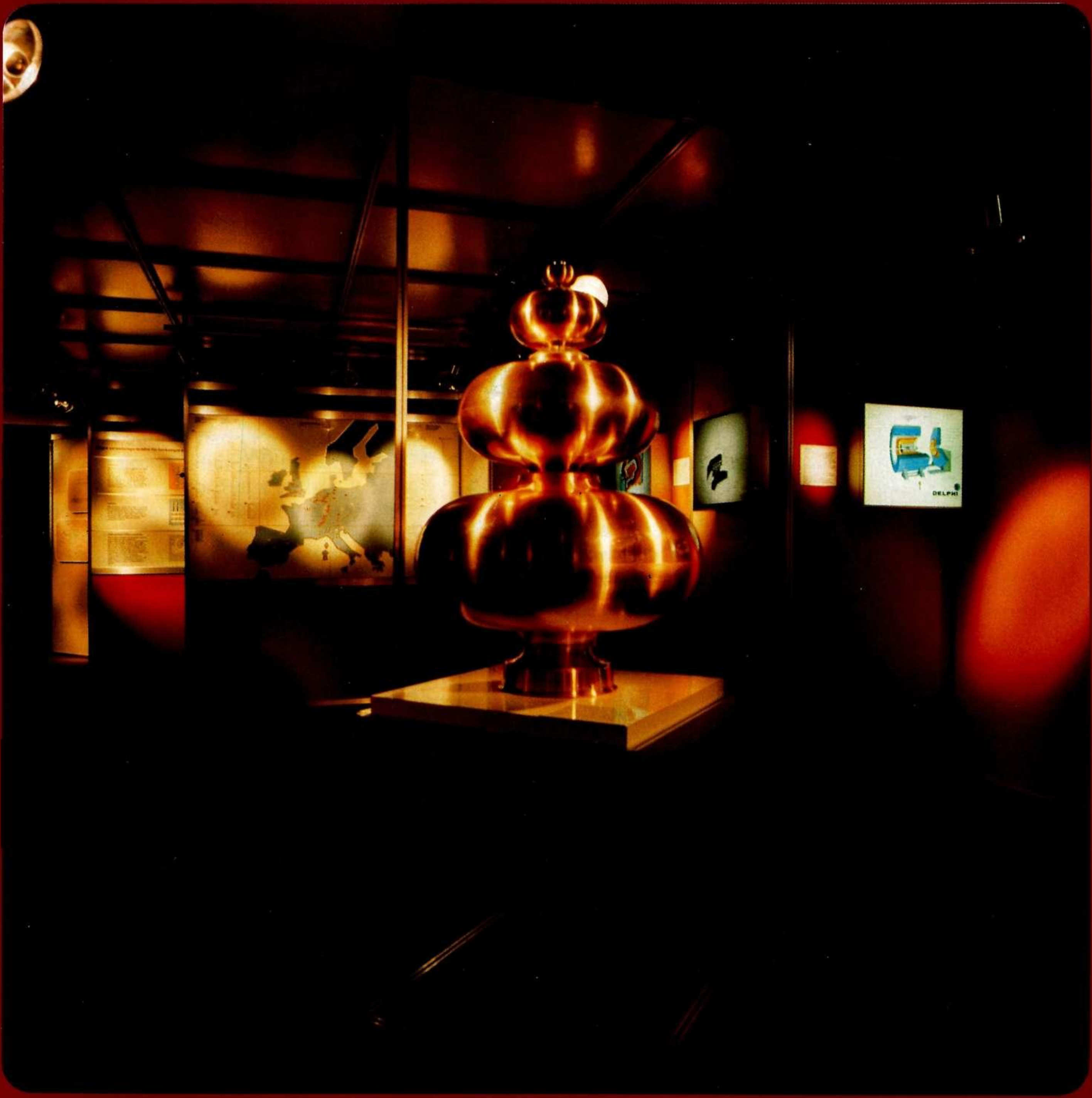
# CERN COURIER

International Journal of High Energy Physics



VOLUME 25 10 DECEMBER 1985

# CERN COURIER

International Journal of the High Energy Physics Community

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Around the Laboratories

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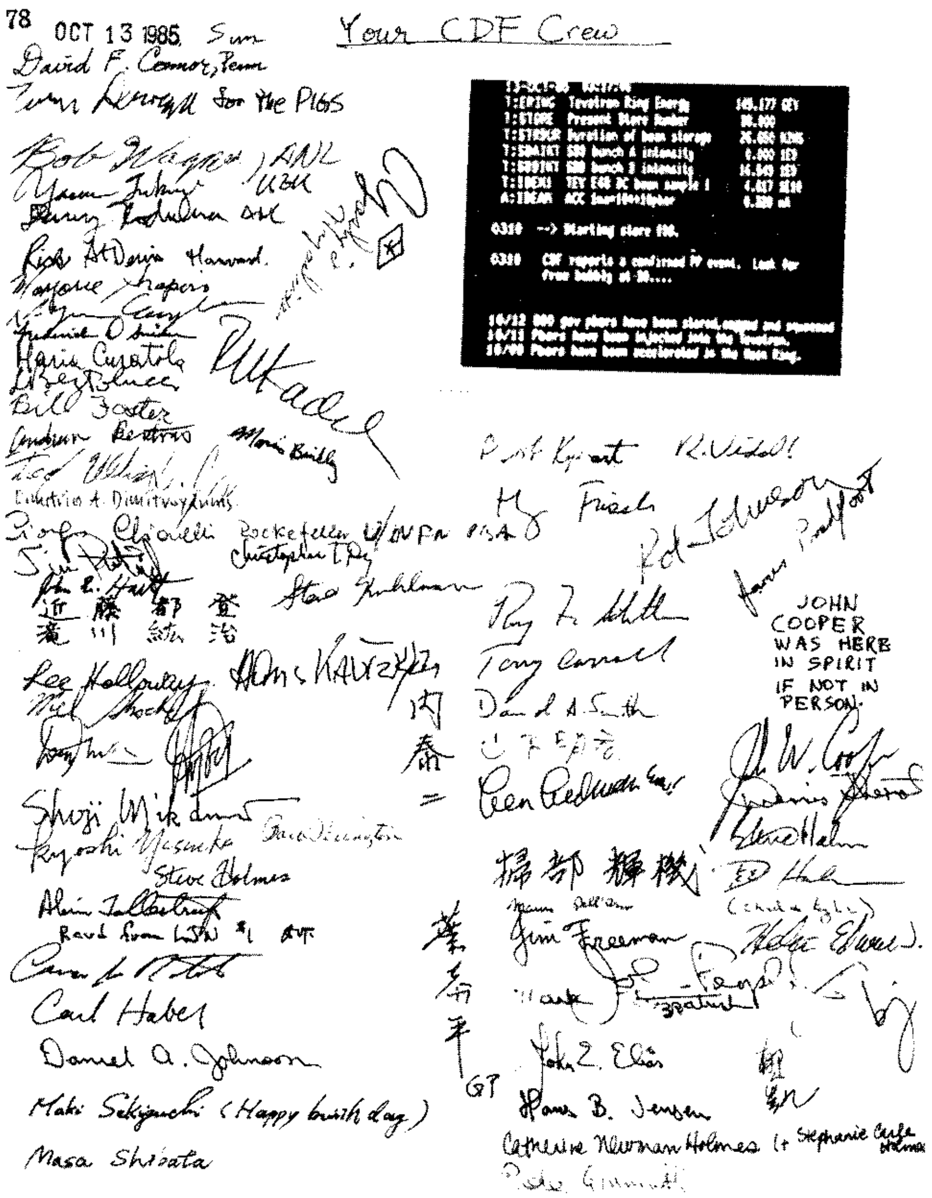
*Cover photograph: One of the exhibits at the recent CERN exhibition in Stockholm's Technical Museum was this sculpture built up from prototype copper superconducting radiofrequency cavities. The biggest one, at the bottom, is designed for operation at 350 Megahertz while the smallest, at the top, is for 3 Gigahertz. These cavities are being developed to boost the accelerating fields of the LEP electron-positron collider now being built at CERN, and other machines, while minimizing consumption of electrical power (Photo CERN 682.9.85).*

# Fermilab opens new horizons

The observation of 1600 GeV (1.6 TeV) proton-antiproton collisions on Sunday 13 October capped a spectacular week of commissioning for the new US Fermilab Collider. By far the highest energy particle collisions ever induced, they were observed in the large and sophisticated Collider Detector at Fermilab (CDF).

Injection of antiprotons into the Main Ring (equipped with conventional magnets) was first attempted on 5 October. The antiproton source had already succeeded in accumulating and storing 0.4 × $10^{10}$ antiprotons with a lifetime greater than 200 hours. That evening three shots of beam were injected into the Main Ring, and on the third shot over 100 turns were observed. By 8 October up to 0.9 × $10^{10}$ antiprotons had been stored in the Accumulator. An elaborate nineteen-point programme of beam choreography started as the antiproton beam was eased from the Accumulator to the Main Ring and then up into the waiting Tevatron (superconducting magnets). After careful checking by transferring protons in the reverse direction, three shots of antiproton beam were again attempted. On the second shot, beam was accelerated in the Main Ring and on the third shot some 6 × $10^8$ antiprotons were accelerated.

On 10 October, antiproton beam was observed in the Tevatron for the first time during a series of seven shots, and two days later more than $10^{10}$ antiprotons were stored in the Accumulator. Antiprotons and protons were successfully synchronized and squeezed together in a Tevatron interaction region about one metre long. That evening a very strong antiproton signal was observed at 800 GeV and first collisions were seen.



Extract from the CDF logbook marking the first 1600 GeV proton-antiproton collisions.

78 OCT 13 1985 Sun

Your CDF Crew

David F. Connor, Penn

for the PIGS

Harvard

Maria Curatolo

Bill Foster

Dimitrios A. Dimitroyannis

Rockefeller

Christopher Day

JOHN
COOPER
WAS HERE
IN SPIRIT
IF NOT IN
PERSON.

Steve Holmes

Jim Freeman

Carl Haber

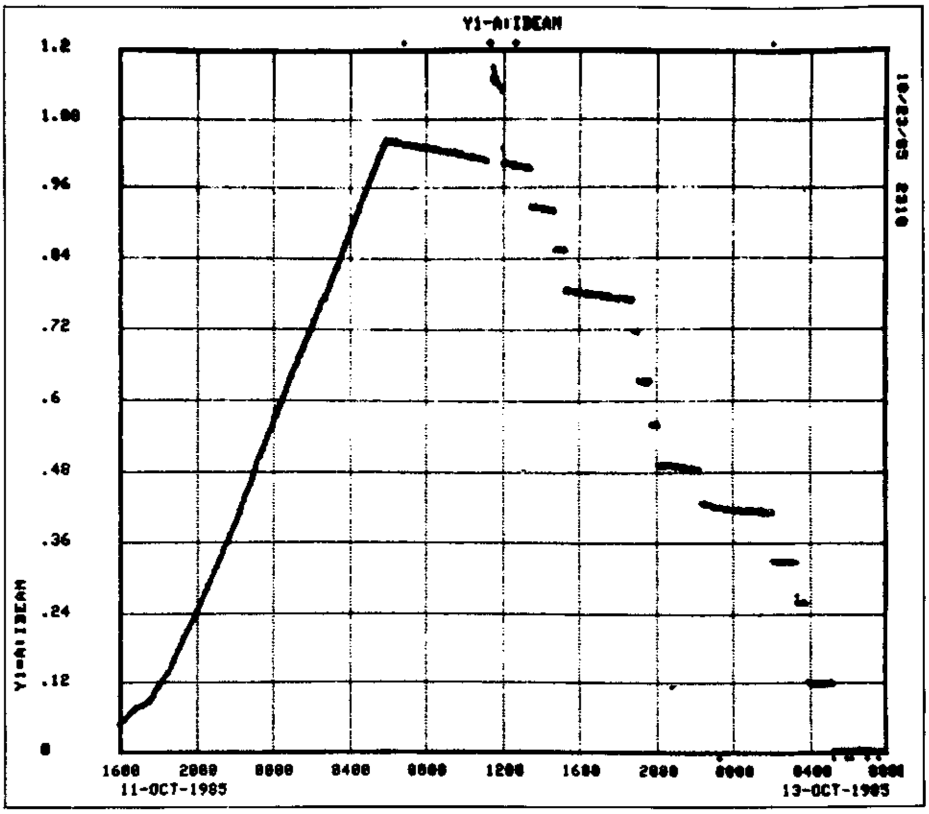
Daniel A. Johnson

Maki Sekiguchi (Happy birth day)

Masa Shibata

The accelerated antiprotons and the proton-antiproton collisions were observed at three different places around the ring. The principal focus was CDF, representing the combined efforts of three US national Laboratories (Argonne, Fermilab and Berkeley), ten US universities (Brandeis, Chicago, Harvard, Illinois, Pennsylvania, Purdue, Rockefeller, Rutgers, Texas A&M, Wisconsin), and major groups from Italy (Pisa and Frascati), and Japan (Tsukuba, KEK, and other institutions). About 30 events were observed in CDF with a trigger which required 2 GeV in either a hadron or electromagnetic trigger tower in coincidence with the counters surrounding the beam pipe in the forward-backward direction.

