron resonances no time to damage beam quality. The scaling principle can therefore be relaxed, the betatron tunes allowed to vary and lattices explored for properties that are favourable to muons. In particular, in 1999 Carol Johnstone at Fermilab showed that it would be very advantageous to make the positive bend D and the negative F (so that their fields decrease outwards rather than increasing as demanded by scaling), with the Fs weaker as well as shorter than the Ds. The circumference could be shortened; the radial orbit spread reduced, allowing the use of smaller vacuum chambers and magnets; and the orbit length made to pass through a minimum at mid-energy (instead of rising monotonically), thus reducing the variation in orbit time with energy – a vital consideration since there is no time for RF frequency modulation. Moreover, constant field gradients could be used (rather than constant field index), simplifying the magnet design and rendering non-linear resonances harmless.

Lattices along these lines have been developed by Johnstone at Fermilab, by Scott Berg, Ernest Courant, Dejan Trbojevic and Robert Palmer at Brookhaven, by Eberhard Keil at CERN and Andy Sessler at LBNL, and by Shane Koscielniak at TRIUMF.

A major advantage of FFAGs over linacs is that their large acceptance obviates the need for muon cooling or phase rotation – and there are significant cost savings.

The latest results from an ongoing cost-optimization study by Berg and colleagues favour the use of linacs up to 2.5 GeV, followed by 2.5–5.0, 5–10 and 10–20 GeV FFAGs. The main ring, to be composed of around 100 doublet or FDF triplet cells, would have a circumference of about 700 m, with orbit lengths varying by only 20 cm. With the orbit time first falling and then rising, Koscielniak and Berg have shown that by exceeding a critical RF voltage an acceleration path can be created that stays close to the voltage peak (crossing it three times), snaking between neighbouring buckets (rather than circulating inside them). By using high-field superconducting 200 MHz cavities it should be possible to accelerate from 10 to 20 GeV in 16 turns, with a decay loss of 10% (25% in the three rings). In order to demonstrate the novel features of such a design – particularly acceleration outside buckets and the crossing of many integer and half-integer resonances – the construction of a 10–20 MeV/c electron model is being considered.

Grahame Rees from the Rutherford Appleton Laboratory is proposing a very different scheme for an 8–20 GeV muon ring using OBFDFBO cells in which the F and D fields are profiled to make each of the 16 orbits exactly isochronous, allowing acceleration at peak RF voltage throughout. The price paid is a somewhat larger circumference of 1255 m. This is one of several European FFAG studies that are being coordinated through Beams for European Neutrino Experiments (BENE).

Yet another non-scaling approach has been taken by Alessandro Ruggiero at Brookhaven in a design for a 1.5 GeV proton FFAG to replace the laboratory's Alternating Gradient Synchrotron (AGS) Booster, or for high-power applications up to 4 MW. Here acceleration is relatively slow (> 1000 turns) so that resonances must be avoided. The tune is therefore kept essentially constant by using a non-linear field profile for which the changes in gradient balance those in flutter, while the non-scaling virtue of low dispersion is retained by using FDF cells with stronger D magnets than F magnets. The 136-cell FFAG, to be located in the AGS tunnel, would accelerate 10^{14} protons per pulse at 2.5 Hz, providing a 40 μA beam.

With this wide variety of new ideas and projects, it seems that FFAGs have at last come into their own. Rather than merely a historical curiosity from the mid-20th century, they are now revealed as a vital answer to the needs of the 21st.

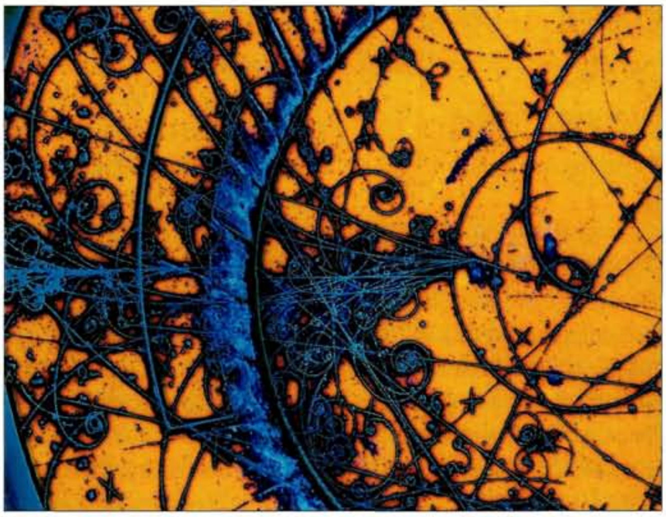
Further reading

For more about the workshop at TRIUMF, see www.triumf.ca/ffag2004.

Michael Craddock, *University of British Columbia and TRIUMF.*

In the tracks of the

Horst Wenninger pieces together many of the aspects that made the bubble-chambe



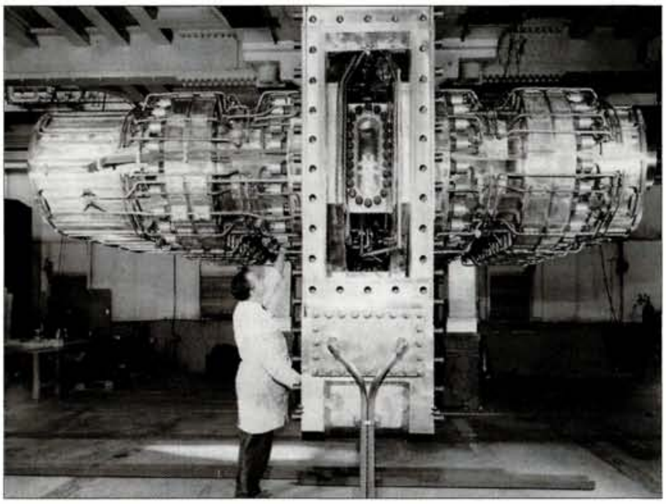
Famous postcard view of a neutrino interaction in BEBC (the Big European Bubble Chamber) filled with a neon-hydrogen mixture.

The last minute of operation of the Saclay 81 cm bubble chamber at the Proton Synchrotron in a separated beam of K^+ mesons in 1971, with the Bologna, Glasgow, Rome, Trieste collaboration and the late Charles Peyrou (with glasses, right of centre) looking on.

The bubble-chamber programme at CERN began in an atmosphere of enthusiasm soon after the foundation of the organization. The then recently invented bubble chamber was marvellously appropriate for exploiting the new CERN accelerator, the Proton Synchrotron (PS), which could reach energies where new phenomena were expected. The emergence of the electronic computer around the same time also provided a means of dealing with the large numbers of bubble-chamber pictures. New instruments would be built to measure the thousands of metres of film, and so began a period of intense activity at CERN.

The bubble chamber, which was invented in 1952 by Donald Glaser in Michigan, played an important role in experimental physics at particle accelerators. Glaser showed that the trajectories of energetic particles could be made visible by photographing the bubbles that form within a few milliseconds after particles have traversed a suitably superheated liquid. For three decades bubble chambers were to dominate particle physics, especially research on strange particles, until the mid-1980s when developments in electronics and new wire chamber detectors, together with the start of a new era of collider physics, brought an end to the bubble-chamber programmes.

The early bubble chambers were very small, but over the years they increased in size with the largest containing 20 m^3 of liquid. More than 100 bubble chambers were built throughout the world, and more than 100 million stereo pictures were taken ("30 years of bubble chamber physics" 2003). More than half of these pictures were taken at CERN by the 30 cm hydrogen bubble chamber, followed by the 81 cm Saclay chamber, the 2 m CERN chamber and finally the Big European Bubble Chamber (BEBC).



With its magnet rolled back during a shut-down of the Proton Synchrotron in 1969, the body of the 2 m hydrogen bubble chamber becomes visible.

In the 1960s bubble chambers became the main tool at CERN for the study of resonances and strange particle physics, keeping hundreds of physicists busy for a decade. The 30 cm hydrogen chamber came into operation at CERN in 1960, followed four years later by the 2 m hydrogen chamber. From the early 1960s CERN also pioneered the use of bubble chambers for the study of neutrino interactions, and it was the great interest in this field that led to the conception and construction of giant bubble chambers such as Gargamelle and BEBC.

In 1966 CERN, France and Germany launched the BEBC project –

bubble chamber

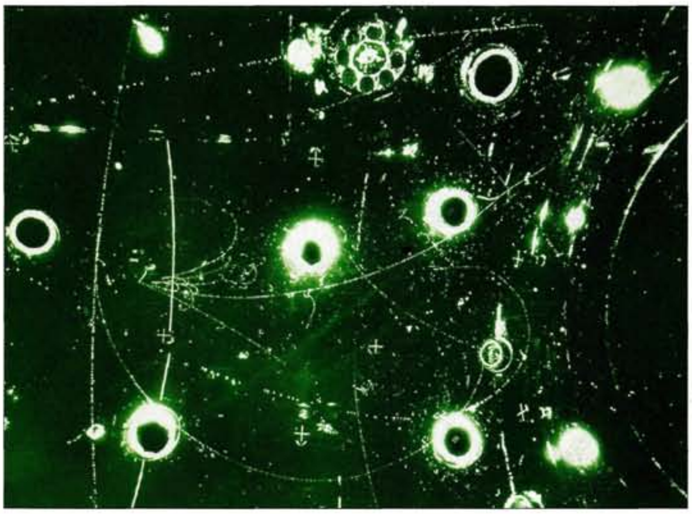
r programme an important part of CERN's development as an international laboratory.

The analysis of bubble-chamber film took place both at CERN and in the collaborating institutes. This is a typical scene of scanners at work on the projection and measuring machines at CERN.

The Gargamelle heavy-liquid bubble chamber during its installation at the Proton Synchrotron in September 1970.

a giant cryogenic bubble chamber surrounded by a 3.5 T superconducting solenoid magnet that operated at CERN in the West Area neutrino beam line of the Super Proton Synchrotron (SPS) until 1984. Gargamelle, a very large heavy-liquid (freon) chamber constructed at the Ecole Polytechnique in Paris, came to CERN in 1970. It was 2 m in diameter, 4 m long and filled with 10 tonnes of liquid at 20 atmospheres. With a conventional magnet producing a field of almost 2 T, Gargamelle was the tool that in 1973 allowed the discovery of neutral currents.

The contacts between the American laboratories and CERN were

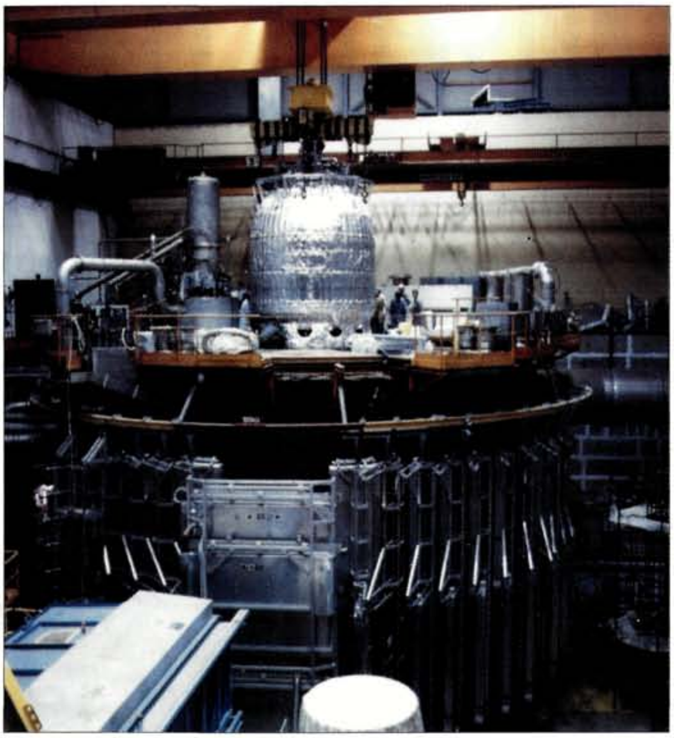


The first observation of "neutral currents" – in this case a hadronic event – in the Gargamelle heavy-liquid bubble chamber.