The E710 experiment, a collabo-



*Plot of stored antiprotons in the Fermilab Accumulator during the key period from 16.00 hrs on 11 October to 08.00 hrs on 13 October. The maximum on the vertical scale corresponds to 1.2 × $10^{10}$ antiprotons. As each shot of antimatter was injected into the Main Ring, the level of stored beam fell. From the Main Ring, antiprotons passed to the superconducting Tevatron, where they collided with waiting protons.*

ration of Bologna, Cornell, Fermilab, George Mason, Maryland, and Northwestern, was in operation at E0, halfway around the ring from B0. They had installed a small fraction of the counters they will use to measure total reaction rates and elastic scattering. There is no low beta insertion to squeeze the beams at E0 so the collision rate should be down by a factor of seventy-five relative to B0. The experimenters were able to see both proton and antiproton beam-gas collisions.

At C0, another group from Duke, Fermilab, Iowa State, Notre Dame, Purdue, and Wisconsin was standing by with 15 per cent of their counters in place for background measurements. They were also able to see antiproton-gas triggers and study the interaction point location. This experiment will look for new phenomena (quark-gluon plasma or quark deconfinement) at high energy densities.

The entire commissioning process linking several rings and two kinds of particles took the accelerator team about 25 shots, totalling 3 × $10^{10}$ antiprotons. Because of this rapid pace it was necessary to conserve precious antiprotons. This meant that the antiproton signals in the beam monitors were weak and a number of special measures had to be employed to facilitate tuning. One of the most exciting was the introduction and acceleration of 'guide-dog' protons in the Main Ring to track the antiprotons. This required the Main Ring radiofrequency to operate in a new and unusual way with sixteen cavities split into two pairs of eight.

Accumulation rates as great as 0.9 × $10^9$ antiprotons/hour were achieved during the commissioning from about 0.8 × $10^{15}$ 120 GeV protons per hour on target. Antiproton intensities accelerated in the Main Ring and injected into the Tevatron were about 2 × $10^8$. Single bunch intensities during collisions were estimated to be approximately $10^{10}$ protons and $10^6$ antiprotons to give a luminosity in the $10^{24}$ cm$^{-2}$ s$^{-1}$ range.

Though this is a factor of a million below the Tevatron design figure, the fact that collisions were observed at all was a major achievement for such a commissioning run as it showed that all systems work, and that the complex logic and equipment of the antiproton source, Main Ring, Tevatron and Collider Detector fit together.

Acceleration of the antiprotons from the source to produce collisions was a team effort involving three major groups – the Accelerator Division, the Antiproton Source Group, and the Detector collaboration. In addition a great deal of useful advice and experience has come from CERN.

## *History*

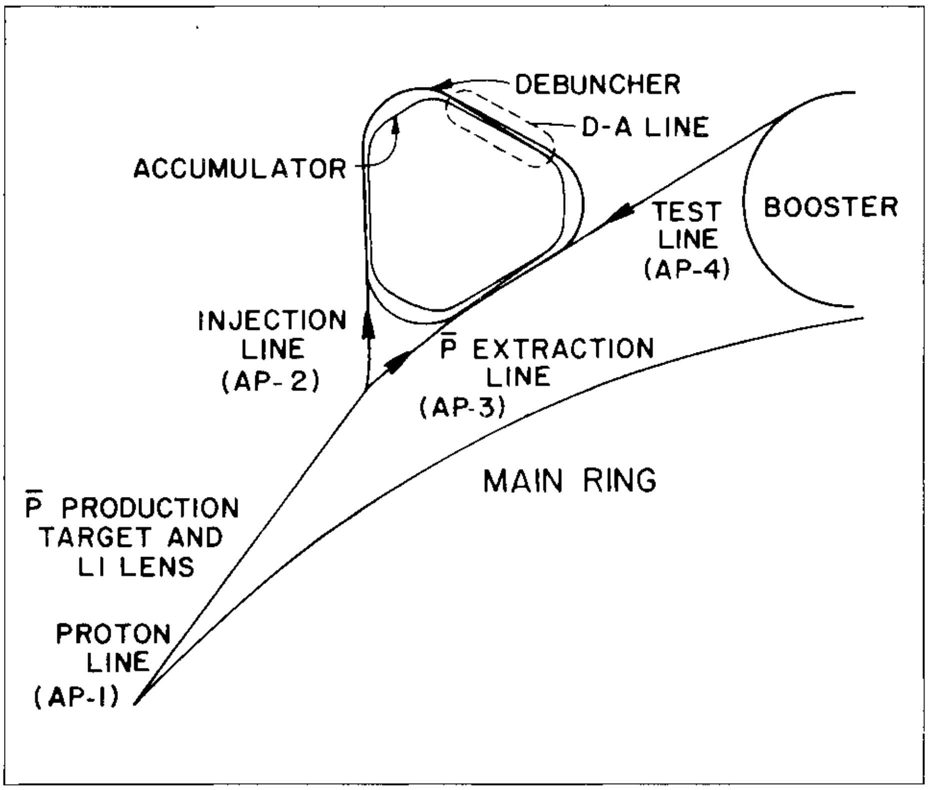
Construction of the antiproton source and the collider facilities began in 1981 with funds from the US Department of Energy. The project proceeded very quickly, thanks to massive efforts. Briefly, the milestones – the giant excavation for the CDF complex started in the summer of 1982. The last superconducting magnet in the Tevatron was installed on 18 March 1983. Construction commenced on the Antiproton Source Tunnel in August 1983 and was completed in December 1984. During the fall of 1983 the Tevatron went into full operation for experiments. In a very encouraging test, beam was stored for thirty hours, and in February 1984 beam was accelerated to 800 GeV. Shortly afterwards the high luminosity system was put into operation at B0. The Tevatron was tied up in a package with ribbons and dedicated on 28 April 1984.

By then magnet production for the two rings (Debuncher and Accumulator) in the Antiproton Source was well underway. Large CDF elements were being fabricated at the same time. Meanwhile the Main Ring, the proton extraction line, and the antiproton production station were completed and important radiofrequency modifications were made on the Main Ring and Tevatron. Development of the stochastic cooling system was boosted by important contributions from Argonne and Berkeley. An extremely significant development was the construction of three new clock systems for linking the various r.f. and extraction activities. By January of this year Main Ring protons had been extracted to the antiproton target station. Protons circulated in the Debuncher ring on 22 April. The last magnet in the Accumulator was installed early in May and the vacuum was buttoned up in June. Beam circulated in the Accumulator ring on 21 August and on 7 September antiprotons were being successfully stacked in the Accumulator.

The rapid progress on the Fermilab Collider was made possible by important earlier work elsewhere. The collider trial had been blazed by electron-positron machines, but physicists realized that the use of protons and antiprotons would vastly increase the energy of the collisions. The breakthrough came at CERN where Simon van der Meer's invention of stochastic cooling made it possible to compress large numbers of antiprotons into a small volume in a magnetic storage device. While CERN went ahead with its ambitious antiproton project, the Fermilab effort was concentrated on building the superconducting Tevatron, designed to provide a beam at 1000 GeV. Thus contrarotating proton and antiproton beams in a Tevatron collider would attain 2000 GeV, several times the energy available from the CERN Collider (up to 450 GeV per beam).

In 1983, CERN's effort was rewarded with the historic discovery of the W and Z particles which carry the weak nuclear force.

*Schematic of the Fermilab Antiproton Source.*



### *How it works*

Operation of the Tevatron as a collider requires the complex orchestration of many rings. Protons are accelerated in the Main Ring to 120 GeV. By strategic manipulation of radiofrequency fields, the protons are grouped for optimum production of antiprotons. The protons are extracted and hit a specially constructed target, producing all kinds of nuclear particles, including antiprotons (one per 30 000 incident protons). A fraction of the antiprotons, those near 8 GeV, are focused by an electromagnetic lens made of a cylinder of lithium capable of carrying a mighty current pulse of 600 000 amps which concentrates the valuable antiprotons. The Fermilab lithium lens follows a design first developed at Novosibirsk in the USSR.

Stochastic cooling compresses a large number of antiprotons into a small volume and reduces their random motions, making it possible to store and accumulate large numbers of antiprotons without having them overflow their storage device. At Fermilab this process starts in the 1700-foot circumference Debuncher storage ring of 345 magnets. Here, a combination of magnetic fields and radiofrequency impulses successively cools and compresses the antiprotons into a sausage-shaped volume as they circulate at 8 GeV.

When the sausage is properly compressed (about 2 seconds) it is passed on to the Accumulator ring of 176 magnets inside the Debuncher. This further compresses the antiproton sausage and gradually accumulates a core stack. As each pulse of antiprotons enters the Accumulator it is massaged with high frequency electromagnetic forces and repositioned within the magnet aperture to add to the core. An accumulation time of several hours yields enough antiprotons to proceed to the next step.

Acceleration starts when about half the antiproton core is extracted into a beamline towards the Main Ring, circulating in the opposite direction to the protons. After acceleration to 150 GeV, the antiprotons are transferred to the Tevatron ring where waiting protons are already stored in circulating bunches. Both groups of particles are accelerated to the maximum energy, passing each other in bunches that are still not dense enough for significant numbers of collisions to take place. At full energy, they are stored for many hours and powerful focusing quadrupole magnets squeeze the beams at two places around the Tevatron ring. At each crossing there is a 50-50 chance that one antiproton will collide with one proton, so at the design luminosity of about $10^{30}$ $cm^{-2}$ $s^{-1}$, some 50 000 collisions will take place at each interaction point per second.

The Collider Detector at Fermilab, or CDF, is used to record the collisions. Its scale and complexity make it a major achievement: 25 feet wide, 31 feet high, 75 feet long and weighing 4500 tons, CDF rolls some 100 feet on a track from the Assembly Hall to the Collision Hall where it surrounds the beam pipe of the accelerator. Carrying hundreds of cables connected to two banks of computers, it is equipped to be sensitive to every detail of the collisions.

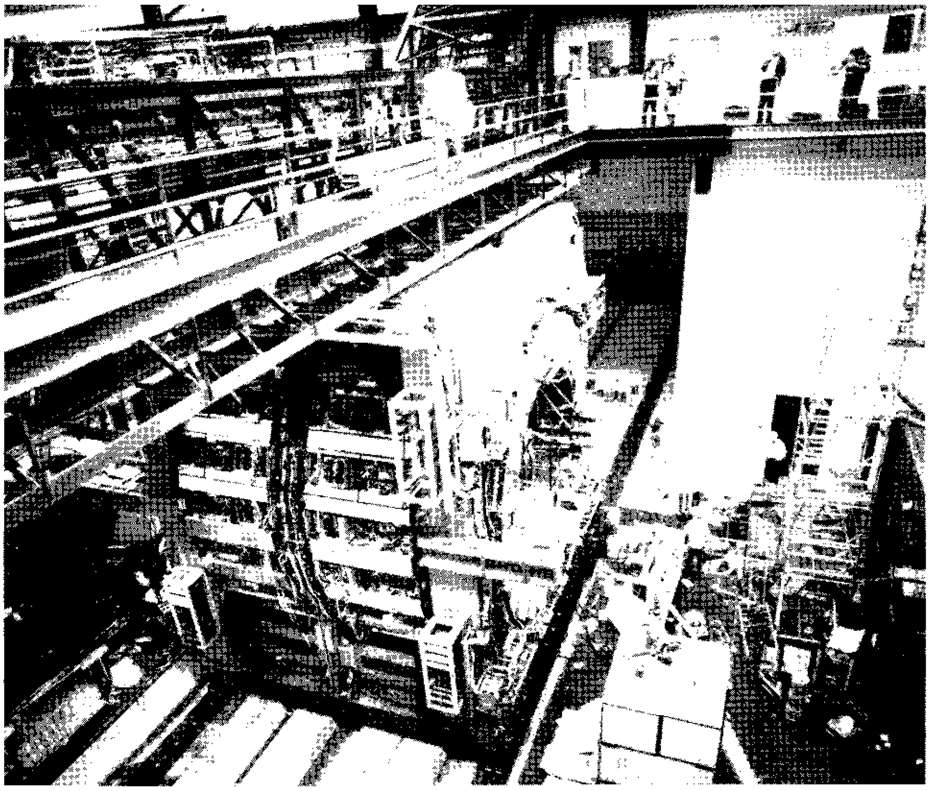
The CDF design was described in our January/February 1984 issue, pages 11-15. The aim of the October commissioning exercise for CDF was primarily to debug the data acquisition system and to look for any unexpected machine-associated backgrounds. In fact the running conditions turned out to be very quiet.

CDF elements in place during commissioning were the central electromagnetic and hadron calorimetry outside the magnet coil, some channels of the outer central muon system, and the Vertex Time Position Chamber (VTPC), together with their data acquisition systems. The VTPC provides tracking information and will eventually be complemented by the Central Tracking System (à la JADE).

Although the collision rate proton-antiproton collision rate was way down on its design figure, the tests were invaluable in building confidence, ready for the first production run later next year to explore these exciting new physics horizons.

## *Collider dedication*

*Two propitious days before the first proton-antiproton collisions were seen, the new Fermilab Tevatron Collider was officially dedicated. Extracts from the fine speeches made at the ceremony will appear in our next issue.*



*The CDF detector during its epic 100-foot journey from its 'garage' position into the Tevatron tunnel.*

# The quark structure of matter

## *Quark's the matter?*

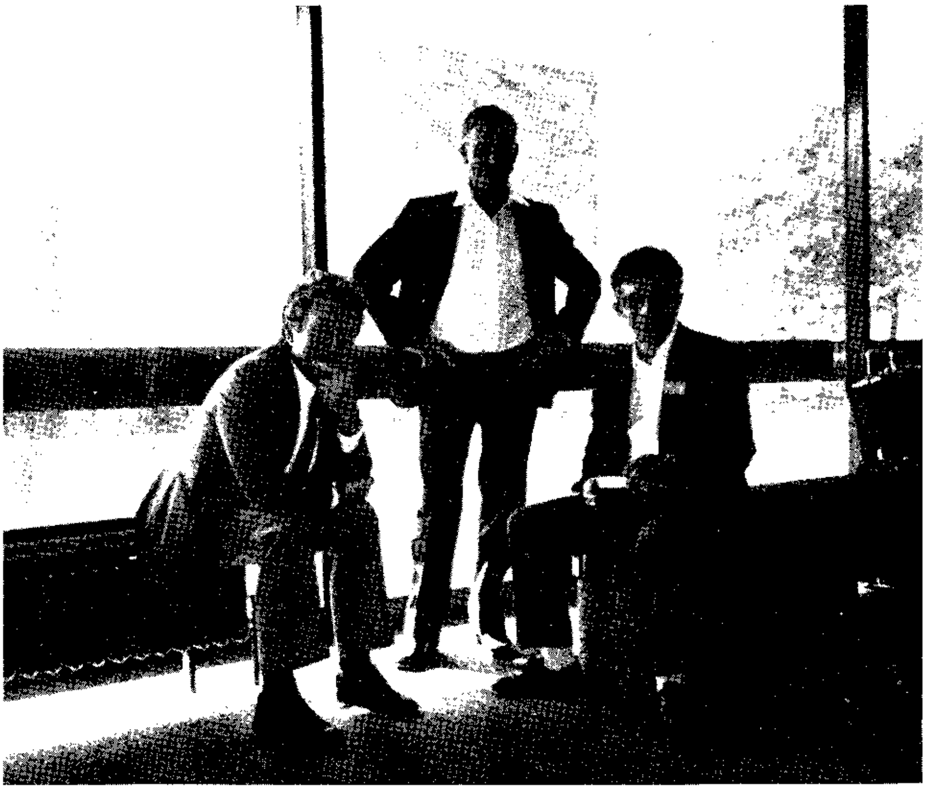
*This month, several articles highlight the growing interest in the implications of the quark picture for the 'bulk' properties of matter. Once quarks were considered solely as nucleon constituents, largely irrelevant for structures bigger than a nucleon. Now that has changed. Recently discoveries show that the quark structure of nucleons depends on the surrounding nucleus, and speculation is growing that under the right conditions quarks and gluons could form new types of matter, very different to conventional nuclei. The article 'Nuclear truth' by CERN's Torleif Ericson (page 425) points out the increasing role quarks are playing in nuclear physics. 'The quark structure of matter' by Maurice Jacob (this page) is a report of a recent topical conference. The editorial feature 'Pumping ion' (see page 427) describes the ambitious plans at CERN to carry out experiments using ion beams to search for new phenomena.*

The quark structure of matter is a theme which is receiving increasing attention in both particle and nuclear physics. More and more nuclear physicists are becoming users of high energy research facilities, and in five years, the quark structure of nuclei is likely to become a prominent component of CERN's fixed target physics research programme.

There are two main reasons behind this trend. The first finds its origin in the 'EMC Effect', discovered at CERN, where probing targets with high energy lepton beams showed that the quark structure of nucleons in nuclei was very different to that of isolated protons. The second reason stems from the present theoretical understanding of the confinement of the colour force binding quarks together. It seems likely that at high enough quark density and/or energy density, the colour force is no longer confined to nucleonic dimensions. A new state of matter – the quark-gluon plasma – could appear.

Important in the early evolution of the Universe, this quark-gluon plasma could be reproduced transiently in high energy collisions using ion beams. The CERN heavy ion programme (see page 427), scheduled to start next year, will explore the conditions where quark-gluon plasma could show up.

While the quark structure of matter is most clearly displayed in very high energy studies and in the experiments at the CERN proton-antiproton Collider, it has also become the backbone of the analysis of many low energy processes, in particular those studied at the LEAR Low Energy Antiproton Ring at CERN. For the future,



*Together at the recent Topical Conference on the Quark Structure of Matter held at Strasbourg and Karlsruhe, left to right, A. Gallmann from Strasbourg, local member of the Organizing Committee, Maurice Jacob of CERN, this year's President of the French Physical Society, and H. Meyer, President of the Particle Physics Division of the German Physical Society.*

the HERA electron-proton Collider now under construction at the German DESY Laboratory in Hamburg will attain energies far beyond those currently used to probe nuclei with lepton beams.

Thus the Topical Conference on the Quark Structure of Matter held in Strasbourg and Karlsruhe from 26 September to 1 October was especially interesting. The first meeting to be jointly organized by the Société Française de Physique (SFP) and the Deutsche Physikalische Gesellschaft (DPG) and bringing together 160 participants, it emphasized the interfaces between particle physics, medium energy physics and nuclear physics. These are being strengthened because of the growing interest in the quark structure of matter, and it was interesting to see that the researchers from different fields were not in any way isolated.

Host institutions were the Parliamentary Assembly of the Council of Europe and the local Centre de Recherches Nucléaires in Strasbourg and the University in Karlsruhe. Co-chairmen of the Organizing Committee were H. Meyer from Wuppertal, president of the particle physics division of the DPG, and Maurice Jacob from CERN, currently president of the SFP.

*By Maurice Jacob*

# Nuclear truth

*There is no single 'true' picture of the nucleus. Instead, there are many alternative pictures, all equally 'true' within their own regions of validity. A relative newcomer on the scene, but no less 'true' than the others, is the description in terms of the quarks and gluons which are the constituents of the nucleons and other particles inside nuclei. Summing up at the Conference on Nuclear Physics with Electromagnetic Probes, held in Paris earlier this year, Torleif Ericson of CERN showed just how many facets there are to the nuclear 'truth'.*

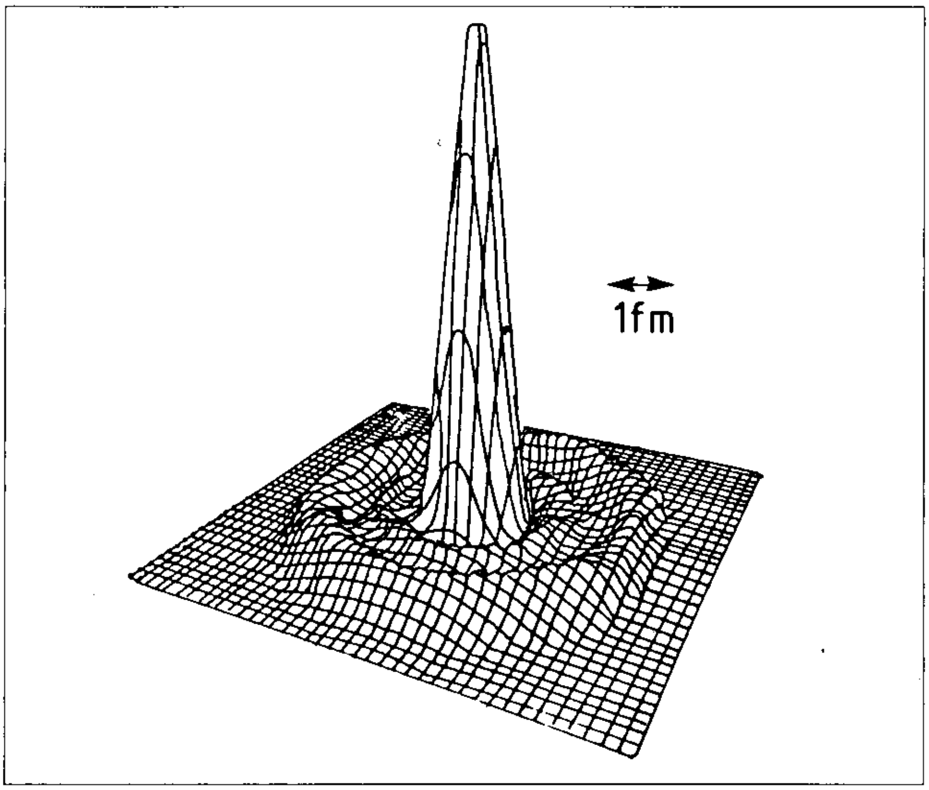
*Torleif Ericson – the many truths of nuclear physics*

What is the 'correct' way to view the nucleus? Should we view it as a system of interacting nucleons or as a system of interacting quasi-particles? Is it more valid to discuss it in terms of particle degree of freedom? Is it not more 'fundamental' to assume that the nucleus is a system of quarks? What is right? What is the 'truth'?

In many areas of physics, there are alternative pictures, corresponding to a whole spectrum of viewpoints which depend on the framework and the scale. It all depends on how one looks at the problems and on what is emphasized. Nuclear physics is especially well-endowed with alternative descriptions.

Nearly classical modes of collective nuclear excitations have been investigated for a long time, but even in this well explored field there are still new features. A prediction made a few years ago that in a deformed nucleus protons

*Electron scattering experiments give this striking distribution for a single nucleon in a high density nuclear region.*



and neutrons could beat against each other in a scissor-like mode corresponding to a magnetic dipole excitation has now been seen. At this level, nuclei appear like chunks of proton-neutron matter.

However electron scattering experiments have in recent years clearly demonstrated how individual nucleons contribute to nuclear structure (see March 1984 issue, page 64). Thus it is also true that nuclei consist of nucleons even in their densest regions, enabling many features to be explained in terms of two-nucleon interactions caused by the exchange of single bosons.

More than eighty years after its discovery by Rutherford, the humble alpha particle is still an invaluable source of nuclear information. Conventionally thought of as the most spherical and symmetrical of all nuclei, the alpha has now been found instead to be a deformed nucleus!

Other discoveries show the limitations of explanations in terms of two nucleon interaction, demanding three-body forces, while further clues show clearly that a picture of nuclei as inert nucleons has definite limitations.

For a long time it was tacitly assumed that the nucleus is a system of non-relativistic nucleons. However in the past few years there has been increasing speculation that the component nucleons are instead relativistic (see June issue, page 183), and now one clear case of relativity has been seen in low energy nuclear physics (photodisintegration of the deuteron).

Another well established nuclear physics picture involves explaining everything in terms of the physics of pions, nucleons and nucleon isobar (delta) resonances. Accumulated evidence shows that the nucleon resonance is a 'true' nuclear component. There is in addition clear-cut evidence for meson exchange currents.

These various ways of looking at nuclear physics in terms of nucleons and resonances interacting via mesons are quite successful and are underlined by many experiments without any recourse to the quarks and gluons which are the constituents of nucleons, pions, etc. Particle physics shows that field theory with quarks and gluons works very well: for nucleons it has even been possible to map the distribution of the different quarks. The central question is: how do quarks and gluons manifest themselves and what criteria for acceptable evidence should we use? What are the 'smoking gun' experiments for nuclear quarks?

We must obviously aim for 'clean' situations where alternative explanations are unlikely or, better, suppressed. Unless other explanations can be ruled out, we do not want to have 10 per cent effects as evidence. Sir Denys Wilkinson has defined the problem in the following terms: 'We must not be tempted into mistaking a demonstration of consistency between nuclear behaviour and expectation based on an explicit involvement of quarks for a proof of that involvement. We gain nothing unless those descriptions bring us an enhanced understanding of nuclear structure and transitions.'

The now-famous EMC Effect (variation of nucleon quark structure with the surrounding nuclear environment) provides the most specific example of a quark effect in nuclei. In a quark description of deep inelastic muon scattering, the quark distribution for a nucleon inside a nucleus differs from that for a free nucleon. Is this changed distribution produced by quark-antiquark pairs showing up as pions, or by the nucleon binding, or is it a genuine new effect on the quark level linked to incipient quark deconfinement from the nucleons as the quark 'bag' gets bigger?