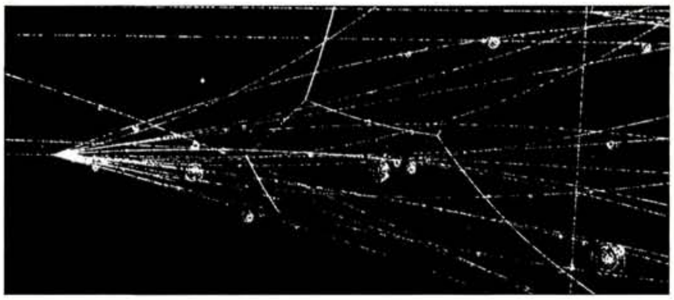
very close. The physicists at the time were inspired by the example of the Lawrence Berkeley Laboratory, where bubble-chamber experiments using beams from the Bevatron were available before CERN's PS started operation. In particular there was close collaboration on the technical side between CERN and the Brookhaven Laboratory. It was during these early years of CERN that the first international collaborations on experiments began, thanks to the distribution of bubble-chamber film and joint analysis efforts. Among the first of the groups measuring film from CERN to start a collaboration were those from Bologna and Pisa, who already had experience analysing film from the 30 cm propane chamber at Brookhaven (Eisler *et al.* 1957). A group from Warsaw with experience in nuclear emulsions, along with other groups who had worked previously with cloud chambers, also soon joined the collaborations with CERN to analyse bubble-chamber film.

The bubble-chamber exposures in beams at the PS were based on physics proposals, often hotly debated in the experimental committees at CERN. The results obtained by the many collaborations using film from the laboratory contributed to establishing bubble-chamber physics at CERN on the world stage. For example, many of the major verifications of SU3 symmetry – apart from the discovery of the Ω^- particle – came from bubble-chamber experiments at CERN during the 1960s and 1970s. The success of SU3 not only illustrated the importance of group theory in contemporary high-energy physics, but also became a vital ingredient of the modern Standard Model of particle physics.

One of the most important highlights of the bubble-chamber era – and an outstanding success story for CERN – was the discovery of weak neutral currents in Gargamelle, the giant heavy-liquid bubble ▷



The 3.7 m BEBC, with the body of the chamber wrapped in superinsulating foil being lowered into the solenoid magnet. Surrounding the magnet the "picket fence" of the external muon identifier is clearly visible, while in the foreground to the left is the external particle identifier for pions and kaons.



An 18-prong event produced by a 16 GeV/c negative pion beam in the 2 m bubble chamber in 1967.

The BEBC chamber body and piston in CERN's Microcosm Garden.

chamber (*CERN Courier* November 1998 p28). The chamber was first exposed to the neutrino beam at the PS, where the decisive detection was made. Parallel with the operation of the chamber and the evaluation of the photographs from the PS exposure, detailed background calculations were made on neutron-induced events, which could simulate neutral currents. It turned out that this background was only 15% of the signal and so neutral currents were established. Later, Gargamelle was transferred to the neutrino beam at the SPS and equipped with an external muon identifier.

Beyond physics

The results of the bubble-chamber programme at CERN extended well beyond the intrinsic interest of the physics. Bubble-chamber studies played a major role in the reconstruction of physics in post-war Europe and had a great impact on its further development. Bubble-chamber pictures could be easily transported, and efforts were made to persuade industry to construct measuring instruments that became commercially available. As had happened for nuclear emulsions a few years earlier, many new groups formed in research centres and universities, where young people were trained. These collaborations produced much of the significant physics. At CERN the use of digital computer and data-handling techniques for experiments began with bubble chambers, and their use in other fields of high-energy experimentation followed later

Bubble-chamber physics became a training ground for physicists, engineers, technicians, and for specialists in computers and data handling. A great number of new techniques were developed to improve particle identification both inside and outside the track-sensitive volume of the bubble chambers. There was the question, for instance, of how best to convert photons resulting from π^0 decays inside a hydrogen bubble chamber. This led at CERN to the operation of track-sensitive hydrogen targets, surrounded by neon-hydrogen mixtures, to improve the photon-conversion efficiency.

Over the years there were many other technical developments (Mulholland and Harigel 2003). Proportional wire chambers surrounding the bubble chambers allowed the identification of muon tracks escaping from the inside through the tanks and magnets of the bubble chamber. Special fish-eye optics, stereo photography and holography were developed to optimize the recording of the particle tracks. Finally, rapid-cycling bubble chambers and hybrid systems, which combined bubble chambers with spectrometers and counters, were constructed. Interaction triggers, in particular for signals of charm events, were used to fire the flash so as to take photographs only of interesting physics events in order to improve on the slow data-taking rate of bubble chambers. CERN's competence in engineering and cryogenics, which was developed in the Track Chamber Division through the building and exploiting of bubble chambers, later benefited the construction of the detectors for the Large Electron Positron collider and the experiments for the Large Hadron Collider (LHC).

A whole generation of physicists wrote their PhD theses based on bubble-chamber data. Perhaps because of the large numbers of young people who were working in the field of bubble chambers and film analysis, many are to be found today as leaders of experimental teams or laboratories, and indeed in many other diverse areas.

Lastly, and arguably most importantly, bubble-chamber physics initiated on a large scale the symbiosis between CERN and its community of users. Laboratories that at first limited their activities to measuring pictures and analysing the results soon diversified their activities and links with CERN expanded. This became one of the ingredients of CERN's success. Bubble chambers had initiated the international collaborations for performing experiments that are now extending to the worldwide collaborative efforts for the LHC.

The bubble-chamber era has now ended and the remains of the major CERN bubble chambers are today exhibits in science museums – BEBC and Gargamelle are in the garden outside the Microcosm exhibition at CERN and the 2 m chamber was donated to the Deutsches Museum in Munich. However, bubble chambers live on in other ways, not only through the many beautiful postcards and books showing bubble-chamber tracks, but also through many of the original ideas and the "bubble chamber philosophy" that continues to play an important role in physics today.

Acknowledgments
The author would like to acknowledge some valuable sources of material. Much of this article is based on a memorandum written in 1987 by the late Yves Goldschnidt-Clermont to the CERN history committee (Goldschnidt-Clermont 1987). The proceedings of the "Bubbles 40" conference, held at CERN in 1993 to commemorate the 40th anniversary of the invention of the bubble chamber, document the evolution and impact of bubble chambers on particle physics and physics discoveries and outline their technological, sociological and pedagogical legacies ("Bubbles 40" 1994). Jack Steinberger from CERN recounted his time with bubble chambers in memories of his early life (Steinberger 1997), also extracted in *CERN Courier* (May 2001 p24), and the impact of Charles Peyrou on the bubble-chamber programme at CERN is recalled in a tribute published after his death in 2003 (*CERN Courier* June 2003 p25).

Further reading

"Bubbles 40" 1994 *Nuclear Phys. B (Proc. Suppl.)* **36**.
F Eisler *et al.* 1957 *Phys. Rev.* **108** 1353.
Y Goldschnidt-Clermont 1987 Memo 10 Nov to CERN history committee "Physics at CERN 1958–1965".
G T Mulholland and G Harigel 2003 "Liquid Hydrogen: Target, Detector" in AIP Conference Proceedings – Advances in Cryogenic Engineering **710** 16.
J Steinberger 1997 *Ann. Rev. Nuc. Sci.* **47** xiii.
"Thirty years of bubble chamber physics" March 2003, Bologna; see www.bo.infn.it/~spurio/bubble.htm and *CERN Courier* July/August 2003 p19.

Horst Wenninger, *CERN*.

The beta-decay route to a high-flux neutrino source

Online isotope separation combined with some imaginative accelerator "gymnastics" could provide a high-intensity neutrino beam at CERN. **Steve Hancock** describes a possible scenario.

Neutrino physics is very much in vogue. The discovery that these elusive particles can oscillate between their three established identities has made the mixing of neutrino flavours more than just "flavour of the month" for theorists and experimentalists alike. Such behaviour introduces the possibility of differences between the matter and antimatter versions of neutrinos. This charge–parity violation, already observed in quarks, may in turn help to explain the disparity between the amounts of matter and antimatter we observe in our universe.

For experimentalists, particle accelerators and nuclear reactors already supplement the neutrinos that come from the Sun or are produced by cosmic rays in the Earth's atmosphere. However, to investigate properly the new phenomena, the demands on neutrino flux far outstrip supply and some distinctly unconventional sources have been proposed to meet the shortfall. The most recent of these is the "beta-beam" concept, which envisages the production of a pure beam of electron neutrinos (or their antiparticles) through the beta decay of radioactive ions circulating in a high-energy storage ring.

Several factors determine a suitable choice of ion. The flux of neutrinos from the decay ring is determined solely by the rate ions can be accumulated, but the flux at a detector a given distance away also depends on the average energy with which the neutrinos are emitted in the rest frame of the parent ion. Further constraints on ion choice are set by the decay losses that can be tolerated in the accelerator chain and by the decay products that could create long-lived contamination in the low-energy part of that chain. Together these considerations suggest two isotopes of particular interest: ^{18}Ne, giving electron neutrinos, and ^{6}He for antineutrinos. Both can be produced in large quantities by the ISOL (isotope separator online) method, which has been used routinely at CERN for more than 35 years.

Efficient production of the helium isotope requires a two-stage target. Spallation neutrons released in a heavy-metal converter by a very intense proton beam can produce large amounts of ^{6}He in a secondary target of beryllium oxide. The advantage of the converter technology is that the primary proton beam does not impinge directly on the sensitive beryllium oxide. This prolongs the lifetime of the target considerably. The proton-rich neon isotope, ^{18}Ne, can be produced directly by spallation in a suitable target material, e.g. magnesium oxide, but this requires irradiation in a primary proton beam. Consequently, it is possible to produce about a factor of 10 more ^{6}He atoms than ^{18}Ne ones because the proton beam power must be limited for the latter. ▷

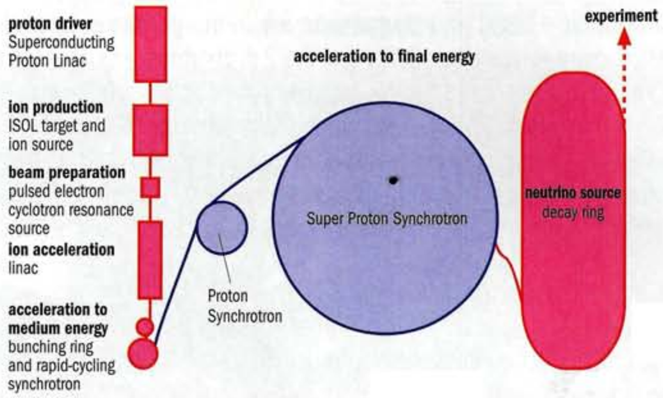


Fig. 1. A schematic view of the proposed beta-beam facility.