It is important to restrict such possibilities by exploiting all the new information we can find. Two novel points came up during this conference: first A. W. Thomas of Adelaide drew attention to the importance of nucleon binding in the EMC Effect and advocated that this be further explored. Second, there was a considerable discussion on the experimental restrictions on nucleon swelling inside nuclei.

New data from wide angle electron scattering on aluminium 27 suggests that the nucleon swells by less than about five per cent, since the assumption of a normal nucleon size works very well. However the detailed analysis was questioned so any firm conclusion is premature; we eagerly await the final analysis. Electron scattering specialists consider five per cent swelling a generous upper limit, but this strong restriction comes from light elements.

Finally, magnetic moments in nuclei scale with the quark bag radius and are therefore sensitive to nucleon swelling in nuclei. While the detailed relation is less transparent, specialists insist that modifications of magnetic moments on the 5-10 per cent level will cause havoc. All of these point to a small nucleon swelling, while the EMC Effect explanation needs about 15 per cent or even more. The situation is further confused by the analysis of quasielastic electron scattering on carbon 12. At low energy release there seems to be evidence for an increased nucleon size.

Although there is no answer to the question of nucleon swelling at present, the issue is now approached in a variety of ways, independent of the EMC Effect. In the future we expect therefore reliable limits from different approaches restricting the theoretical explanations of the EMC Effect.

The issue of how to find evidence for quarks in nuclei was examined by an expert panel, but with inconclusive results. The big Stanford linac now probes the deuteron down to distances of about 0.2 fm, a factor two better than before. At this level, the experiment clearly is sensitive to detailed features well on the level of the structure in any quark description. Most likely, the deuteron electrodisintegration and the three-nucleon form factor at this level are even better systems to study such effects, and we can now expect them.

Second, the system of hypernuclei and nuclear physics with strange particles should provide a happy hunting ground. Since lambda and sigma hypernuclei can be regarded as nuclear systems with controlled and tagged impurities, they are a rich source of physics. In particular, the strange quark can be directly 'observed'.

A third approach to quark physics uses relativistic heavy ions. The idea is to squeeze so much energy density into an interaction volume that a phase transition to a quark-gluon plasma develops. There are good theoretical reasons to believe that such an effect should occur, although the accompanying background might obscure the otherwise spectacular signal. This means that low energy exploration of quark physics will be a very important complement to the high energy relativistic approach.

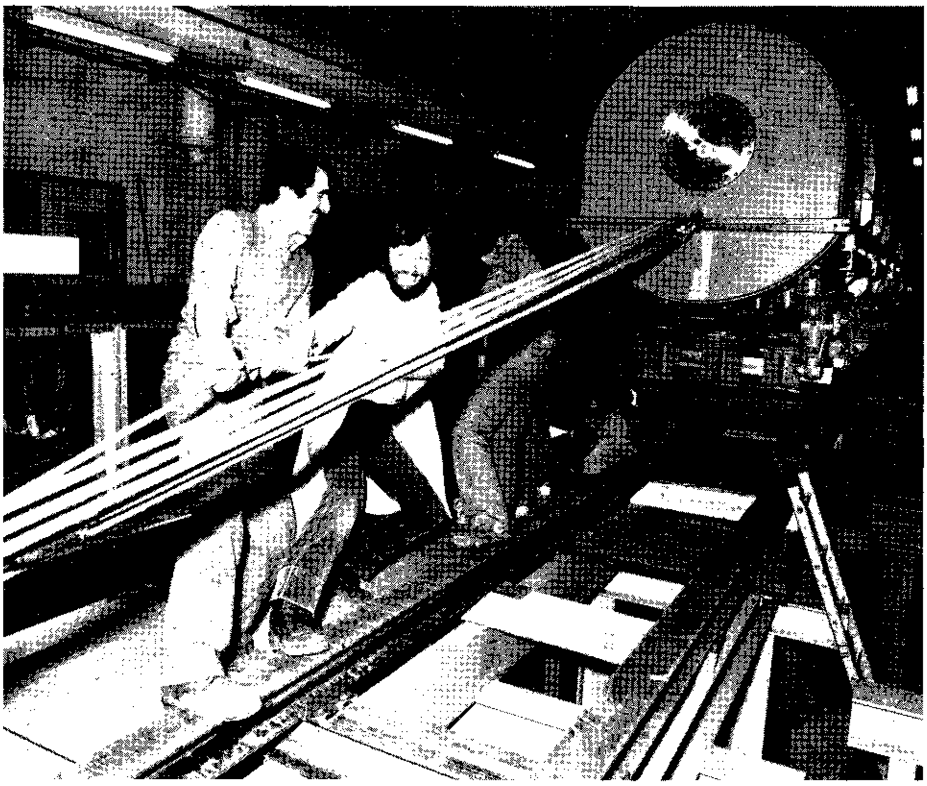
The characteristic feature of electron machines is their ability to isolate exact features. For this reason the heavy ion approach and the electron approach are not rival ones but complementary. It is by a common attack by these means that we hope to establish quark field theory as a nuclear 'truth' as well.

In conclusion, as we examine the physics of nuclei on various levels we find many 'truthful' descriptions. These are not contradictory to each other; each of them is invaluable for our understanding of nuclei inside its own region of validity. It is characteristic that each of the approaches uses a wealth of detailed knowledge, for instance from particle interactions, which is quantitatively incorporated in the appropriate 'truth'. The many new developments presented at this conference bear ample witness to the many 'truths' in nuclear physics.

# Pumping ion

*Earlier this year, Linac 1 at CERN's Proton Synchrotron was moved back 12 metres to allow improved shielding. This way installation work for the new heavy ion injection system could proceed in parallel with normal PS working.*

*(Photo CERN 370.1.85)*



In 1982 a Darmstadt (GSI)/Berkeley/Heidelberg/Warsaw team proposed that oxygen ions be accelerated in the CERN 'Proton' Synchrotron in order to be able to study collisions between nuclei at energies higher than were available at the heavy ion machines at Darmstadt (the UNILAC linear accelerator) or Berkeley (the Bevalac synchrotron). Since the proposing Laboratories were able to do much of the work and provide much of the financing for the injection system for oxygen ion acceleration, the proposal was accepted despite the crowded CERN programme and the necessary development work began in a Berkeley/CERN/Darmstadt collaboration.

Interest in using the ions, both from the PS and from the SPS, has escalated to give an ambitious experimental programme (described below). Major items of equipment are coming together at CERN, and first tests with the ion beams are scheduled when the CERN machines come back on the air at the beginning of 1986.

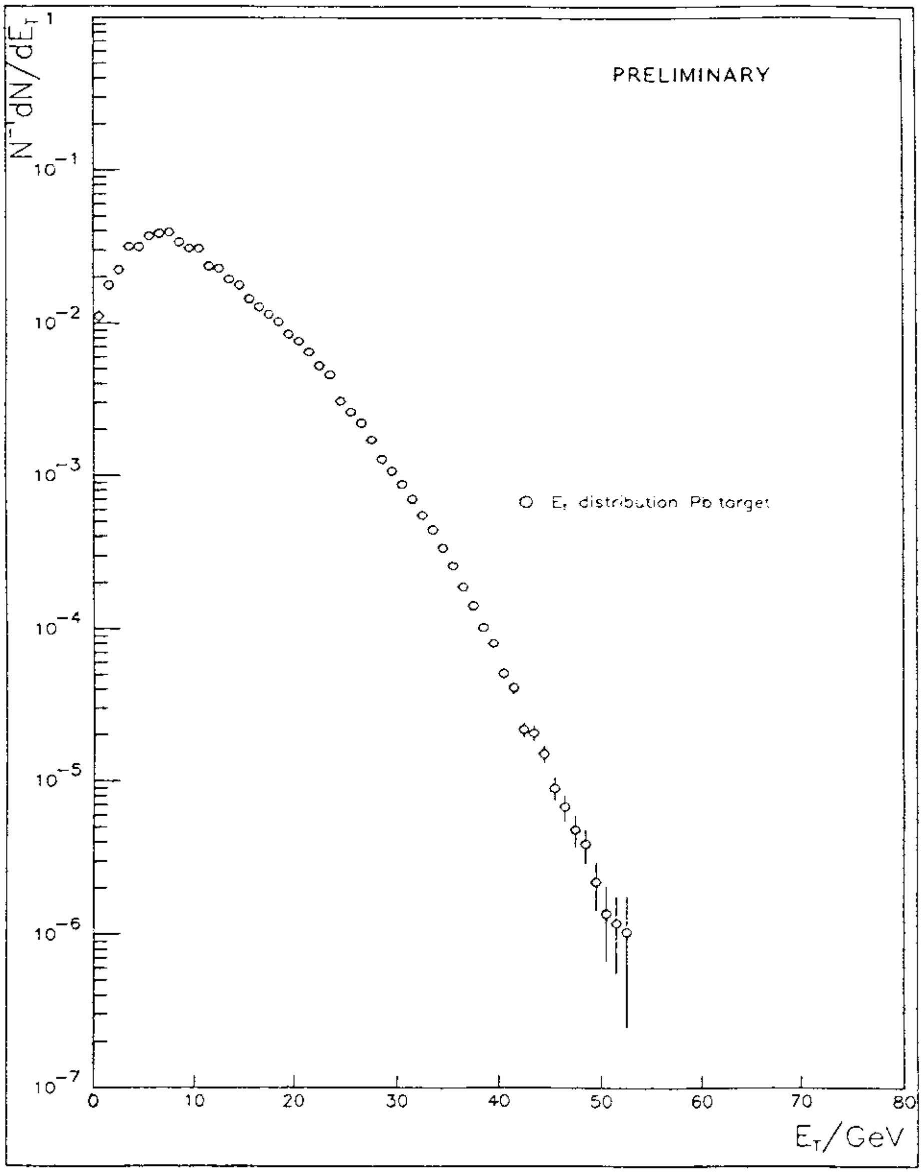
An important element in the decision to pursue ion beams was the existence of Linac 1 (the 'old' linac) still linked to the PS Booster. This linac had already been used in the acceleration of deuterons and alpha particles and there was thus already experience of coping with particles other than protons. The trick for the ions is to increase the accelerating (and focusing) fields so that the ions travel down the linac at exactly half the velocity of the usual protons. That way the ions stay in step with the accelerating fields in the drift tube gaps.

Knowledge of the sparking limits in the first tank of the linac dictates the permissible field levels which in turn imply a charge to mass ratio for the ion species of at least 0.38. A further limitation is that the beam diagnostics throughout the PS complex need a minimum beam current of about 10 microamps from the linac in order to pick up adequate signals.

These two constraints led naturally to the selection of oxygen 6+ ions (oxygen atoms stripped of six electrons). They have a charge to mass ratio at the limit of what is acceptable and adequate ion current can be drawn from an ECR (Electron Cyclotron Resonance) source. An additional requirement is that the ions be injected into the first tank at about 140 keV per nucleon; this can be provided by a radiofrequency quadrupole. These conditions defined the major features of the injection system to accelerate oxygen 6+ ions to an energy of 12.5 MeV per nucleon.

The ECR source has been developed at CEN Grenoble and over a year ago achieved an over 80 microamp ion beam of the required quality. It was taken to GSI in May of this year where it was joined by a radiofrequency quadrupole (RFQ) from Berkeley. The RFQ, which is designed to take the oxygen 6+ ions from 5.6 keV to 140 keV per nucleon, follows the design of the heavy ion RFQ installed and successfully operating on the Bevalac. Preceding the decision to use this was the successful experience with the RFQ built at CERN which demonstrated that the necessary matching of the particle beam bunches to the accelerating field 'buckets' in the first tank of the linac could be successfully accomplished.

The ECR source, a low energy beam transport system and the Berkeley RFQ achieved 140 keV



*Transverse energy distribution observed in 200 GeV proton collisions in a lead target at CERN, extending far beyond the proton-nucleon kinematical limit near 20 GeV. This intriguing result for wide angle scattering promises well for studies with heavy ion beams.*

per nucleon ions with a current of up to 80 microamps in recent tests at Darmstadt. All these units are now being transferred to CERN for installation at Linac 1. This machine will then have two pre-injectors, each with an RFQ. The linac has already been moved back from its initial position for improved shielding. Without this the necessary work on the ion systems could not go on while the PS was being run for protons and antiprotons.

Although the losses of ions, due to charge stripping in encounters with molecules of residual gas, are tolerable in the single passage of the beam down the linac, it is necessary to convert to fully stripped oxygen 16 before injection into the PS Booster where the ions need to live for many turns. Also the Booster r.f. system needs to perform some gymnastics to cope with ions having only half the velocity of the usual protons. A 'harmonic jump', where the beam is debunched and then reformed at half the initial r.f. frequency, is applied. (This is done in the Booster so as not to add yet another manoeuvre to the already complex programme of the r.f. system in the PS ring.)