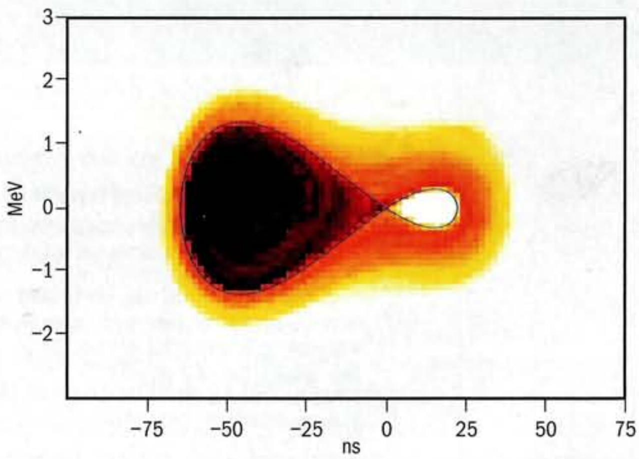


Fig. 2. Tomographic measurement of longitudinal phase-space density during asymmetric bunch pair merging in the CERN PS. By controlling the relative phase and voltage ratio of a dual-harmonic RF system, it is possible to merge unequal emittances. Here, one "bunch" is a phantom: an empty bucket was conserved during its transportation into the core of a much larger bunch where the (white) empty phase space was merged with the (dark) central region of the particle distribution. Tomography reveals a well preserved empty bucket entering the bunch as the acceptance of the populated bucket shrinks and particles bleed out around the separatrix (blue curve).

The next steps, following isotope production, are to strip off all the remaining electrons and bunch the beam prior to acceleration. It is hoped that both tasks can be accomplished efficiently by a high-frequency (60 GHz) electron cyclotron resonance source. While such a system does not exist today, theoretical calculations are encouraging and a first feasibility test could be envisaged in the near future. Once fully stripped, the ions would be accelerated in a linac to increase their lifetime. The acceleration of high-intensity radioactive ion beams to around 100 MeV/u using a linac has already been studied by the EU-financed EURISOL study (*CERN Courier* April 2004 p23).

Further acceleration could be achieved using the existing CERN accelerator infrastructure. However, space-charge effects at injection dictate a beam energy of at least 300 MeV/u before the intensities required for the beta-beam can be digested by CERN's Proton Synchrotron (PS). This constraint, together with the need for bunches much shorter than those provided by the linac, means that an additional stage of bunching and acceleration is required. The most promising scenario involves multi-turn injection of the linac beam into a rapid-cycling synchrotron, followed by bunching, acceleration and transfer to the PS. This procedure is repeated until all RF buckets are filled and the beam is then accelerated to its top energy and sent to the next synchrotron at CERN, the Super Proton Synchrotron (SPS).

Injection into the SPS is an established space-charge bottleneck, so the bunches must fill the maximum available transverse aperture. It is also foreseen to keep them as long as possible using a new RF system during the early part of acceleration until the standard high-frequency system can take over near the transition energy.

Finally, the decay ring will be an accumulator for the bunches delivered by the accelerator chain. Accumulation is possible because the half-life of the highly relativistic stored ions is more than an order of magnitude longer than the cycling time of the injectors. It is proposed to stack the ions by asymmetric bunch pair merging (figure 2). This relies on a dual-harmonic RF system to combine adjacent bunches in longitudinal phase space such that a fresh, dense bunch is embedded in the core of a much larger one, while diluting the emittance of the beam as little as possible. Each new bunch must be injected in the neighbouring RF bucket to an existing bunch in the stack, but this cannot be done using conventional kicker magnets and septa because of the short risetime that would be required.

An alternative injection scheme exploits the fact that the stack is located at only one azimuth in the decay ring and that the revolution period is relatively long. The new bunches are off-momentum and are injected in a high-dispersion region on a matched dispersion trajectory. This allows a full turn to bring the off-momentum orbit inside the machine at the entry point of the beam. Subsequently, each injected bunch rotates a quarter of a turn in longitudinal phase space until the initial conditions for merging the bunch pairs are met and stacking can proceed.

The aim is to collect an unprecedented 10^{14} helium ions (5×10^{12} neon ions) in just four bunches, each only 10 nanoseconds long. This is to ensure that enough neutrinos are localized in time sufficiently well to overcome the background issues at the detector in Fréjus some 130 kilometres away in France.

Steve Hancock, *CERN*.

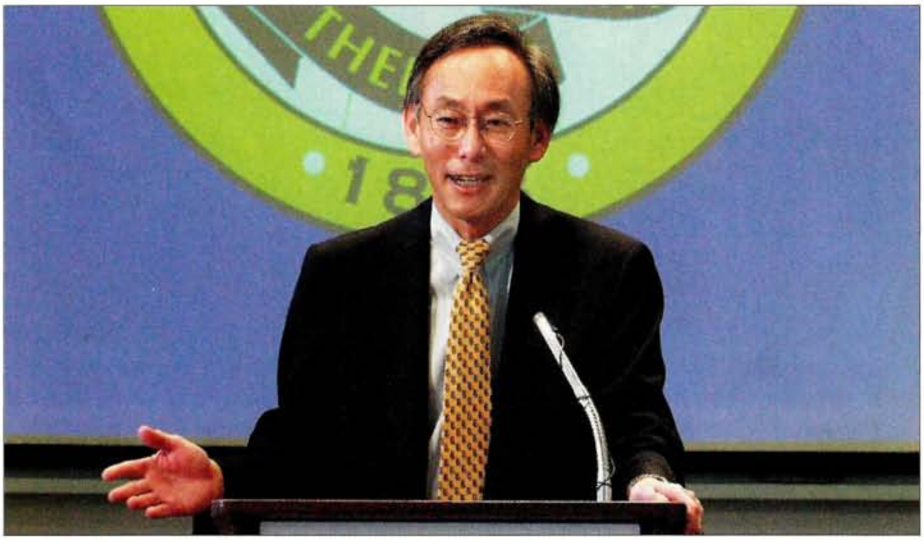
PEOPLE

LBNL

Berkeley names Nobel laureate Steven Chu as next director

The University of California (UC) Board of Regents has named Steven Chu, professor in the physics and applied-physics departments at Stanford University and a co-winner of the Nobel Prize in Physics, as director of the Lawrence Berkeley National Laboratory (LBNL). Chu, who earned his doctorate from UC Berkeley, is currently the Theodore and Francis Geballe Professor of Physics and Applied Physics at Stanford, where he has been on the faculty since 1987. He will be the sixth director of the LBNL, which is managed by the University of California, and will take office on 1 August.

"Steve Chu brings to this position outstanding leadership qualities and a record of superior achievement in science," said UC president Robert C Dynes. "His combination of skills is precisely what we need to keep the LBNL at the forefront of scientific excellence and to guide the lab wisely through the upcoming potential contract competition." Chu is taking over from Charles Shank, who will take a sabbatical and then return to the UC Berkeley campus to continue teaching and research.



Nobel prize winner Steven Chu will become the sixth director of the LBNL in August.

Chu was awarded the Nobel Prize in Physics in 1997, together with Claude Cohen-Tannoudji and William D Phillips, "for the development of methods to cool and trap atoms with laser light". Beginning in 1989, Chu expanded his research scope to include polymer physics and biophysics at the single-molecule level. At Stanford, with three other professors, Chu initiated Bio-X, a campus-wide initiative that brings together researchers from the physical and biological sciences with those from engineering and medicine. He also played a key role in establishing and funding the Kavli Institute for Particle Astrophysics and Cosmology at Stanford.

Charles Shank, the outgoing director of LBNL, visited CERN on 26 May. His tour included visits to the ATLAS experiment's assembly hall, the test-beam facility for many of the experiment's components, and the underground cavern where he saw progress in installation.

LBNL is making important contributions to the ATLAS Inner Detector, in particular for the silicon strip and pixel detectors that will sit closest to the interaction region in the Large Hadron Collider (LHC). Here Shank (right) is seen in the cleanroom facility for the Inner Detector together with Kevin Einsweiler from the Pixel System group at LBNL. Shank also visited the assembly hall for the CMS experiment and the test facility for the LHC magnets.

DESY

Forty years of synchrotron radiation research

The class of '68: DESY's synchrotron radiation pioneers Ruprecht Haensel (second from the left), Christof Kunz (fourth from the left) and Bernd Sonntag (seventh from the left), along with their team of visiting researchers, technicians and students.

Albrecht Wagner, left, congratulates Peter Stähelin, the "father" of synchrotron radiation research, at the ceremony at DESY – a few days after Stähelin's 80th birthday.

On 19 May 250 guests from all over the world joined DESY in celebrating the anniversary of the laboratory's work with synchrotron radiation. "The first measurements with the light beam from the DESY ring accelerator started in 1964. DESY was one of the laboratories in which the worldwide success story of research with synchrotron radiation began," Albrecht Wagner, DESY's director-general, explained in his welcoming address. Today, more than 1900 scientists from 31 countries come to DESY each year to carry out experiments with synchrotron radiation.

At the beginning of the 1960s the intense radiation generated when accelerated electrons travel around a curved path was regarded by physicists at DESY and elsewhere as an unwanted, disruptive effect. Early on, however, Peter Stähelin, the research director at the time, recognized the experimental opportunities offered by synchrotron radiation. In 1962 he instructed the young physicist Ruprecht Haensel to fathom out the perspectives of the new light source for his PhD thesis. After much pioneering work, measurements with synchrotron radiation finally began at the electron synchrotron in 1964.

Stähelin's plan succeeded; more and more scientists from various fields began to analyse their samples with synchrotron radiation. The larger storage ring DORIS began operation in 1974, initially providing experimental opportunities for both the particle-physics community and the users of synchrotron radiation. Since 1993 DORIS has been used exclusively as a dedicated radiation source. Another important step came in 1980 with the establishment of the Hamburg Synchrotron Radiation Laboratory, HASYLAB, which maintains a large experimental hall with 40 measuring stations at DORIS and three test measuring stations for hard X-ray radiation at the PETRA synchrotron.

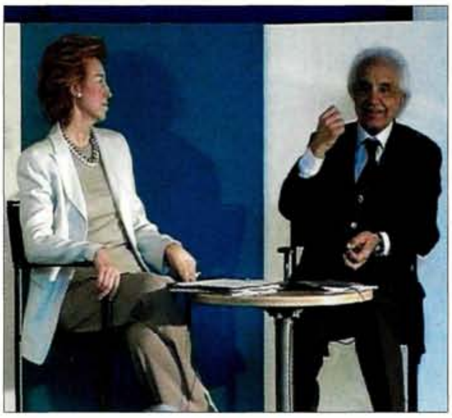
The future of research with synchrotron light at DESY looks equally promising. From 2007 onwards PETRA will be converted into the most brilliant storage-ring-based X-ray source in the world. Starting in 2005 a 260 m long free-electron laser, VUV–FEL, will provide radiation in the vacuum ultraviolet (VUV) and the soft X-ray range. At the same time the FEL will serve as a prototype for the 3.3 km long European X-ray Free-Electron Laser, XFEL, which will produce even shorter wavelengths in the X-ray range and start operation in 2012.

XFEL was approved by the German Federal Ministry of Education and Research in February 2003 on condition that it should be realized as a European project, with 50 percent of the costs born by the partner states. Negotiations with interested European states are now well underway.