The Linac, Booster and PS beam diagnostics have been upgraded to cope with the low beam intensities and so has the SPS. A variety of considerations (avoiding transition energy, intensity problems, beamline parameters) mean that the lowest beam energy from the SPS will be 40 GeV per nucleon but rising from there to an energy of 225 GeV per nucleon, so that the emerging ions can have energies up to 3600 GeV (3.6 TeV)!

## *Experiments*

Experiments with ion beams and with particle beams hitting nuclear targets are already hinting strongly at new physics. As well as the realization that under certain conditions nuclei can be viewed as assemblies of quarks and gluons (see page 423), heavy ion experiments have also revealed other new aspects of the behaviour of nuclear matter, providing new ideas for astrophysics (see July/August 1984 issue, page 243).

There is also a strong conviction that once ion beams exceed some threshold energy, crashing them into laboratory targets could finally produce the long-awaited quark-gluon plasma – a new type of matter with properties very different to ordinary nuclear material.

When the first plans to use heavy ion beams in the CERN high energy machines were put forward (see July/August 1983 issue, page 223), the idea was that the collisions would be monitored in the West Experimental Area of the SPS using a streamer chamber and the 'Plastic Ball/Plastic Wall' detector used in lower energy heavy ion beams at the Berkeley Bevalac.

Since then interest has grown considerably. Even with the big North Experimental Area of the SPS housing most of the experiments, there were more potential customers than CERN's restricted facilities could handle.

The Plastic Ball study, still for the West Area, now involves a Berkeley/Darmstadt (GSI)/Lund/Marburg/Munster/ Oak Ridge/Warsaw group. The 820-module Plastic Ball scintillator identifies reaction products by energy loss. Downstream calorimetry and a multiplicity detector complete the apparatus.

The streamer chamber experiment proposed with the Plastic Ball has migrated to the North Area and involves a collaboration of Athens/Bari/CERN/Cracow/Darmstadt/Frankfurt/Freiburg/Heidelberg/Berkeley/Marburg/Texas A and M/ Warsaw/Zagreb. The equipment, including the streamer chamber, comes from a previous North Area experiment which finished taking data in 1980.

Finding evidence for quark-gluon plasma is the goal of Athens/Bergen/Berkeley/Birmingham/Brookhaven/Carnegie Mellon/CERN/Chandigarh/City College, New York/Cracow/Madrid/Santiago/Strasbourg/Vienna group which will look explicitly for the production of (anti)baryons carrying the strangeness quantum number. Formation of quark-gluon plasma is expected to result in an increase of secondary strange particles. A powerful superconducting magnet will disperse the intense sprays of secondaries, while a Time Projection Chamber will look for heavy particle decays. The calorimeter from the old European Hybrid Spectrometer completes the setup.

The other North Area heavy ion studies are offshoots from large experiments originally built for use with particle beams. A Brookhaven/CERN/Heidelberg/Los Alamos/Lund/McGill/Montreal/Moscow/Novosibirsk/Pittsburgh/Saclay/Stockholm/Tel Aviv group has modified a big experiment originally proposed to study lepton production by particle beams (see September 1984 issue, page 281).

For ion beams, the apparatus will include additional large angle spectrometry and soft photon detection. Multiple target arrays with suitable spacing will be used to minimize secondary interactions and optimize triggering rates. Already initial tests with proton beams have shown intriguing effects producing very high (50 GeV) transverse energies far beyond the allowed kinematics of proton-proton interactions. This promises well for the heavy ion beams.

Another modification of an existing experiment is by a Bergen/CERN/Clermont Ferrand/Lisbon/Lyon/Neuchâtel/Orsay/Palaiseau/Strasbourg/Valencia collaboration using apparatus built to investigate the production of muon pairs by particle beams (see April issue, page 104). For heavy ion work, the apparatus will be supplemented by beam counters, calorimetry, and special targets.

In addition to the large electronic detectors, several studies using emulsions are planned, with participating institutions from Europe, North America, India and Egypt.

First heavy-ion beams are scheduled for next September, with a sizeable run just before the 1986 end-of-year shutdown. These experiments promise relatively rapid results, and already some two hundred physicists are involved.

Inevitably the physicists are already thinking of ions beyond oxygen since heavier nuclear masses could give additional information. A beam of sulphur ions of much lower intensity is possible from the source and could be squeezed through the linac and Booster together with the oxygen beam without too much difficulty, although passing through the transition energy will be problematic in both the PS and SPS. Exotic ideas are therefore being generated about accelerating oxygen and sulphur, tuning the machines on the oxygen, and calculating from that to the appropriate settings for the sulphur. But all that is some way into the future, there is already plenty to keep the ion enthusiasts busy.

# Niels Bohr centenary

This year marked the hundredth anniversary of the birth of Niels Bohr, one of the giant figures of modern physics. In addition to his great scientific achievements, Bohr was a major influence on the discovery and exploitation of nuclear fission. After the Second World War, he played a key role in shaping European scientific collaboration and in the establishment of CERN as Europe's particle physics Laboratory.

When Bohr trained as a physicist at the turn of the century, theory and experiment were far from being separate compartments of physics. One of his early achievements was a Danish Academy of Sciences and Letters gold medal award for his ingenious experimental technique for making surface tension measurements. In Copenhagen he went on to specialise in electrons, at first in the theory of metals.

In 1911, the young Bohr's preoccupation with electrons took him to the Cavendish Laboratory in Cambridge, where J.J. Thomson had discovered the electron in 1897. However bigger things were happening in Rutherford's laboratory in Manchester, where the nuclear picture of the atom had just been discovered, and where Moseley was mapping out the X-ray spectra of the elements.

Despite Rutherford claiming 'I know what the atom looks like', atomic mechanics were a mystery. According to classical ideas, atoms would collapse. Bohr was to forge the vital link between the experimental breakthroughs of Rutherford and the then new ideas of quantum theory as proposed by Planck and Einstein a few years previously.

In their initial meeting, Rutherford told Bohr he was interested in 'promising simplicity', but cautioned the young researcher from building too much theory from meagre experimental evidence – advice always worth heeding.

Bohr was set to work on an experimental problem, but despite his demonstrated prowess in laboratory craft, it soon became clear that he was more attracted to analytical thought and discussion. Later he wrote: 'in the spring of 1912 I became convinced that the electric constitution of the Rutherford atom was governed by the quantum of action'. Rutherford listened to the ideas and suggested to Bohr to write them up, saying later 'this young Dane is the most intelligent chap I've ever met'.

Instead of writing up immediately, Bohr went home and got married, returning to England after his honeymoon to give his manuscript to Rutherford, who suggested that it should be substantially shortened if people were to read it.

In Copenhagen, and after frequent correspondence with Rutherford, Bohr perfected his ideas on the electron structure of atoms and established the vital links with both optical spectroscopy and with the new X-ray measurements. These ideas were of course very revolutionary and naturally aroused a lot of opposition. However the weight of experimental evidence soon built up, leading to Einstein's often quoted remark – 'Then it is one of the big discoveries'.

In the 1920s, Copenhagen's Institute of Theoretical Physics became one of the world centres of quantum theory. As well as Bohr, there were Heisenberg, Pauli, Kramers, Ehrenfest, Gamow, Bloch, Landau, Casimir,...

Later, Bohr's interest turned towards the nucleus, and the middle 1930s saw the emergence of his 'liquid drop' model of the nucleus (remember his early work on surface tension). With the death of Rutherford in 1937, Bohr inherited the mantle of Europe's premier nuclear physicist. Equipped with Europe's first operational cyclotron, Copenhagen took over from the Cavendish Laboratory as the world focus of nuclear physics. This period also saw the discovery of nuclear fission.

Shortly before the outbreak of the Second World War he visited the United States and witnessed the developments being made there in understanding nuclear fission. After the occupation of Denmark, he stoically continued with his work, one of the visitors to his laboratory during this time being Heisenberg.

Then begins the period in Bohr's life which reads like something from a spy novel. In 1943 came Chadwick's secret message, hidden in a key, summoning Bohr to the UK. After the rigours of his flight from neutral Sweden to Britain in the bomb bay of an unmarked Mosquito aircraft, he quickly became integrated into the Allies' wartime nuclear physics team, and went to the US where work was in progress.

With characteristic foresight, he tried to impress on the Allied wartime leaders the implications of nuclear energy and the possibilities for international collaboration, although his meeting with Churchill was distinctly unsuccessful.

## *Bohr and CERN*

After the trauma of the war, it was not long before the idea of a European 'nuclear physics' Laboratory was mooted to help boost European science and to repair the cultural ravages of the conflict. While the idea gained approval relatively quickly, the way of going about it was less clear.

One viewpoint advocated building a big European accelerator as soon as possible. Another, of which Bohr was initially a protagonist, maintained that the big machine could come later, initial collaboration capitalizing on existing machines such as those at Liverpool in the UK and Uppsala in Sweden. However a common accord was hammered out at a series of UNESCO conferences.

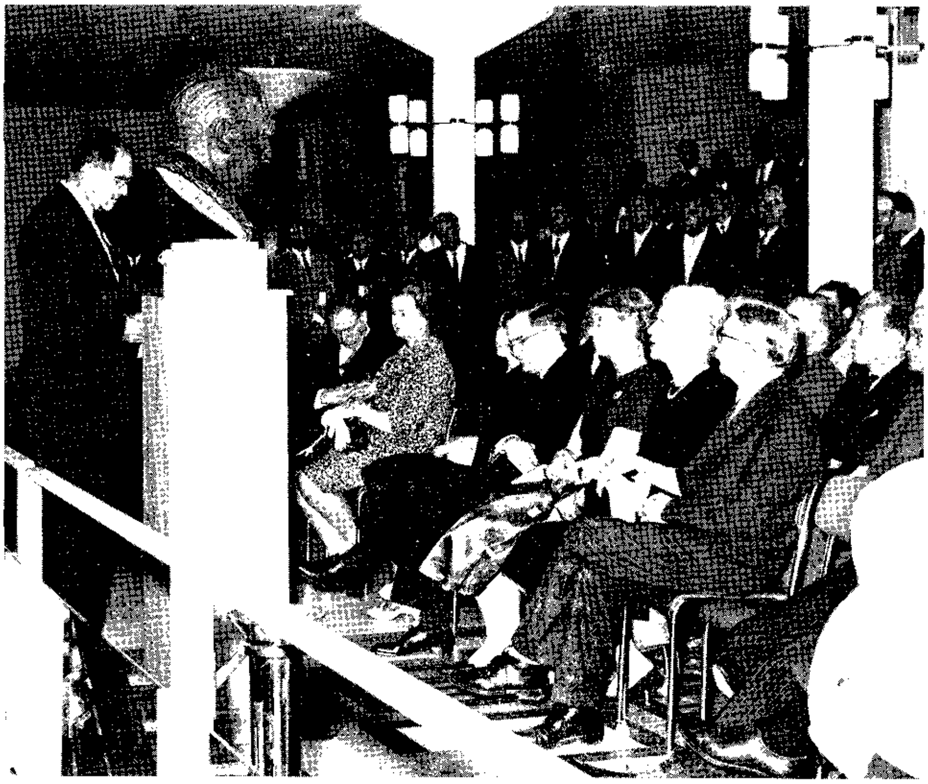
During the early fifties, it was natural that European theoreticians should continue to come to Copenhagen, and even after the decision was taken to build CERN's first big machine at Meyrin, Geneva, CERN's Theory Group continued to be based in Copenhagen. Bohr was its first head, but Christian Møller took over in 1954.

The CERN Theory Group officially transferred to Meyrin in 1957, but Copenhagen was still assured of a place on the international map thanks to the establishment in 1957 of the Nordic Institute for Theoretical Atomic Physics – Nordita – which has gone on to become a leading centre in nuclear structure research.

Bohr was a founding member of CERN's Scientific Policy Committee, at a time when the Chairman was Heisenberg, Vice Chairman Leprince-Ringuet, and other members were Alfven, Bernardini, Blackett, Cockcroft and Scherrer.

One of Bohr's final visits to CERN was in February 1960, when he formally switched on the new Proton Synchrotron, giving Europe, for a short time, the highest energy particle accelerator in the world. He died in 1962.

Viktor Weisskopf was to write: 'It was Niels Bohr's personality, weight and work that made CERN possible. There were other personalities who started and conceived the idea. The enthusiasm and ideas of these other people would not have been enough, however, if a man of his stature had not supported it, if he had not participated in every important act, if he had not sat with the others and worried about every detail.'



*Viktor Weisskopf, Director General at the time, unveils a bust of Niels Bohr at CERN.*

*(Photo CERN 178.6.63)*

# Around the Laboratories

## CERN
## Collider 90

The proton-antiproton Collider at the CERN SPS has been a unique physics tool since the first collisions were recorded in 1981. However with higher energies at the Fermilab Tevatron, the CERN experiments will no longer have the field to themselves. In addition, new electron-positron colliders now being built at Stanford (SLC) and at CERN (LEP) will soon provide additional and more precise means of exploring a region of physics which was opened up at the CERN proton-antiproton Collider.