The 2003 prize of the Association of the Friends and Sponsors of DESY for the best PhD thesis covering DESY research has been awarded to Jürgen Wendland (left) from the Simon Fraser University in Canada, for work carried out on the HERMES experiment at HERA. His thesis, "Polarized Parton Distributions Measured at the HERMES Experiment", has made a decisive contribution to the explanation of the proton spin. Wendland determined the spin contributions of the quarks separately for each type of quark, and has been able to show for the first time that "sea" quarks and antiquarks clearly contribute to the spin of the proton to only a minor degree. This suggests that the gluons are an important source of the proton spin. Here Wendland is shown receiving the prize from Erich Lohrmann, the chairman of the association.

LEARNING WITH COSMIC RAYS

CERN webcast inaugurates Italian project



On stage in front of the camera, Letizia Moratti (left), the Italian minister of education, universities and research, and Antonino Zichichi, the initiator of the Extreme Energy Events project for schools.

Letizia Moratti, centre, with CERN's director-general Robert Aymar, left, and Antonino Zichichi.

A major webcast on 3 May linked CERN and high schools all over Italy on the occasion of an extended visit to the laboratory of Letizia Moratti, the Italian minister of education, universities and research. The webcast was to inaugurate the Extreme Energy Events project, which Moratti has approved for the promotion of scientific culture in Italian schools.

On stage in front of the camera Moratti was joined by the initiator of the project, Antonino Zichichi from Bologna University. The audience in the LAA building at CERN included an important delegation from Moratti's ministry, the Italian ambassador, collaborators from Bologna University and students from the Italian School of Lausanne. Receiving the broadcast via the Web were students and teachers in hundreds of Italian high schools.

During the webcast Zichichi presented the first module of the multigap resistive plate chamber (MRPC) constructed in the LAA laboratory at CERN. In a new approach that is designed to bring school students into contact with modern scientific tools, MRPCs will be constructed by students in the participating schools and then networked together to measure and analyse cosmic-ray data across Italy. Luisa Cifarelli, a professor at Bologna University, discussed the physics behind the project and explained the origin of cosmic rays, presenting simulation data of extreme-energy cosmic-ray showers over Italy. The ALICE team from Bologna then demonstrated the different steps in the construction of MRPCs, readout electronics assembly and cosmic-ray tests that were done in the LAA laboratory and the Physics Institute at Bologna University.

Zichichi also presented the basic frontier research activities being prepared at CERN for the Large Hadron Collider (LHC), which seek answers to the questions raised in our current understanding of subnuclear physics. Lucio Rossi, head of the LHC magnet group at CERN, described the activities in the magnet assembly hall and reminded the audience of the long history of the development of superconducting magnets, which was initiated in Italy by Zichichi.

Following the webcast Moratti held discussions with the CERN directorate, and visited the LHC magnet assembly hall, the cavern for the ALICE detector and the CERN Computer Centre, where Fabrizio Gagliardi and his team presented their activities on the Grid project.

Dutch schools project wins innovation award

A Dutch project that involves teams of high-school students studying ultra-high-energy cosmic rays has won the 2004 Altran Foundation for Innovation award. The award will provide the High School Project for Astrophysical Research with Cosmics (HiSPARC) with technology consultancy worth €1 million from Altran, the French consulting group.

HiSPARC began in 2000 in Nijmegen, and has since evolved to become a nationwide network of cosmic-ray detectors, with more than 35 schools involved, clustered on five universities. The project is also supported by the Dutch high-energy physics institute NIKHEF. Students in the participating schools build the detection system (scintillating plastic tied to a digital oscillator and a global positioning system for time stamping) to take local measurements and then combine their results to look for cosmic-ray showers over areas of 10 km^2.

Under the award scheme, Altran offers one year of technological advice in the form of personalized assistance in areas such as project management, cost optimization and communication. For the 2004 award Altran chose the theme "Discovering, understanding and enjoying science through innovation".

LETTERS

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

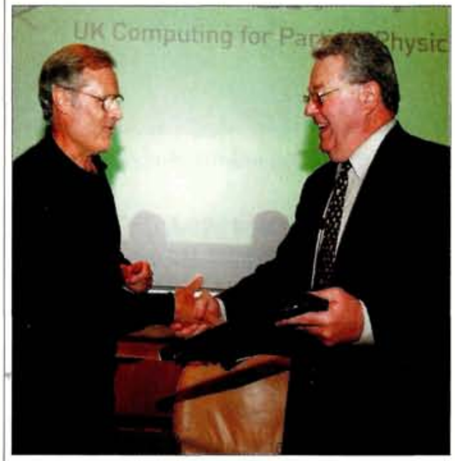
Back in 1963

It was with interest that I read the 1963 archive page regarding the construction of a new synchrocyclotron based on one already in operation at CERN (*CERN Courier* June 2004 p11). I did not know the machine once in operation here in the United States was based on CERN technology. The "Space Radiation Effects Laboratory" is long since gone, but the building constructed to house the synchrocyclotron is now the site of the Thomas Jefferson National Accelerator Facility's "Test Lab". The building is home to the Institute for SRF Science and Technology, where superconducting components for Jefferson Lab's accelerator were, and still are, designed and assembled. *CERN Courier's* short article brought this site full circle and took me back in time. Thank you.

Linda Ware, public affairs manager, Thomas Jefferson National Accelerator Facility.

AWARDS

British researchers receive awards for Grid development



Frank Harris of Oxford University (left photo), and Andy McNab of Manchester University receive their CERN–UK awards from Robert Aymar, the director-general of CERN.

On 2 June two of the British researchers who have been at the forefront of Grid computing at CERN received achievement awards in recognition of the UK's contribution to next-generation computing. Andy McNab of the University of Manchester was presented with a CERN–UK award for outstanding achievement in Grid development, and Frank Harris of Oxford University was given a CERN–UK lifetime achievement award.

McNab has made key contributions to developing a robust security model for the Large Hadron Collider Computing Grid, while Harris has played an important role in the progress of online computing while based at CERN for the past 15 years.

The awards were presented by CERN's director-general, Robert Aymar, during a meeting of GridPP, a collaboration of particle physicists and computing scientists from the UK and CERN.

Wolf prize goes to particle physicists

The 2004 Wolf Prize in Physics has been awarded to three important figures in modern particle physics: Robert Brout of ULB, Brussels, François Englert, now at Tel Aviv University and professor emiritus at ULB, and Peter Higgs, professor emiritus at Edinburgh University. The Wolf Foundation rewarded the trio for "pioneering work that has led to the insight of mass generation whenever a local gauge symmetry is realized asymmetrically in the world of sub-atomic particles". They shared the prize of $100 000, which was awarded at a ceremony at the Knesset in Jerusalem on 9 May.

MEETINGS

The Spanish School on High Energy Physics, TAE04, is to be held in Santiago de Compostela from 13–24 September. TAE (Taller de Altas Energías) is an annual workshop aimed at first and second year graduate students who are starting research in experimental or theoretical high-energy physics. This year's school will cover basic material on astroparticle physics, experimental techniques, quantum field theory and physics beyond the Standard Model. For further information, see http://www-fp.usc.es/tae.

The High Energy Physics Group of The Institute of Physics is holding a meeting to celebrate **The 50th birthday of CERN** on 29 September at The Institute of Physics in London. There will be presentations on CERN – past, present and future. For further details, see http://groups.iop.org/HE/cern.html, or contact Roger Barlow at roger@hep.man.ac.uk.

RICH2003, the 5th International Workshop on Ring Imaging Cherenkov Counters, is to be held in Playa del Carmen, Mexico, on 30 November to 5 December. Dedicated to the centenary of Pavel Cherenkov's birth, the conference will consist of topical sessions on various aspects of the use of RICH and related detectors. The sessions will present technical details and physics results. For further details, see www.ifisica.uaslp.mx/rich2004.

CORRECTION

In the article concerning the latest results from the E949 experiment at Brookhaven National Laboratory (*CERN Courier* May 2004 p6), the Standard Model branching ratio for the decay $K^+ \to \pi^+ \nu\bar{\nu}$ was given incorrectly. It should have read $(7.7 \pm 1.1) \times 10^{-11}$; thus the experimental result is about twice the prediction.

CERN

Indian gift unveiled at CERN

The statue of the Indian deity Shiva at CERN was unveiled by His Excellency K M Chandrasekhar (seated), Anil Kakodkar (left) and Robert Aymar (centre).

On 18 June CERN unveiled an unusual new landmark – a statue of the Indian deity Shiva. The statue is a gift from CERN's Indian collaborators to celebrate CERN's long association with India, which began in the 1960s. It was unveiled by His Excellency K M Chandrasekhar, ambassador (WTO Geneva), shown above signing the visitors' book, Anil Kakodkar, chairman of the Atomic Energy Commission and secretary of the Indian Department of Energy, and CERN's director-general, Robert Aymar. The statue was made in India in the traditional style. The original sculpture was a wax model, around which a soil mould was made. Melting the wax left a hollow into which liquid metal was poured, and once cooled the mould was split and the statue polished and given its antique finish.

Iranian supplier HEPCO receives CMS Gold Award

Ali Mohammad Rafiee (left) from HEPCO receives the CMS Gold Award from CMS spokesman Michel Della Negra.

As part of the fifth annual CMS awards, Iranian contractor HEPCO has received a Gold Award, for top suppliers, in a ceremony held on 14 June (for the other award winners, see *CERN Courier* May 2004 p35). HEPCO received the award for the excellent quality of work in constructing two 20 tonne support tables, two 75 tonne shields and supporting brackets to lower the Hadron Forward Calorimeter into the CMS detector cavern, to tolerances that were very difficult in structures of this size.

NEW PRODUCTS

Acqiris has introduced new 3U single-slot PXI digitizers that provide high-speed waveform recording in any PXI and CompactPCI chassis. The DC140 and DC135 deliver bandwidths of 1 GHz and 500 MHz, respectively, and offer multiplexing capability. Both digitizers come complete with software, including the AcqirisLive control program. For more details, see www.acqiris.com.

Delta Elektronika has added a small, 150 W triple-output power supply to its EST150 series of switch-mode power supplies. Weighing only 3.5 kg, the new EST150 has an output ripple of less than 0.5 mV RMS and very low spikes. Two outputs provide 20 V at 2.5 A and the third gives 10 V at 5 A. For further information, tel: +31 111 413 656, or see www.DeltaPowerSupplies.com.

Electron Tubes is offering HVSys, a remotely controlled, multi-channel, photomultiplier power-supply system, which provides individual channel control and monitoring via three wires. The HV is generated at the photomultiplier base via the PSM series of power bases, using a +12 V supply with a supply current of less than 25 mA per channel. For further information, e-mail: info@electron-tubes.co.uk, tel: +44 1895 630 771, or see www.electrontubes.com.

HiTek Power has announced the addition of the HiGen 120 to the HiGen family of X-ray generator power supplies. The 120 W modular unit supplies up to 60 kV at up to 2 mA and is powered from a 24 Vdc input. Output ripple is better than 0.1% peak-to-peak and stability is ±0.1%. For further information, call Carey Austin on: +44 1903 712 400, e-mail: sales.uk@hitekpower.com, or see www.hitekpower.com.

Thales Computers has launched its new Fast Track COTS delivery programme, ensuring delivery of its COTS (commercial off-the-shelf) single-board computers in two weeks or less. For further information, including the boards covered by this programme, tel: +1 800 848 2330, e-mail: lkirby@thalescomputers.com, or see www.thalescomputers.com.

TRIBUTES

MRST meeting acclaims Pat O'Donnell

The 26th Montreal–Rochester–Syracuse–Toronto (MRST) conference on high-energy physics, "From quarks to cosmology", was held on 12–14 May at Concordia University, Montreal. The meeting celebrated the retirement of Patrick J O'Donnell, professor of theoretical physics at the University of Toronto and one of the original organizers of the MRST series. Many of O'Donnell's collaborators attended and speakers included Harry Lipkin, Gabriel Karl, Mark Wise and David London, who highlighted his seminal contributions to hadron spectroscopy and B physics. O'Donnell has also had a "second career" as a movie actor and scientific consultant, notably in *Good Will Hunting*. The meeting was followed on 15 May by a one-day "Harryfest" at McGill University, which celebrated the retirement of Rutherford Professor of Physics, Harry Lam.

Luciano Paoluzi honoured in Rome

A ceremony was held on 27 April at the Physics Institute of the Rome University Tor Vergata to dedicate the meeting hall to the memory of the distinguished physicist Luciano Paoluzi, who died two years ago. Giorgio Salvini, Nicola Cabibbo and Enzo Iarocci were among the speakers who remembered Paoluzi's generous and wise personality and revisited his main achievements. Paoluzi was among the pioneers in exploiting the Frascati electron synchrotron and the electron–positron storage ring, ADONE, and participated in the discovery of multihadronic production. He actively collaborated in the UA1 experiment at the proton–antiproton collider at CERN and in the GALLEX experiment at the Gran Sasso underground laboratory. He headed the FENICE experiment at ADONE, measuring for the first time the neutron time-like form factors, and led the construction of the huge KLOE drift chamber at the ϕ-factory, DAFNE, at Frascati. Paoluzi was also involved in INFN management for almost 20 years.

OBITUARY

Mervyn Hine 1920–2004

Mervyn Hine, one of the early pioneers of CERN, passed away on 26 April following an accident at his home in Switzerland. He was born in 1920 in Berkhamstead, England, and at the age of 16 went to King's College, Cambridge, to study physics, where he was awarded a first-class degree after only two years. During the Second World War he worked on radar research in Malvern with John Adams, who was later director-general of CERN. Following the war, Mervyn completed his doctorate at King's College and afterwards carried out pioneering work on particle accelerators at the Harwell Laboratory. In 1952 he, John Lawson and John Adams published a seminal paper on the management of resonances that pointed the way forward in the design of big machines.

In 1953 Mervyn and Adams moved to Geneva to work at CERN on the Proton Synchrotron (PS). Mervyn made essential contributions that shaped the strong focusing (or alternating gradient) principle into a practical design for an accelerator that could be built, albeit with extreme attention to accuracy. As a result, the PS could attain over 25 GeV rather than the 10 GeV possible with the conventional choice of weak focusing. Mervyn served as Adams's alter ego, and together they formed an outstanding pair of leaders for the first generation of CERN machine physicists and engineers. They were often referred to as "the Harwell twins".

Early in 1960, with the PS commissioned, Mervyn became director for applied physics, first under John Adams as director-general and then under Victor Weisskopf, who succeeded Adams in 1961. A close collaboration ensued and Mervyn's role expanded well beyond applied physics, in particular to medium-term planning for the whole laboratory. Weisskopf confided in Mervyn and sometimes would ask advice if he felt he had made a mistake or hurt someone. Mervyn's answer, often quoted later by Weisskopf, would be: "Put your regretter on zero."

In early 1962 CERN Council set up a working party under Dutch delegate Jan Bannier to address a budget overrun crisis. With his assistant Gabriel Minder, Mervyn designed and implemented CERN's Functional Programme Presentation, a high-level planning instrument with a formal four-year rolling procedure (described in Mervyn's article written shortly before his death; *CERN Courier* June 2004 p17). As he said later: "I was amused how, by plotting national-science cost forecasts on logarithmic paper, their straight-line 20–25% per annum growth rates surprised the group and made our proposed 13% increase look modest." Without this, it is unlikely that the member states would have accepted funding simultaneously three CERN programmes with yearly growth percentages in two digits. This was particularly important for building the Intersecting Storage Rings (ISR), regarded as "unwise" by laboratories in the US, who would not fight for the necessary funding but adopted a "wait and see" attitude.

Mervyn loved *l'esprit français* – he regularly read *Le Monde* and *Le Canard Enchaîné* and knew every bit of French official politics and gossip. This made him a natural planning companion of Henri Laporte, the leader of CERN's Site and Buildings Division in the late 1960s and 1970s. Mervyn would often meet Laporte in the cafeteria for breakfast, and that is where CERN's building programme would develop informally. As Laporte said recently: "Mervyn amazed me with his curiosity and enthusiasm for new topics, technical or not. His insights would be original, sometimes paradoxical but always useful." Supervision of the whole building programme was also greatly helped by Mervyn's excellent relationships with Bernard Gregory, the director-general at the time, and George Hampton, the director for administration (whose obituary Mervyn wrote in the May 2004 issue of *CERN Courier* (p39)).

Mervyn was even closer to Kjell Johnsen, his old-time friend in charge of planning both the ISR and the 300 GeV Super Proton Synchrotron (SPS). According to Johnsen, Mervyn played a vital part in the ISR project as an intermediary between the machine designers and the CERN management, particularly Weisskopf. Trusted and respected by both sides, his influence and judgement were often crucial. He had the technical ability to assess the machine's feasibility and the political ability to convince others that this risky undertaking was justified. The great success of the ISR 30 years ago was the essential first step for high-energy physics to move from fixed-target machines towards the collider designs that dominate today. Along that path at CERN lay the SPS (modified as a collider), the Large Electron Positron collider and, now, the Large Hadron Collider.

From 1964–1971 Mervyn also supervised CERN's computer development, recognizing that the advances in detector technology such as large bubble chambers required adventurous steps in data analysis and computing power that were not understood by many physicists. He arranged for CERN to receive one of the very first CDC 6600 supercomputers after long discussions with Seymour Cray, the American designer of the machine.

He was also involved in numerous high-level technical negotiations with multinational suppliers, always arguing that it was a major development opportunity for them to supply CERN, for which they should be prepared to pay! Mervyn's financial talents also served the CERN pension scheme, via Georges ▷

OBITUARY

▷Tièche, Günther Ullmann and Kees Zilverschoon. He loved treating long-term pension issues in the same way as physics programmes, that is with rigour and a feeling for the human element. One of his last unfinished papers in 2004 is entitled: "Pensions in 2040".

After ceasing to serve as a director in 1971, Mervyn joined the Computing and Data-handling Division and worked on several forward-looking projects. Few people know that he was a main driving force behind the launch and development of CERNET, the first general-purpose local-area network at CERN which, beginning in the early 1970s, interconnected central mainframe and minicomputer systems on the site. This was an early step away from the chaos of heterogeneous networking standards prevailing at that time, almost a decade before the arrival of Ethernet at CERN and later the Internet.

From 1978–1983 Mervyn conceived and directed the STELLA satellite project, interconnecting six European laboratories at the then radical wide-area speed of 1 Mbit/s. As his deputy, I appreciated the political skill he showed as he dealt with entrenched monopolies such as the feared PTTs. For CERN to be permitted to transmit data from an antenna on the roof of the computer centre required weeks of negotiation, culminating (successfully) over a bottle of white Valaisan wine in the presence of the director-general of the Swiss PTT. I also observed Mervyn's learning curve, one of the steepest in my experience. By the end of STELLA, apart from its project management, he knew every important technical detail, relishing particularly the elegant mathematics of the coding theory used to reduce transmission errors to acceptable values.

On retiring from CERN in 1985, he devoted much of his energy to assist his wife Jenny, the secretary of the International Association for Transactional Analysis. Mervyn served as the association's treasurer and also helped to run the courses and meetings that Jenny organized in their home at Founex, near Geneva.

Mervyn often visited the US, where his daughter Alison and grandson Benjamin live in Ann Arbor, Michigan, and England, where his daughters Jessica and Marion live in Suffolk. He did not particularly enjoy travelling but was very international in spirit, crossing European as well as intercontinental cultural divides easily, always with his sense of humour and curiosity intact and alive. We have no way to replace him but our memories of Mervyn are plentiful and full of vitality.

● Many of Mervyn's friends and colleagues, as well as his family members, have contributed to this article, which I have had the privilege of editing. Gabriel Minder provided the single largest source of information.

Ben Segal, Founex, Switzerland.

RECRUITMENT

For advertising enquiries, contact *CERN Courier* recruitment/classified, Institute of Physics Publishing, Dirac House, Temple Back, Bristol BS1 6BE, UK.
Tel: +44 (0)117 930 1028. Fax: +44 (0)117 930 1178. E-mail: sales@cerncourier.com.
Rates per single column centimetre: mono $74/€68/£47, single colour $76/€71/£49, full colour $80/€74/£51. Please contact us for more information about publication dates and deadlin

SIEMENS

What's the big appeal?

Siemens Magnet Technology

Magnet Engineer

Part of the Siemens Group, Siemens Magnet Technology is a world leader in the design and manufacture of superconducting magnets for MRI body scanners, and has achieved significant export growth and technological advancement. To help meet demand for our innovative new magnet technology, we have recently increased our manufacturing capacity with a £10 million expansion programme of the Oxfordshire factory.

Joining our multi-disciplinary Magnet Team, this is a key position that offers a real opportunity to be continually stretched by technical and analytical challenges. Primarily concentrating on the physics and engineering of superconducting magnets through to installation, your main responsibilities will include:

- Maintaining and developing state-of-the-art competence in magnet engineering and manufacturing processes
- Identification of magnet risks and agreeing handling strategies
- Awareness of magnet patent situations and the risk of violation
- Management of an allocated budget for development projects
- Dealing professionally with customers, vendors and technology partners
- Actively participating in the cross-functional implementation of innovative product, process or technology solutions.

You'll ideally be an engineering graduate, either with a PhD or with a good honours degree and relevant industrial experience. A self-starter by nature, you will have a desire to see things through to conclusion and be able to demonstrate effective personal management and a practical approach to problem solving.

In return you'll be rewarded well with a very competitive salary and an excellent range of company benefits. If all this appeals to you, please send a full CV to Julie Parkin-Morse, Human Resources, Siemens Magnet Technology Limited, Wharf Road, Eynsham, Witney, Oxon OX29 4BP, or call 01865 850349 for an application form.

Siemens is a global network of innovation employing more than 425,000 people in 190 countries. We operate within the areas of Information and Communications; Automation and Control; Power; Transportation; Medical; Lighting; Financing and Research and Development. You could say that we're integral to the way the modern world works.

Go. Spin the globe.
www.siemens.co.uk/jobs

University of Bern
Faculty of Science

Applications are invited for a
Full Professorship in Theoretical Physics

opening September 1, 2006 at the Institute for Theoretical Physics, University of Bern, Switzerland. Candidates should have a strong research record in the area of quantum field theory applied to particle physics. The current research activities at the institute include effective field theories, nonperturbative methods in quantum field theory, the standard model, in particular heavy quark physics, and unified field theories of particle physics. The successful candidate is expected to strengthen the interaction between these research fields at our institute and to participate in the teaching and supervision of students.

The University of Bern encourages women to apply for this position.