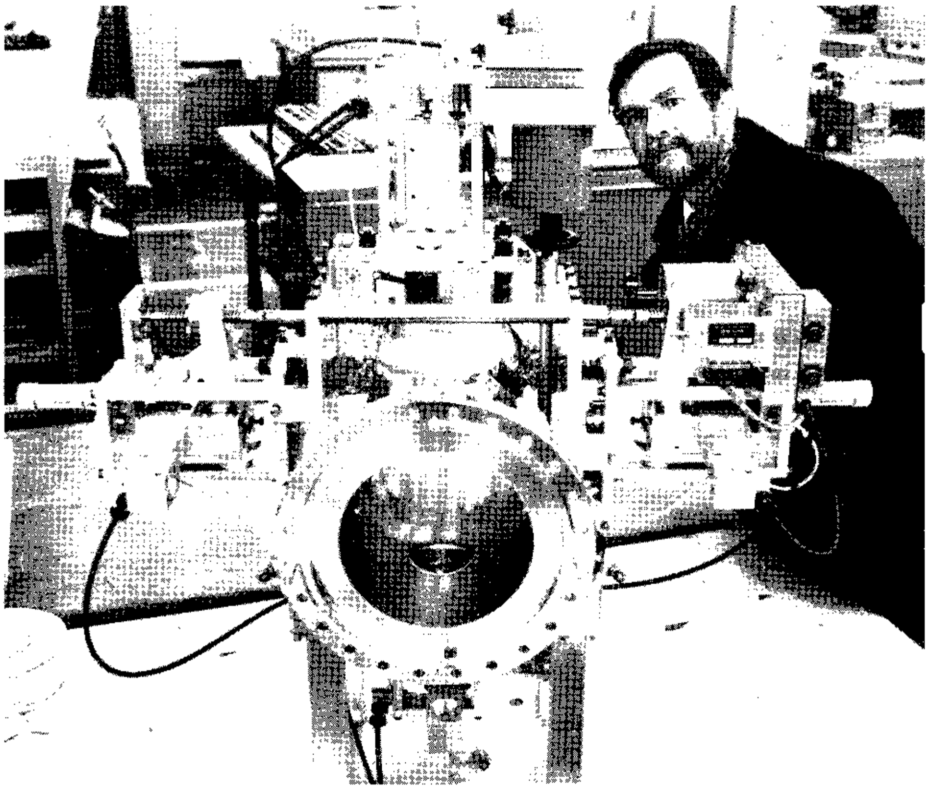
To boost the Collider's performance, the decision was taken at CERN in 1983 to build the ACOL Antiproton Collector. This is scheduled to start operation in 1987, increasing the number of antiparticles available for the Collider. With ACOL, the Collider will remain highly competitive for several more years. But what of the longer term future?

To look at possible future scenarios for the CERN Collider, a workshop was organized at Zinal, Switzerland, in June. It brought together about 80 physicists, many of whom had participated previously in physics and in detector working groups. The Zinal programme covered plans for the current major experiments at the Collider (UA1 and UA2), the new Fermilab Collider and its detectors, physics perspectives, new detector technologies, and possible future detector configurations.

The meeting identified a clear physics 'window' covering the few years immediately after the startup of ACOL. During this time the Fermilab Collider and the new electron-positron machines would still be running up to their optimum performance, and the CERN Collider could continue to make valuable contributions, such as tracking down supersymmetry or any heavier quarks.

*Assembly at CERN of the r.f. kicker for the new Antiproton Accumulator stochastic cooling system. When CERN's revamped antiproton facilities get underway again in 1987, proton-antiproton collision rates should be substantially improved, providing added impetus to the experimental programme.*

*(Photo CERN 557.2.85)*



However the higher collision energies of the Tevatron (up to 1000 GeV per beam compared to 450 GeV at CERN) will probe regions inaccessible elsewhere. In addition the new electron-positron machines will provide a higher level of precision.

While the plans to upgrade the UA2 detector were fairly clear, UA1's direction (see November issue, page 384) was not yet concrete at the Zinal workshop. This made it difficult to propose specific solutions for future detectors. However the danger of prematurely discounting a powerful physics tool was realized, and future experiments should not be vetoed simply because they run counter to current dogma.

Several longer-term physics objectives were identified at Zinal. A precise comparison of the masses of the W and Z particles (the carriers of the weak nuclear force) would provide valuable insights into the inner workings of the currently accepted 'Standard Model'. Other subjects for further study are the production of 'jets' of hadrons containing heavy quarks, or arising from gluons, and the production of heavy hadrons, either singly or in pairs carrying opposite quantum numbers.

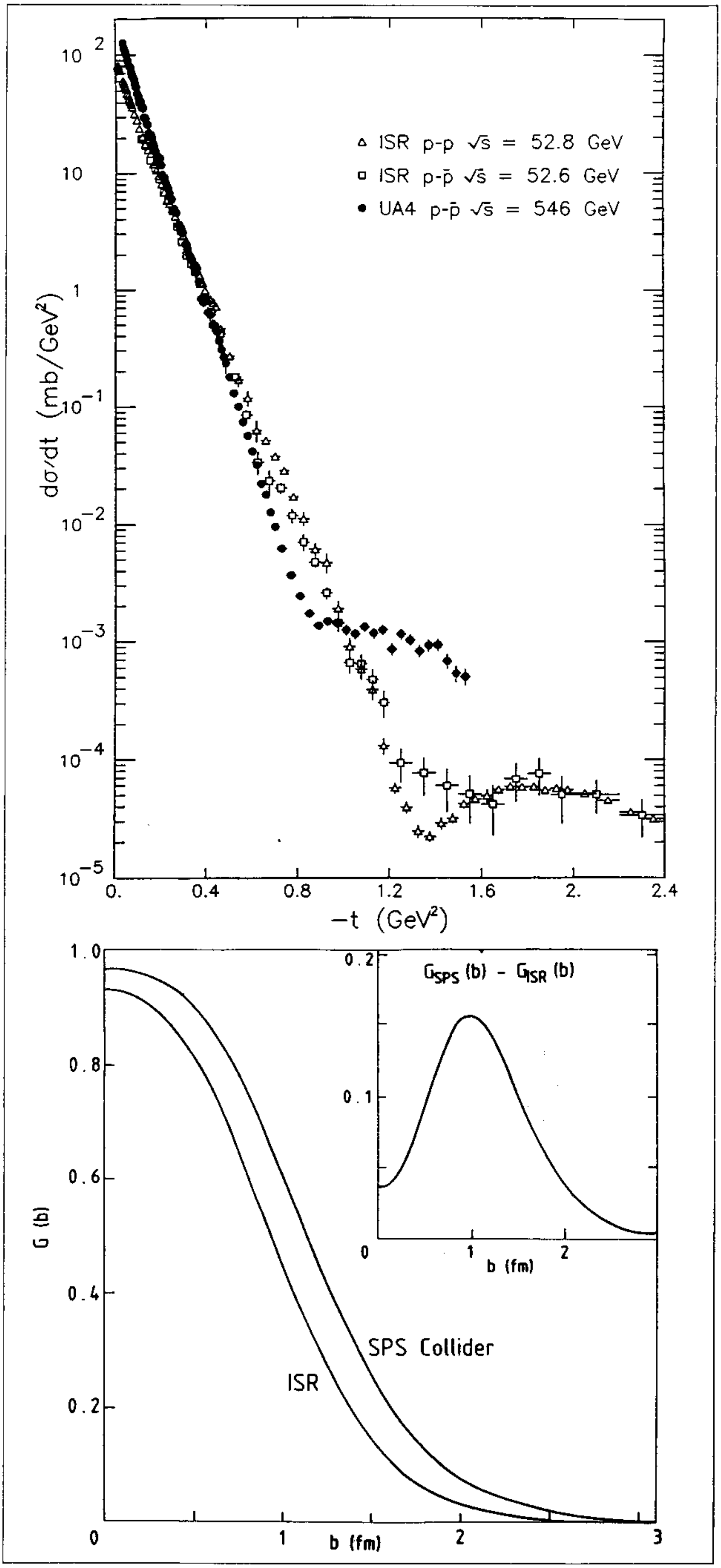
In addition, the high data-taking rates at hadron colliders provide fertile ground for developing new instrumentation techniques for possible future machines. Parallel operation of lepton and hadron colliders would provide a 'balanced' research programme.

The Zinal organizers concluded 'in order to maintain a vigorous high energy programme through the early 90s it is desirable that a coordinated strategy be developed involving the current UA experiment upgrades and any possible new detector.'

## *Growing particles*

*Earlier this year, the UA4 experiment (Amsterdam/CERN/Genoa/Naples/Pisa) studying proton-antiproton elastic scattering (when the colliding particles 'bounce' off each other) took its final data at the CERN Collider.*

*Comparisons of proton-proton and proton-antiproton elastic scattering at lower energies (Intersecting Storage Rings, ISR, open data points) showed that the famous diffractive 'dip' in proton-proton scattering was less marked in the proton-antiproton case, becoming more a 'shoulder'. At the Collider (solid data points) the proton-antiproton 'shoulder' is shifted. An alternative way of looking at the data (below) uses the impact parameter (b, distance of approach) analysis, and shows that the absorbency or 'blackness' (vertical axis) of the colliding particles increases with energy. These results provided plenty of discussion at an elastic scattering workshop held at Blois, France, during the summer.*



## Spreading the message

The official opening of the 'Italy at CERN' exhibition on 9 October gave Italian Minister for Research and Technology Luigi Granelli the opportunity to underline his country's concern for the future welfare of CERN at a time when factions in other Member States are looking to reduce their support (see November issue, page 375).

In Italy, the funding for basic sciences has increased considerably in the past few years. (The same appears to be true in the US, where the Presidential Advisor for Science, testifying before a House Committee, said 'basic research is a vital underpinning for our national well-being'.)

Speaking at CERN, Minister Granelli pointed out CERN's special position. 'In many fields, Europe's lack of international status doesn't fall out of the blue. It stems from European incapacity to achieve the necessary "critical mass" to assure competitivity. However, in high energy physics, this has been achieved.'

After extolling the goal of European scientific unity and pointing out some of the implications for industry, Granelli declared 'European governments should never forget that it is impossible to imagine a satisfactory rate of technological applied research which is not preceded by adequate investment in fundamental research. Too many consider fundamental research as a luxury.'

'It is entirely anachronistic that at a time when CERN is being upheld as a model which could be emulated, and when we state that this is one of the few fields where Europe feels to be in the forefront, that we lack the political, financial and economic conviction to back CERN, not only for the present, but for the future,' he maintained.

The 'Italy at CERN' exhibition was organized by the Italian Institute for Foreign Trade (ICE), and representatives from some 60 firms visited the Laboratory during the week.

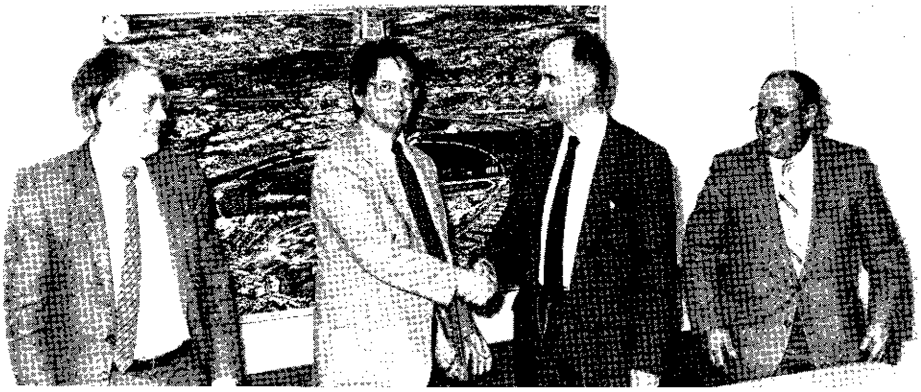
*For the official opening of the 'Italy at CERN' exhibition on 9 October, Italian Minister for Research and Technology Luigi Granelli mounts the steps of the Administration Building as CERN Director General Herwig Schopper (left) turns to greet Remo Paolini, Italy's Ambassador to the International Organizations in Geneva. In his opening ceremony speech, Minister Granelli left his audience in no doubt about Italy's concern for the future welfare of CERN.*

*(Photo CERN 133.10.85)*

## *Brookhaven to participate in HERA*

*A Memorandum of Understanding between the German DESY Laboratory and the US Brookhaven Laboratory which foresees Brookhaven participation in the construction of the new HERA electron-proton collider at DESY was signed in Hamburg on 14 October. DESY was represented by Directorate Chairman Volker Soergel and by Bjorn Wiik, one of the HERA project leaders. Director Nick Samios and Associate Director Paul Reardon signed for Brookhaven.*

*Under the agreement, Brookhaven will contribute expertise and specialized equipment for the quality control of superconducting magnets and for the HERA cryogenic system, and will be able to use all the tooling developed at DESY for the HERA magnets. Other fields of cooperation could follow. This significant new inter-Laboratory collaboration will help to have the new machine ready for physics in 1990.*



*After the signing of the new agreement between DESY in Germany and Brookhaven in the US on collaboration for the HERA electron-proton collider at DESY. Left to right Bjorn Wiik, Nick Samios, Volker Soergel, Paul Reardon.*

*(Photo DESY)*

*On 1 October, UK Prime Minister Margaret Thatcher inaugurated the new spallation neutron source, now named ISIS, at the Rutherford Appleton Laboratory.*

## RUTHERFORD APPLETON ISIS inauguration

The spallation neutron source which produced its first beams last year and which began its experimental programme in June was officially inaugurated on 1 October by UK Prime Minister Margaret Thatcher, who bestowed on the machine the name 'ISIS'.

This was an especially proud moment for the Laboratory team who over seven years oversaw the construction of the new machine from the ashes of the old Nimrod proton synchrotron, closed in 1978. A proud moment too for new UK Science and Engineering Research Council Chairman Bill Mitchell of Oxford, who on the first day in his new office could see the inauguration of the largest project that the SERC has undertaken.

Initially referring to the machine by its old name of Spallation Neutron Source (SNS), Prime Minister Thatcher said that the 60 million pound capital cost was worth 'every penny'. 'Basic research can be a springboard to the creation of wealth, as well as to other less tangible but equally significant outcomes. I and my ministerial colleagues understand the importance of basic science,' she declared.

After thanking the Prime Minister, former SERC Chairman Sir John Kingman pointed out the strong international interest in the machine and looked forward to increased participation from Europe and further afield.

'It is characteristic of "big science" that it pushes engineering to its very limits and beyond and often leads to advances in engineering practice, new techniques, new materials, new methods of control, which may well find applications in different areas, some of them closer to everyday life than the apparently arcane areas of science which will be pursued,' continued Sir John. 'If science is to advance, our scientists must have the necessary tools and, today, these include large facilities. Nevertheless, in the end, new ideas and a new understanding of Nature come not from machines but from scientists and I cannot overemphasise the importance of maintaining a flow of some of our best young talent into basic research. This is in no way inconsistent with our concern for the application and exploitation of science in support of the economy; indeed, in the long run, a healthy science base is an essential precondition for technological innovation in Industry.

We, as scientists, can hardly expect Government to accord the importance and priority to basic science which it needs if we do not put our own case clearly and convincingly to the nation as a whole. We need to convey both the intellectual excitement of the scientific chase and the extent to which the life of an advanced society relies on the results, often the unforeseen results, of past scientific achievements.'

*Rutherford Appleton Laboratory Director Geoff Manning (left) explains the ISIS ceramic vacuum vessel to the UK Prime Minister and to Italian Minister for Research and Technology Luigi Granelli. ISIS is generating international interest, with West Germany and India already involved. Italian participation in a new spectrometer is being discussed. In October Minister Granelli also visited CERN for the 'Italy at CERN' exhibition (see page 434).*

*(Photos RAL)*

# People and things

*Klaus Böckmann*

## *Klaus Böckmann 1929-1985*

*Klaus Böckmann of Bonn died on 17 October. For more than twenty years he was actively involved in experiments at CERN, first in hadron experiments with the 2 m hydrogen bubble chamber, then with BEBC and neutrino beams. In more recent years he made significant contributions to the UA5 streamer chamber experiment at the CERN proton-antiproton Collider. He built up fruitful connections with many physicists from Eastern Europe, and played an important role in the affairs of CERN users. To his colleagues he appeared as an inspiring scientist with a remarkable feeling for physics.*

## *Yog Prakash*

*On 2 September Yog Prakash of Jammu University, India, died. An experimentalist whose talents would have qualified him to work at a major Laboratory, he chose instead a base in one of the more remote corners of his home country, bringing the excitement of research to the very able but otherwise isolated students in Kashmir and the upper Punjab. At his death he was part of a bubble chamber study for the Fermilab Tevatron neutrino beam, and a planned exposure of emulsions in the Berkeley heavy ion work.*

## *On people*

*The Executive Committee of the American Physical Society's Division of Particles and Fields for 1986 is as follows: Chairman Stephen Adler (IAS Princeton), Vice-Chairman Lee Pondrom (Wisconsin), Divisional Councillor Gerson Goldhaber (Berkeley), Past Chairman James Cronin (Chicago), Secretary-Treasurer Bernard Pope (Michigan State), and Members Maris Abolins (Michigan State), Michael Creutz (Brookhaven), Gordon Kane (Michigan), Jonathan Rosner (Chicago), Stewart Smith (Princeton) and Lawrence Sulak (Michigan).*

## *Meetings*

*The CERN Accelerator School is organizing a course 'Applied Geodesy for Particle Accelerators' from 14-18 April, at CERN. Participants should have a basic knowledge of geodesy. Further information from Mrs. S. von Wartburg, LEP Division, CERN, 1211 Geneva 23, Switzerland.*

*An international workshop on the quark-gluon plasma and relativistic nuclear collisions will be held in Kiev (USSR) from 19-24 May, organized by the Ukrainian Academy of Science. Those interested in participating should contact G. M. Zinovjev, Institute for Theoretical Physics, Academy of Science of the Ukrainian SSR, 252130 Kiev 130, USSR.*

*Neutrino 86, the 12th International Conference on Neutrino Physics and Astrophysics, will be held in Sendai, Japan, from 3-8 June. Further information from Neutrino 86 Secretariat, Bubble Chamber Physics Lab, Tohoku University, Sendai, Japan 980. Participation is by invitation only.*

# ACCELERATOR PHYSICS
## THE UNIVERSITY OF HOUSTON INVITES APPLICATIONS FOR

**Senior Faculty Position**

The University of Houston seeks candidates for a tenure slot faculty position at the level of Full Professor or Associate Professor. The position involves teaching and research. Applicants should have records of outstanding research accomplishments in the field of Accelerator Physics. A concentration toward the theoretical side of the discipline is preferred. Salary will depend upon qualifications and experience.

Presently a group of four to six researchers and several graduate students are involved in projects such as design work on the SSC; analytical and computational accelerator theory of more general applicability; ion source physics and design; superferric magnet design; and linac and RFQ development. Significant Computer power and laboratory facilities are available. Work is done at the University, and at the Texas Accelerator Center, where researchers from The University of Houston, Texas A&M, and Rice University collaborate on Accelerator Physics and Design.

**Post Doctoral Research Associate**

Candidates are sought for a position as Post Research Associate, to work with members of the present U.H. Accelerator Physics Research Group. A PhD. in Physics or an allied Engineering Field is required. Resumes with the names of at least three persons who can provide professional evaluations should be sent to:

**Professor James Benbrook**
**Dept. of Physics**
**University of Houston**
**Houston, Texas 77004**
**USA**
**(713) 749-2351**

**Graduate Research Assistants**

Research Assistantships are available for students with a bachelors or masters degree, who meet entrance requirements for graduate study in the Physics Dept., leading to the Ph.D. Requests for applications should be sent to the above address.

***The University of Houston is an Equal Opportunity/Affirmative Action Employer.***

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# POSTDOCTORAL FELLOWSHIP

Postdoctoral Fellowship available in the Biology & Medicine Division for qualified Ph.D. to participate in a research program of studies on high energy heavy ion interactions with matter. Research involves application of heavy ion beams to biology and medicine. Projects will include studies of beam fragmentation, multiple Coulomb scattering, and heavy ion transport.

The research involves a comprehensive experimental program at the LBL Bevalac, and requires a recent Ph.D. in experimental high energy or nuclear physics. Preference will be given to candidates with experience in FORTRAN programming and data analysis, as well as familiarity with high energy physics or nuclear physics instrumentation. Applicants must be able to interact with other scientists and technical support personnel. Requires demonstrated ability to conduct research with minimal supervision. Stipends range from $1750-2035, depending on experience.

Send C.V. and three reference letters to:

**Dr. Walter Schimmerling, c/o Mr. Ronald Lowder,**
**LAWRENCE BERKELEY LABORATORY,**
**Employment Office 90-1042,**
**1 Cyclotron Road, Berkeley, CA 94720.**
**Please specify Job #A/3573.**

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# HIGH ENERGY PHYSICS
# UNIVERSITY OF ARIZONA

The Department of Physics intends to expand its experimental and theoretical programs in high energy physics by adding both senior and junior level tenure-eligible faculty. Highest priority is being given to filling senior positions this year.

Candidates for these positions should have a significant record of scholarly achievements and a demonstrated ability to attract external support for their research. The successful applicants will be expected to conduct independent research, supervise graduate students, and participate in departmental teaching activities.

Send letter of application with statement of professional goals, resume, and if desired, names of references to: **Professor D. J. Donahue, Head, Department of Physics, University of Arizona, Tucson, AZ 85721.** Formal considerations of applications will commence January 31, 1986. The University of Arizona is an affirmative action, equal opportunity employer.

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# University College London Department of Physics and Astronomy

Applications are invited for the post of physicist/programmer in the UCL Experimental High Energy Physics Group. The work would initially be divided approximately equally between:-

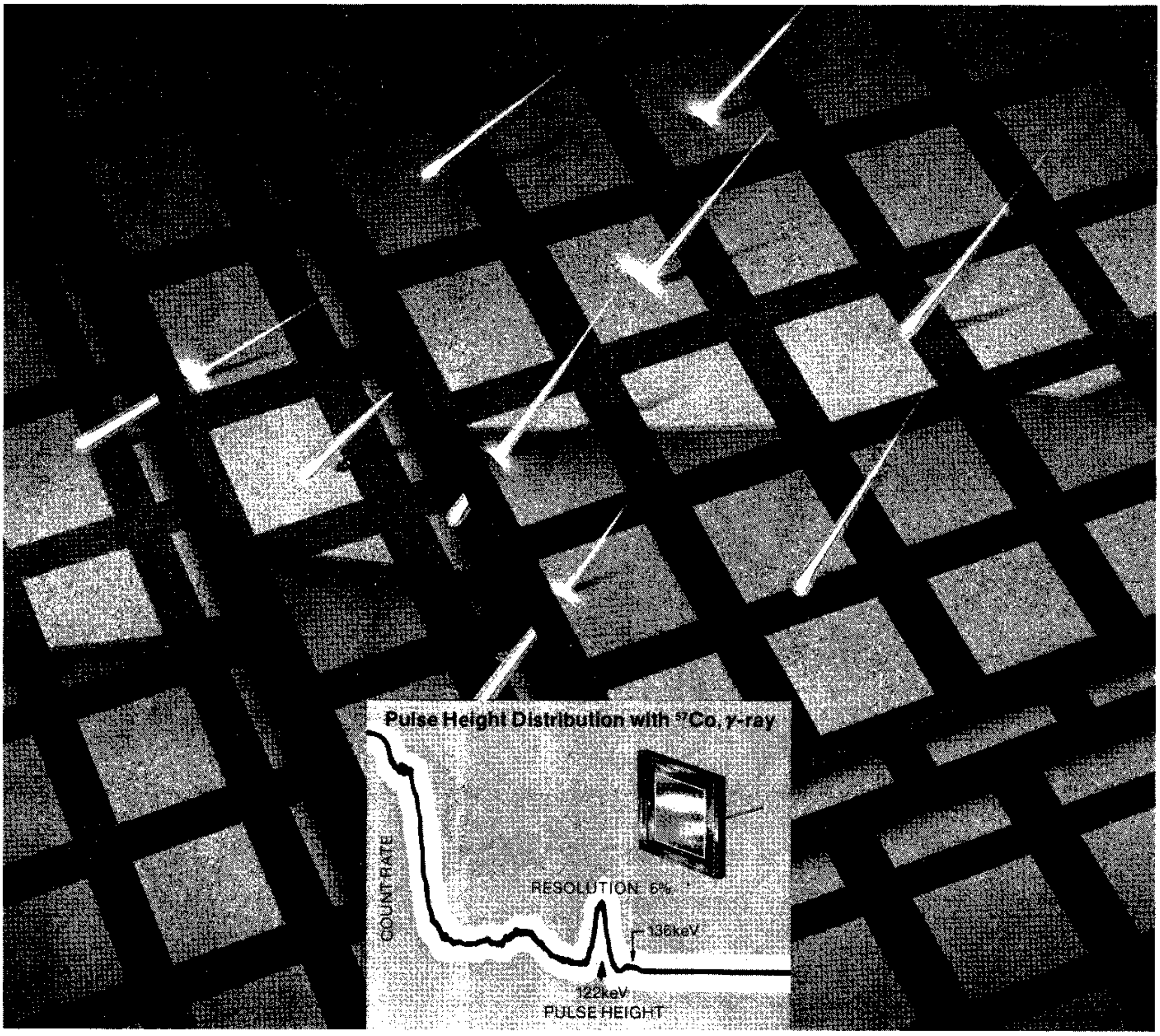
i) preparation for the OPAL experiment at the LEP collider (hardware and Monte Carlo work, in particular), and
ii) programming work for the group as a whole, as a member of the software team.