Applications, including a curriculum vitae, a publication list, copies of the most important publications and a brief outline of past and future research should be sent to the address below by November 1, 2004.

Prof. P. Messerli, Dean of the Faculty of Science,
Sidlerstr. 5, CH-3012 Bern

For further information you may contact
Prof. U.-J. Wiese (wiese@itp.unibe.ch)

Universität Karlsruhe (TH)

The Center for Elementary Particle Physics and Astroparticle Physics (CETA) invites applicants for

Postdoctoral (BAT IIa)
and Graduate Student

positions.

CETA is an interdisciplinary research center with four focus lines: Theoretical particle physics, experimental high energy physics, astroparticle physics and HEP computing. About 150 scientists of the University of Karlsruhe and the Forschungszentrum Karlsruhe are involved in particle phenomenology, in the experiments CDF, CMS, KLOE, AMS, Auger, Edelweiss, Kascade, Katrin and in the German center for grid computing, GridKa. This announcement is meant for candidates interested in heavy flavour physics or top quark physics with CDF, in the construction and commissioning of the CMS Silicon Strip Tracker, in the development of software and the preparation of physics analysis in CMS, and in Grid Computing. We offer to the Postdoctoral Physicist the possibility of one to two years of stay in Fermilab or CERN.

Profile: The Graduate Student candidate should have a diploma or comparable degree in particle physics. The Postdoctoral Physicist candidate is expected to have a PhD in particle physics and experience in detector or software development and in data analysis. Candidates are expected to actively participate in teaching duties while stationed in Karlsruhe. The initial duration of this position is two years with the possibility of extension for further three years.

The University of Karlsruhe is an equal opportunity employer and welcomes applications from women. Handicapped applicants will be treated preferentially if equally qualified.

The application together with a curriculum vitae, the names and addresses of three referees should be sent before **September 30th, 2004** to **Frau M. Schorn, CETA, Universität Karlsruhe (TH), Wolfgang-Gaede-Straße 1, D-76131 Karlsruhe.**

For further information, please contact **Prof. Th. Müller**
(email: thomas.muller@cern.ch, phone: 0049-721-6083524, www.ceta.uni-karlsruhe.de)

The Cockcroft Institute

An International Centre for Research in Accelerator Science and Technology

7 Fixed-Term (3 year) Research Positions and 3 PhD Studentships

in Linear Collider Accelerator Science and Technology

The Cockcroft Institute is a newly created international centre for Accelerator Science and Technology in the UK. It is a joint venture of Lancaster University, the Universities of Liverpool and Manchester, the Council for the Central Laboratory of the Research Councils (CCLRC at the Daresbury and Rutherford Appleton Laboratories), the Particle Physics and Astronomy Research Council (PPARC), and the North West Development Agency (NWDA). The Institute's aim is to provide the intellectual focus, educational infrastructure, and the essential scientific and technological facilities for Accelerator Science and Technology research and development which will enable UK scientists and engineers to take a major role in accelerator design, construction and operation for the foreseeable future.

LANCASTER UNIVERSITY

2 Research Associates
2 PhD Studentships

The first post, attached to the Microwave Research Group (Engineering), is to work in a team on the design, excitation and control of crab cavities for linear colliders with non-zero crossing angles. Crab cavities maximise luminosity by precise rotation of charge particle bunches prior to collision. **Quote ref: A310**

The second post, attached to the Particle Physics Group (Physics), is to work principally on developing the collimation system as a crucial element of the Beam Delivery System (BDS). This will involve simulating the interaction of the beam with the collimator environment, including wake field effects and optimising the collimator layout. The project includes associated experimental tests. **Quote ref: A311**

The PPARC funded PhD studentships are available to work on the crab cavity (Engineering Department) and the collimation system (Physics Department) and further details may be found at **http://www.lancs.ac.uk/cockcroft-institute/opportunities.htm**. Informal enquiries about the posts can be made to Dr Amos Dexter, **A.Dexter@lancaster.ac.uk** (Engineering) and Dr Andre Sopczak, **A.Sopczak@lancaster.ac.uk** (Physics).

To apply or receive further information online, please visit **http://www.lancs.ac.uk/depts/personnel/jobs or, telephone Personnel Services, quoting appropriate reference on answerphone +44 1524 846549.**

CCLRC

ASTeC

2 Radio Frequency Engineers/Scientists

One position is concerned with the development of accelerator structures aimed at manipulating high energy electron and positron beams in a LC. Experience in the use of simulation codes such as CST Microwave Studio, HFSS, MAFIA and Magic are essential. The appointee will join a collaboration which includes ASTeC (Daresbury and Rutherford Appleton Laboratories) and the Microwave Research Group, Department of Engineering, Lancaster University **http://www.comp.lancs.ac.uk/engineering/research/microwave/New_site/index.html**)

Another position is concerned with the development of the RF power system for the manipulation of the high energy particle beams. Experience in the design and development of high and low power, high frequency RF systems, including drive amplifiers and feedback loops, is desirable. Informal enquiries can be addressed to **Professor Mike Poole (M.W.Poole@dl.ac.uk)**.

Further particulars and details of the application procedure are available from **Human Resources, Daresbury Laboratory, Warrington WA4 4AD on +44 1925 603 114, via email: recruit@dl.ac.uk, or at http://www.astec.ac.uk/Vacancies.htm.** **Quote ref: VND 228/04**

THE UNIVERSITY of MANCHESTER

Research Associate

An accelerator physicist is sought to work on the design of the Beam Delivery System (BDS) for a future Linear Collider, in the particular area of simulation studies of the beam and the halo.

The postholder would be responsible for maintaining relevant simulation codes (including MERLIN) and applying them to descriptions of the BDS, and for using them to study backgrounds, luminosities, feedback requirements, and other quantities of interest.

This is part of the LC-ABD project, aimed at producing a complete and detailed design study of the BDS, in a way as independent as possible of the final choice of technology, location, etc. Strong computing experience, including simulations ('Monte Carlo programs') is essential. The post needs communication and teamworking skills, and the ability to work on one's own initiative.

Further details about the group can be found at **http://www.hep.man.ac.uk or by email to roger.barlow@man.ac.uk, to whom applications (CV, letter, and the names of two referees) should be sent.** **Quote ref: 730/04**

THE UNIVERSITY of LIVERPOOL

2 Research Scientists
PhD Studentships

One position is concerned with the responsibility for the design and optimisation of beam diagnostics. The work will be based on the sophisticated computer codes for accelerator optics which are in continual use and development by members of the Daresbury ASTeC group. The work of the appointee will be central both to the work of the ASTeC LC group concerned with lattice design and simulation, and to the work of other LC-ABD groups.

Another position is concerned with the development of an intense positron source for a LC using a helical undulator insertion device, its optimisation for both luminosity and polarisation, and the robust delivery of its polarisation to the LC interaction region. The appointee will join a collaboration which includes ASTeC (Daresbury and Rutherford Appleton Laboratories), Liverpool, and Durham Universities (**http://www.astec.ac.uk/id_mag/Projects/LinearCollider.htm**). Prototype design and construction work is already underway, and first steps have been taken to adapt spin-tracking computing codes for the new challenges of the next LC.

PhD studentships are available to work on any of the linear collider accelerator projects that Liverpool University is involved in and further details may be found at **http://www.lancs.ac.uk/cockcroft-institute/opportunities.htm**. Informal enquiries can be addressed to **Professor John Dainton (jbd@hep.ph.liv.ac.uk)**.

Further particulars and details of the application procedure are available from the **Director of Personnel, The University of Liverpool, Liverpool L69 3BX on +44 151 794 2210 (24 hr answer-phone), via email: jobs@liv.ac.uk, or at http://www.liv.ac.uk/university/jobs.html.** **Quote ref: B/RA/DAIN**

Applicants should ideally have a PhD or equivalent expertise and experience in particle physics, accelerator physics or microwave engineering. **The closing date for all Research Associate/Scientist/RF Engineer positions is 6th September 2004. The PhD Studentships are available from 1st October 2004 or as soon as possible thereafter. Initial salaries up to £24,820 for university posts and up to £26,435 for CCLRC posts.**

www.lancs.ac.uk/cockcroft-institute

Laurentian University

Canada Research Chair (Tier II) in Particle Astrophysics

Applications for this position in the Department of Physics & Astronomy are invited from candidates with strong research and publication records in experimental particle astrophysics.

Laurentian University in Sudbury, Canada is 30 minutes from the Sudbury Neutrino Observatory and SNOLAB, the international facility for Underground Science, now under construction. The six member particle astrophysics group is a founding member of SNO and SNOLAB and has major involvement in the supernova detection program, water assay and purity research, radioisotope monitoring, backgrounds and analysis for SNO. Our group has also joined the EXO (Enriched Xenon Observatory) collaboration with interests in ultralow background requirements and xenon purification and we are exploring other physics interests at SNOLAB. The Chair will direct contributions to future developments at SNO and/or to new experiments at SNOLAB. He or she will also teach at the graduate and undergraduate level – teaching experience and bilingualism are assets.

Applicants should send a detailed curriculum vitae and outline of research/teaching interests, and have 3 referees send letters of reference to CRC@nu.phys.laurentian.ca. For further information, see laurentian.ca/physics and www.chairs.gc.ca. A review of candidates will start September 1, and continue until the position is filled.

Laurentian University is committed to equity in employment and encourages applications from all qualified individuals including women, aboriginal peoples, visible minority members and persons with disabilities.

SNOLAB

The Physics Department of the Massachusetts Institute of Technology invites applications for the faculty positions described below. Faculty members at MIT conduct research, teach undergraduate and graduate physics courses and supervise graduate and undergraduate participation in research. Candidates must show promise in teaching as well as in research. Preference will be given to applicants at the assistant professor level.

Applicants must submit a curriculum vitae, a list of publications, and a brief description of research interests and goals. Applicants must arrange for three letters of reference to be sent directly to the appropriate search committee chair by the search deadline.

NUCLEAR AND PARTICLE EXPERIMENTAL

Currently, the research groups in the Nuclear and Particle Division and Laboratory for Nuclear Science have strong interests in strong interaction physics (PHOBOS, BLAST, Jefferson Lab, STAR and CMS heavy ions), flavor physics and electroweak symmetry breaking (BaBar, CDF, CMS), and dark matter searches (AMS). We are also initiating a program in accelerator science and technology. This search is broad in scope so that applicants with research interests in other areas of nuclear and particle physics are strongly encouraged to apply. Applicants should submit the materials above-mentioned to **Prof. Boleslaw Wyslouch, c/o Ms. Anna Maria Convertino, Department of Physics, Building 24-422, MIT, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139-4307**. The deadline for applications is December 1, 2004.

NUCLEAR AND PARTICLE THEORY

Positions in the Center for Theoretical Physics for physicists with interests among the following areas: theoretical particle physics within and beyond the standard model, QCD and theoretical nuclear physics, string theory, and the interfaces between all these areas and cosmology and astrophysics. Applicants should submit the materials mentioned above to **Prof. Krishna Rajagopal, Department of Physics, Building 6-300, MIT, 77 Massachusetts Avenue, Cambridge, MA 02139-4307**. The deadline for applications is November 12, 2004.

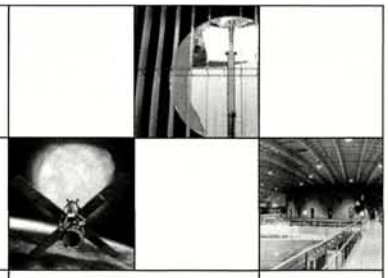
MIT is an Affirmative Action/Equal Opportunity Employer. Qualified women and minority candidates are especially encouraged to apply.

Massachusetts Institute of Technology

web.mit.edu/hr

PAUL SCHERRER INSTITUT

PSI



The Paul Scherrer Institut is a centre for multi-disciplinary research and one of the world's leading user laboratories. With its 1200 employees it belongs as an autonomous institution to the Swiss ETH domain and concentrates its activities on solid-state research and material sciences, elementary particle and astrophysics, energy and environmental research as well as on biology and medicine.

The Laboratory for Particle Physics invites applications for the position of a young Postdoctoral

Detector Physicist

Tasks

The applicant should participate in the construction of the pixel barrel detector for the CMS experiment. The laboratory assumes a major responsibility for the construction of the CMS pixel barrel. It has developed the pixel sensor, readout chip and bump bonding technique. After this R&D work the module production phase must now be prepared and carried through. As a member of the pixel group the candidate will be expected to organize and actively participate in the production of some hundreds of modules including tests of individual components and quality control after each major assembly step.

Profile

Hands-on experience in building and working with silicon detectors, and familiarity with complex front-end electronics systems are required. Organizing the module production involves the coordination of a small team of technicians and students.

The initial term of this position is three years with the possibility of extension.

For further information please contact:

Dr. R. Horisberger, phone (+41 (0)56 310 32 06,
e-mail roland.horisberger@psi.ch, or
Dr. K. Gabathuler, phone (+41 (0)56 310 32 51,
e-mail kurt.gabathuler@psi.ch

Interested candidates are asked to submit
an application before September 30 to
Paul Scherrer Institut, Human Resources,
Mrs. Elke Baumann, ref. code 1412,
5232 Villigen PSI, Switzerland

Further information on PSI: www.psi.ch

SNOLAB

Mining for knowledge
Creuser pour trouver... l'excellence

Administrative Office
Carleton University
2424 Herzberg Building
1125 Colonel By Drive
Ottawa, ON Canada K1S 5B6
Fax: (613) 520-7546
Research Scientist Positions

SNOLAB, a new facility which will feature the deepest permanent underground laboratory in the world, is currently recruiting two Research Scientists who will take leading roles in the experiments to be conducted at this facility. The scientific programme of the facility will be determined by peer review of experimental proposals but is expected to focus on detection of dark matter, detection of neutrino-less double beta decay, supernova neutrino detection, and precision studies of solar neutrinos. Further information about SNOLAB can be obtained at **www.snolab.ca**.

The successful applicants will have a PhD and an outstanding record of research in experimental nuclear or particle physics with several years of post doctoral experience.

Applications from qualified candidates should include a statement of research interests, a detailed CV and names of at least three referees. Candidates must arrange for all necessary information be mailed or faxed to SNOLAB c/o the address or fax number listed above or emailed to **SNOLAB_application@physics.carleton.ca** with Research Position in the subject line.

The successful candidates will be employed by one of the member universities of the SNO Institute. Salary and benefits will be comparable to Assistant Professorship appointments. The appointment will be reviewed annually, and be ongoing subject to budgetary confirmation and mutual agreement.

Applications will be accepted until the position is filled. All qualified candidates are encouraged to apply. The applications of Canadians and Permanent Residents will be given priority. SNOLAB is committed to equality of employment for women, aboriginal peoples, visible minorities, and persons with disabilities. Persons from these groups are encouraged to apply.

Member Institutions: University of British Columbia, Carleton University, University of Guelph, Laurentian University, University of Montreal, Queen's University

POSTDOCTORAL RESEARCH IN EXPERIMENTAL PARTICLE PHYSICS

The Department of Physics invites applications for a postdoctoral research position in experimental particle physics. The appointed individual will be based at SLAC to participate in data analysis, software and hardware development on the BABAR experiment at the SLAC B factory. Candidates should be recent Ph.D. recipients and should submit a resume, statement of research interests and list of publications to

Professor Owen Long, Department of Physics,
University of California, Riverside, CA, 92521, USA,
owen@slac.stanford.edu.

The applicant should arrange for three letters of recommendation to be sent to the above address.

Review of applications will begin September 1, 2004 and will continue until the position is filled.

UCR
UNIVERSITY OF CALIFORNIA, RIVERSIDE

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

Fermilab, the highest-energy physics laboratory in the world, conducts basic research to advance understanding of the fundamental nature of matter and energy. At our campus in suburban Chicago, Fermilab builds and operates the accelerators, detectors and other facilities that physicists need to carry out forefront research in high-energy physics.

POST DOCTORAL POSITION
Superconducting Magnet Technology

A post doctoral research associate position is available in the Fermilab Technical Division for candidates with Ph.D's in experimental physics, magnet technology, or related field. The successful applicant will join a team of physicists, engineers and technicians in the development and test of state-of-the-art superconducting accelerator magnets. Present projects include high gradient quadruples for the Fermilab BTeV and LHC interaction regions; and the development of Nb3Sn magnets for future accelerator upgrades. The Post doctoral research associate will participate in one or more program activities including magnetic design; fabrication oversight; and development of test instrumentation and analysis software for superconducting magnets.

Post doctoral appointments are normally for three years with one-year renewals possible thereafter. All applicants should be able to perform in a team environment, and have good communication and planning skills.

Located 40 miles west of downtown Chicago, Fermilab offers competitive salary and excellent benefits packages. For consideration, please forward curriculum vitae, publications list and the names of at least three references to: **Dr. Robert Kephart, Head Technical Division, Fermi National Accelerator Laboratory, P.O. Box 500, M.S. 316, Batavia, IL 60510-0500.** Fermilab is an EOE/AA Employer M/F/D/V

Fermilab

Consorci per a la Construcció, Equipament i Explotacio del Laboratori de Llum Sincrotró: CEELLS

Open positions for Physicists/Engineers at the Spanish Synchrotron Light Source

CEELLS is a public Consortium which has to build a 3rd generation Synchrotron Light Source consisting of an electron accelerator with a small emittance and a circumference of around 260 m in Spain, near Barcelona. The Light Source will house initially 5 beamlines.

Positions are open (or will be open soon) for physicists, beamline scientists, instrumentation engineers, mechanical engineers and computer scientists. We will also consider phD students and post-docs associated to some of the positions.

Interested people (candidates) should look for more detailed information in **www.cells.es** and send their application letter plus CV by post or e-mail to us.

Going to work on an experiment at CERN?

Visit **http://cern.ch/ep-div/UsersOffice/**

PENNSTATE

Position in LIGO Gravitational Wave Data Analysis and Grid Computing

The Penn State Center for Gravitational Wave Physics (CGWP) has funding for positions at the postdoctoral scholar level or higher to take part in the analysis and interpretation of observations from the Laser Interferometer Gravitational Wave Observatory (LIGO). At least three years of funding is available for each position.

LIGO has critical production requirements to process 300 TBytes of data per year of fundamental and pressing scientific importance. This is one of the earliest and most intensive tests to date of grid computing concepts using real-world geographically dispersed, heterogeneous, high performance data processing resources with different local management and technical histories. Working in this environment will provide invaluable experience in the realities of grid computing, an extraordinary opportunity to influence the future of grids and computing in general, and participation at the birth of the exciting new field of observational gravitational wave physics.

The Penn State LIGO Scientific Collaboration (LSC) group is part of the LIGO Global Grid Virtual Organization, contributing local resources of 312 processors and 34 TB storage (approximately 1/4 of the total aggregate resources). The LIGO VO is part of the larger International Virtual Data Grid Laboratory (iVDGL), which is pioneering the application of Grid-paradigm computing for large, forefront experiments in physics and astronomy. The iVDGL includes computing, storage and network resources in the U.S., Europe, Asia and South America.

The Penn State LIGO Scientific Collaboration (LSC) group is among the largest and most active in the Collaboration with two faculty, five postdocs and technical staff members, five graduate students, and five undergraduate students. It plays a leading role in the analysis and interpretation of LIGO data, including analysis in collaboration with other gravitational wave detector experiments worldwide. It is part of the larger Penn State relativity group, which is among the largest and most active in the country with six faculty, sixteen postdocs, eighteen graduate students, and twelve undergraduate students engaged in research in all areas of gravity.

Penn State is also home to the Center for Gravitational Wave Physics (CGWP), funded by the National Science Foundation as part of its Physics Frontier Centers program. The mission of the CGWP is to foster research of a truly interdisciplinary character linking the highest caliber astrophysics, gravitational wave physics and experimental gravitational wave detection in the pursuit of the scientific understanding of gravity and the development of gravitational wave observations as a tool of observational astronomy. Each year the CGWP hosts at Penn State several major workshops and conferences addressing all areas of gravitational wave physics and astrophysics.

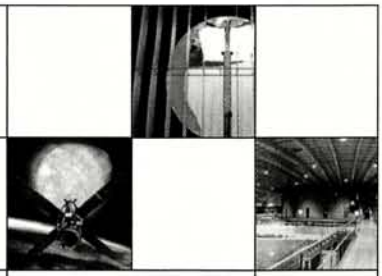
Academic background in physics with Ph.D. in hand and a strong interest in computing will be preferred for these positions. Applicants with a computer science background and demonstrated experience in computing for large scale experimental physics will also be favorably considered and do not require a PhD. Applicants should send a CV, statement of research interests and relevant experience, and arrange for three letters of recommendation to be sent to

LIGO Staff Search Center for Gravitational Wave Physics 104 Davey Laboratory, PMB 89
University Park, PA 16802. USA

Applications will be considered beginning immediately and will continue until the available position is filled. For more information see our websites at
http://gravity.psu.edu and
http://ligo.aset.psu.edu.

Penn State is committed to affirmative action, equal opportunity and the diversity of its workforce.

PAUL SCHERRER INSTITUT
PSI



The Paul Scherrer Institute is a centre for multi-disciplinary research and one of the world's leading user laboratories. With its 1200 employees it belongs as an autonomous institution to the Swiss ETH domain and concentrates its activities on solid-state research and material sciences, elementary particle and astrophysics, energy and environmental research as well as on biology and medicine.

Operating a system of cyclotrons with the highest proton beam power worldwide requires a high level of reliability, permanent development and the continuous integration of new technologies. We are looking for an

Electrical or Mechanical Engineer

Your tasks
Your main task will be the design and procurement of various types of electromagnets for the PSI beam transport systems and experimental facilities. You will follow the manufacturing process and supervise the acceptance testing. Your responsibility includes the supervision of servicing, repair or modification of new and existing magnets.

Your profile
You are a creative engineer with a good understanding of the technical aspects involved in the design of devices operated under difficult conditions. You already have experience with the design of electrical and mechanical components and are familiar with quality control procedures. Design work at PSI is done using modern computer programmes and computer aided design CAD. You will be trained to use these programmes but some PC experience will be expected. You are prepared to travel for short trips abroad. You like to work in a team and you have a good working knowledge in English and German.

We are looking forward to your application.

For further information please contact
Mr. David George, Tel.(+41 (0)56 310 35 88,
e-mail david.george@psi.ch.

Please send your dossier to: Paul Scherrer Institut,
Human Resources, Mr. Thomas Erb, ref. code 8850,
5232 Villigen PSI, Switzerland.

INDEX TO DISPLAY ADVERTISERS

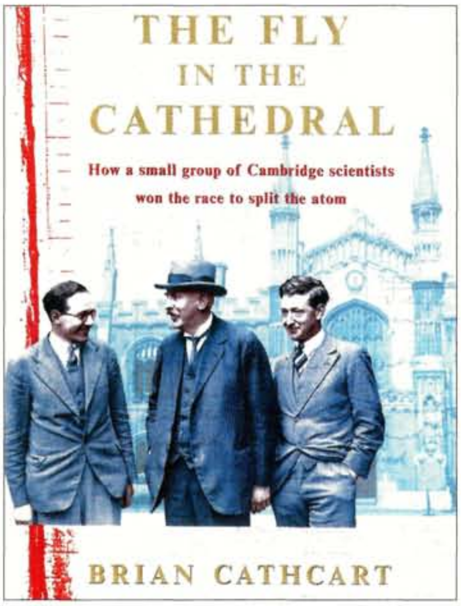
The Fly in the Cathedral by Brian Cathcart, Viking. Hardback ISBN 0670883212, £14.99.

The "fly" in question is the nucleus and the "cathedral" is the atom, and this is the account of "how a small group of Cambridge scientists won the race to split the atom". The story begins in 1909, after Ernest Rutherford's student, Ernest Marsden, found that when alpha particles are scattered by a gold foil the Rutherford formula is not exactly satisfied. There is therefore evidence that the nucleus is not just a point, but a "fly". After moving from Manchester to Cambridge, Rutherford and his collaborators wanted to know more about what is inside the "fly".

In the Cavendish Laboratory at Cambridge in 1927 there were two lines of approach to the study of the nucleus: the traditional one using naturally produced particles such as alphas, gamma rays, etc, and another that was trying to accelerate particles artificially in the laboratory.

James Chadwick was following the first approach, and this led him to the discovery of the neutron in 1932 and to the Nobel prize in 1934. In 1930 two German physicists, Walther Bothe and Herbert Becker, had reported that by bombarding beryllium nuclei with alpha particles from a polonium source they had registered the emission of a powerful neutral radiation. Later, the Joliot-Curies reproduced the phenomenon and proved that the mysterious radiation could knock protons out of a block of paraffin – something that gamma rays of available energies could not have done. When their "*Note aux comptes rendus de l'Academie des Sciences*" arrived in Rome in January 1932, according to what Gian-Carlo Wick, who was present, told me, Ettore Majorana exclaimed: "*Stronzi* (idiots), they have not understood that it is the neutron." Soon after, Chadwick proved by careful experimentation that it really was the neutron, with a mass close to the proton. Another important experiment belonging to the same category, but not mentioned in the book, is the photo-disintegration of the deuteron into a proton and a neutron by Chadwick and the then young Maurice Goldhaber (who is now 93 years old, see *CERN Courier* May 2004 p33). They showed that the neutron was slightly heavier than the proton.

The other approach, trying to accelerate particles, marked the beginning of a new era that CERN continues, through its past achieve-



ments and its future projects. This is why the detailed account given in this book, including the successes and failures and the personal lives of the protagonists, seems so interesting.

The main protagonists were a young Irishman, Ernest Walton, a Briton named John Cockcroft, their friend Thomas Allibone from the Metropolitan-Vickers laboratory, and naturally Rutherford himself, who said in his address as president of the Royal Society in November 1927: "It would be of great scientific value if it were possible in laboratory experiments to have a supply of electrons and atoms of matter in general, of which the individual energy of motion is greater even than that of the alpha particle. This would open up an extraordinary new field of investigation that could not fail to give us information of great value, not only in the constitution and stability of atomic nuclei but also in many other directions."

Cockroft and Walton worked very hard within the limits allowed by the rules of the Cavendish Laboratory, which closed at 6 p.m. and during holidays. But the friendly competition between Europe and the US was already fierce, a little like we see today! In the US Lawrence and Livingstone were working on their cyclotron, Van de Graaf had the machine that bears his name, and Lauritsen had his X-ray machine. There were also competitors in Europe, such as Greinacher, who independently of Cockcroft and Walton had the idea of voltage multiplication.

At this point it is necessary to mention a theoretician of Russian origin, George Gamow, who, as the author explains very well, played an important role in predicting that the attempts of Cockcroft and Walton would be successful. Gamow was probably the first to realize that quantum mechanics applied not only to the electrons running around the nucleus but also to the constituents of the nucleus. Before the discovery of the neutron he was extremely unhappy at having electrons inside the nucleus because their wavelength was much larger than the size of the nucleus. He produced a beautiful explanation of the alpha decay of nuclei by the tunnelling of alpha particles through the Coulomb barrier of the nucleus, a typical quantum mechanical effect. The alpha particles don't need to have an energy as high as the classical barrier but can "borrow" energy for a short time to cross it. This was very important for the Cambridge machine builders because it meant that protons can penetrate inside the nucleus without having the full energy to cross the barrier. Even Rutherford, who had some repulsion for theory, liked this.

The Cockcroft–Walton accelerator finally started working at the beginning of 1932, but the protons they directed at beryllium and lithium targets did not seem to produce any clear effect. They were looking for gamma rays and saw practically none. This was a serious disappointment and they feared that Lawrence, with a higher energy, would win the race. Rutherford was beginning to get irritated. So they tried using a scintillation detector of zinc sulphide that had been used in the past to detect alpha particles and then they saw a beautiful signal, which was immediately interpreted by Rutherford to be a pair of alpha particles. This was at 800 000 volts, clearly below the classical Coulomb barrier. Then in complete agreement with Gamow's theory, they lowered the voltage to 150 000 volts and still saw the effect. In this case Rutherford broke the rule of closing the laboratory at 6 p.m. The time of the "night shift" was approaching.

The reaction observed was $p + {}^{7}Li \rightarrow \alpha + \alpha$ with a kinetic energy release of 8 MeV. It was a tremendous success and as the subtitle of the book says, they "won the race to split the atom". The press jumped on that, but Cockcroft and Walton disliked the statement that this could be "a new source of energy". In fact the press was right. The discovery of the fission of uranium was not too far away and this kind of proton-induced fission, except ▷

for the fact that it uses light elements, is not fundamentally different from what is proposed now by Carlo Rubbia as a new source of energy. Later, long after the unfortunate death of Rutherford due to delays with a hernia operation in 1937, Cockcroft and Walton received the Nobel prize in 1951.

There are also many other people who are rightly quoted in the book, such as Kapitza, who after spending several years in Cambridge was forced by Stalin to stay in the USSR; Blackett, who started cosmic-ray research with Occhialini; and the theoreticians – Dirac of course, but also Mott, Massey, Hartree and so on.

To end this review I would like to complete the postscript of the book, in particular regarding the links of Cockcroft with CERN. A biography of Cockcroft by Ronald Clark says (on page 101) that he "loaned someone from Harwell to build one of the accelerators of CERN". This accelerator was the Proton Synchrotron (PS), and the "someone" was John Adams. Cockcroft directed radar research in Malvern during the Second World War and one of the people he hired was an engineer called John Adams (once, John complained to me that journalists thought he was originally a "mechanic"). Another was Mervyn Hine (who died very recently, see p39). When the war was over Cockcroft retained these two people at the Atomic Energy Research Establishment at Harwell, where they worked on accelerator research; they then moved to CERN with the fantastic success that we all know. Until 1992 the pre-injector of the PS was a Cockcroft–Walton accelerator, and Cockcroft was a member of the CERN Scientific Policy Committee from 1956 until 1961. So there is a link between Rutherford, Cockcroft and Adams for which we must have a great deal of gratitude.
André Martin, CERN.

Ettore Majorana – Notes on Theoretical Physics, edited by Salvatore Esposito, Ettore Majorana Jr, Alwyn van der Merve and Erasmo Recami, Kluwer. Hardback ISBN 1402016492, €175 (£111/$193).

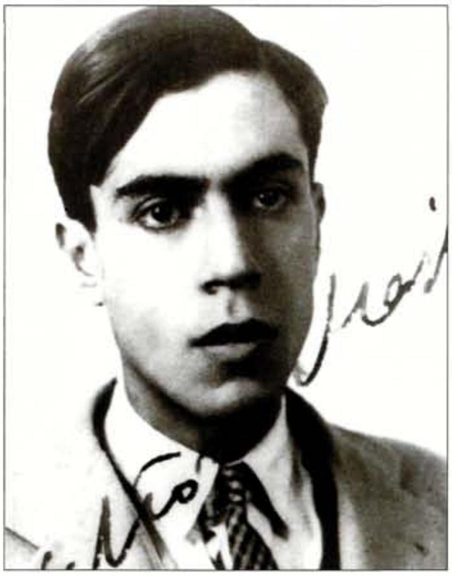


Photo copyright E Recami and Majorana family.

Ettore Majorana was the Vincent van Gogh of theoretical physics, endowed with phenomenal talent but tortured by his own personality; both were geniuses whose unconventional epic work was first recognized by only a few contemporaries, but whose fame ultimately came only after a premature death, by suicide for van Gogh, and possibly so for Majorana too.

Enrico Fermi once said: "Few are the geniuses like Galileo and Newton. Well Ettore was one of them." Appointed professor at the University of Naples in 1937, Majorana mysteriously disappeared in March 1938 after a brief trip to his native Sicily. After having cabled "I shall return tomorrow", he was not aboard the ferry from Palermo when it docked at Naples. Despite extensive searches, no trace of him was ever found. The only clue was an enigmatic remark "The sea has refused me (*il mare mi ha rifiuato*)" in the same cabled message from Sicily, suggesting that his plan to jump overboard unseen on the outward trip had failed and so he had opted for another attempt on the return journey. It was a major loss for Italian physics, compounded later that year when Fermi emigrated to the US.

After having first studied engineering, Majorana graduated in physics with Fermi in 1928 and went on to become a key member of Fermi's newly established and subsequently famous Rome group of the early 1930s (which included, among others, Edoardo Amaldi, Ugo Fano, Bruno Ferretti, Bruno Pontecorvo, Giulio Racah, Emilio Segrè and Gian Carlo Wick).

Majorana was chronically diffident, and this shyness extended to his own publications. He formally published just nine papers in his lifetime, including his 1932 relativistic theory of particles with arbitrary spin. His final paper in 1937 was called "A Symmetrical Theory of the Electron and the Positron" and introduced the revolutionary concept of what became known as a "Majorana particle" – a neutral spin 1/2 particle that is its own antiparticle – now of vital importance for neutrino physics. However, Majorana's archived papers in the Domus Galileana in Pisa show that he had already formulated these ideas in 1933, soon after the positron had been discovered.

This book looks instead at Majorana's first steps in physics research, carefully documented by him in five notebooks (*Volumetti*) from 1927–1932, about one notebook per year, and extending from his formal coursework to original research covering topics ranging from the effect of a magnetic field on melting point to solutions of the Fermi–Thomas equation. These papers are translated into English but retain Majorana's original format and conventions.

As Majorana's contributions to physics have increased in value, several other collections of his work have appeared. There is also Recami's excellent biography *Il Caso Majorana* (Mondadori), but the volume now published by Kluwer is the first rendition of any of Majorana's work into English. This book is the outcome of some dedicated and painstaking work by the editors in translating a wealth of difficult material and reproducing Majorana's original presentation. It was commendably supported by the Italian Embassy in the US and by the Italian government. After this effort, the highly motivated editors are looking towards a new volume of Majorana's subsequent research notes.
Gordon Fraser, Divonne-les-Bains.