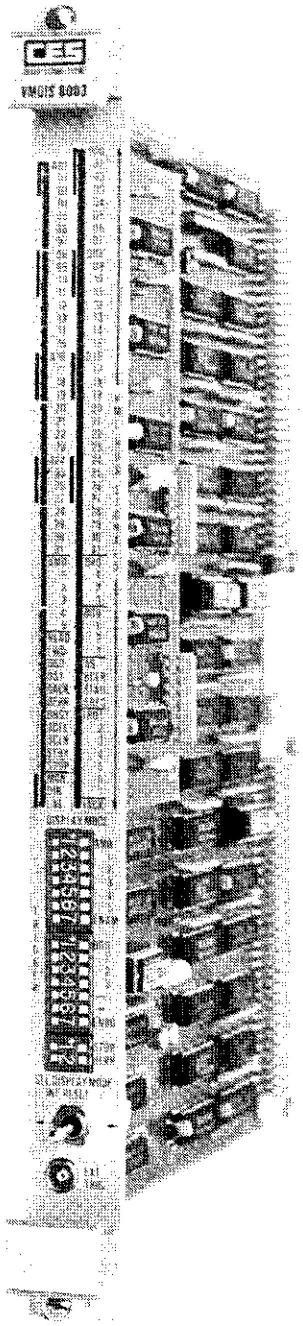
The software team has two other experienced physicist programmers, a graduate programmer and a junior programmer. They provide support for all of the group's activities including proton decay (IMB), fixed target (WA75, WA78, NA34), neutrino bubble chamber (NA31), OPAL at LEP and ZEUS at HERA (if approved). Equipment includes a VAX 11/750, a GEC 4085 which acts as a workstation for the RAL mainframes, a Megatek graphics engine, PDP11s and various microprocessors.

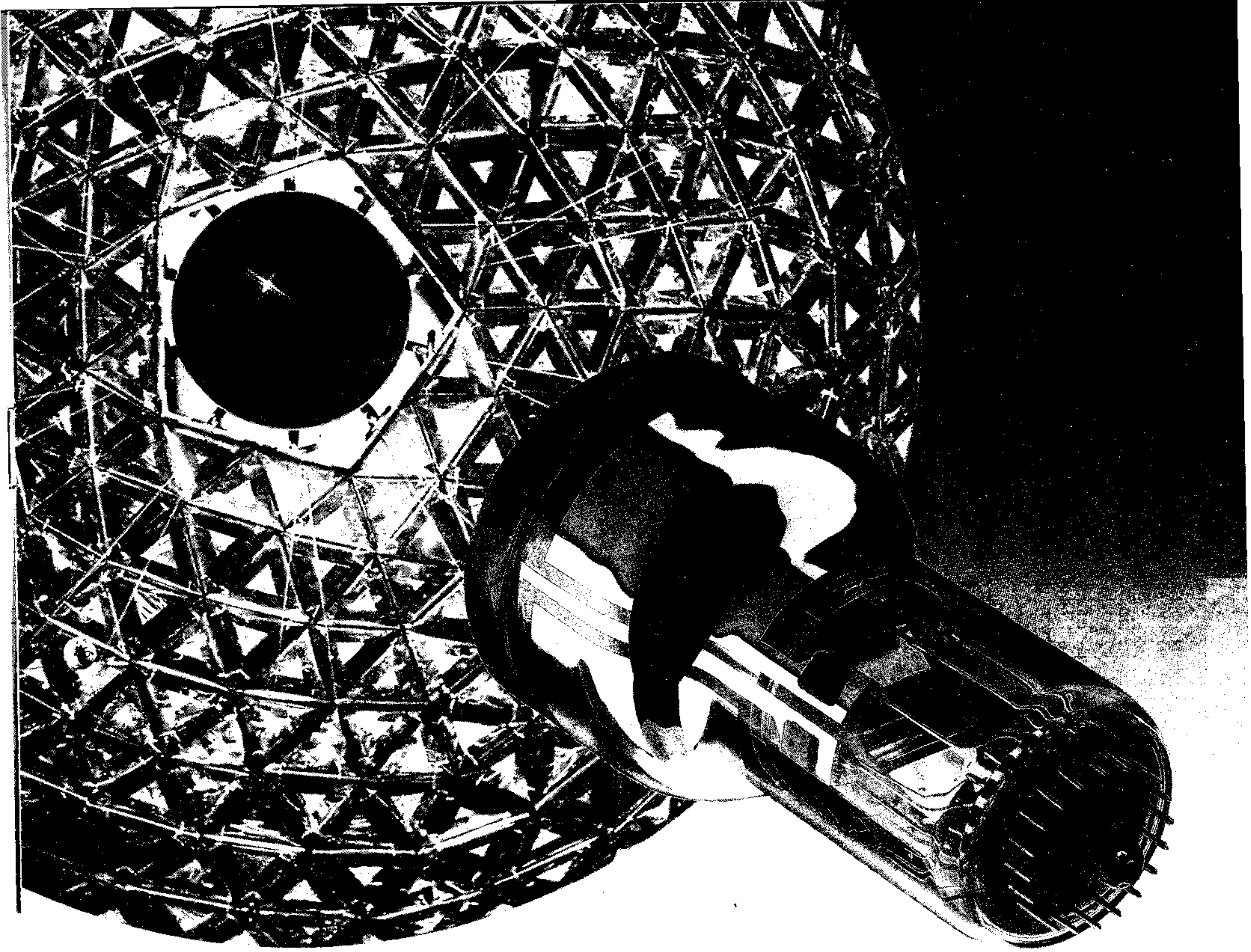
The candidate should have a Ph.D. in elementary particle physics. Some postdoctoral experience of work with detectors would be an advantage, as well as a good knowledge of physics and a professional attitude to programming. The job would be based in London, but the candidate must be prepared to spend long periods working in Geneva or Hamburg. This is a new post, funded by the SERC as part of the rolling grant to the group. After an initial probationary period there is a possibility of indefinite continuation of the appointment so long as grant-support for the post continues.

Salary in scale IA £7,820 – £12,635 – £1,297 London Allowance (under revision).

**Applications to Dr D. J. Miller, Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, from whom further particulars may be obtained.**


Pulse Height Distribution with $^{57}$Co, γ-ray
COUNT RATE
RESOLUTION: 6%
136keV
122keV
PULSE HEIGHT


CES
VMDIS 8003



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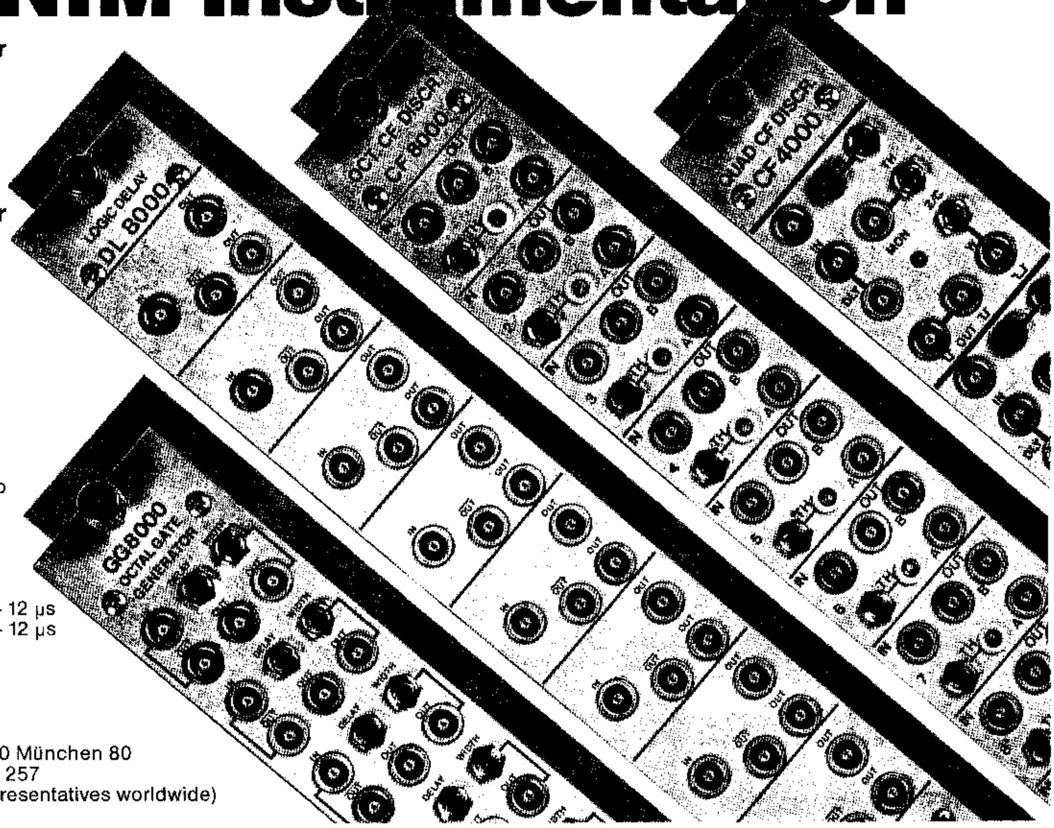

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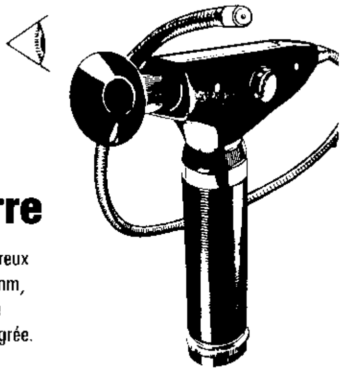

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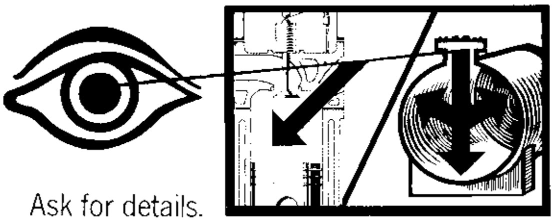

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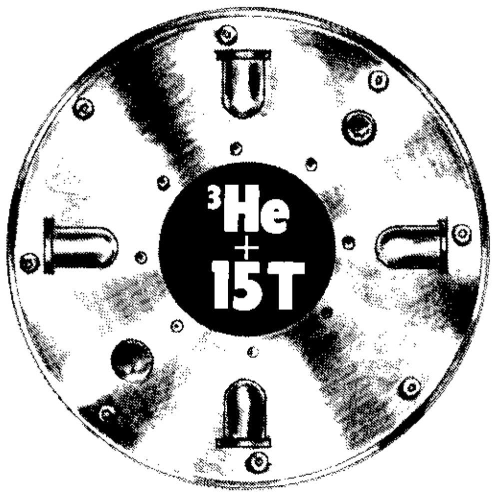

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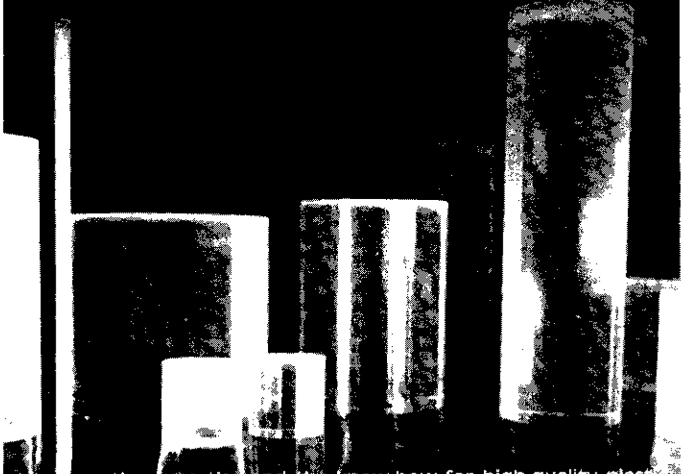

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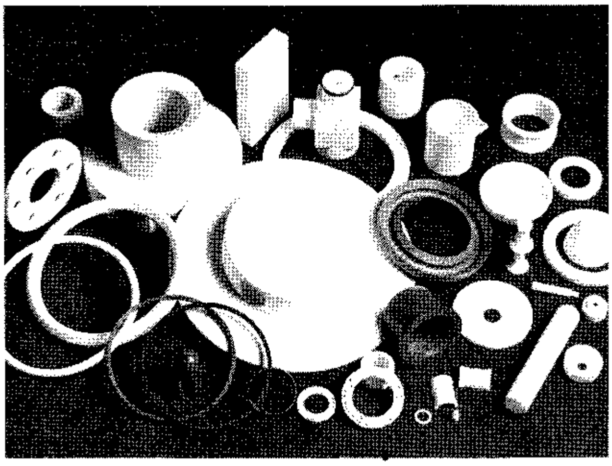

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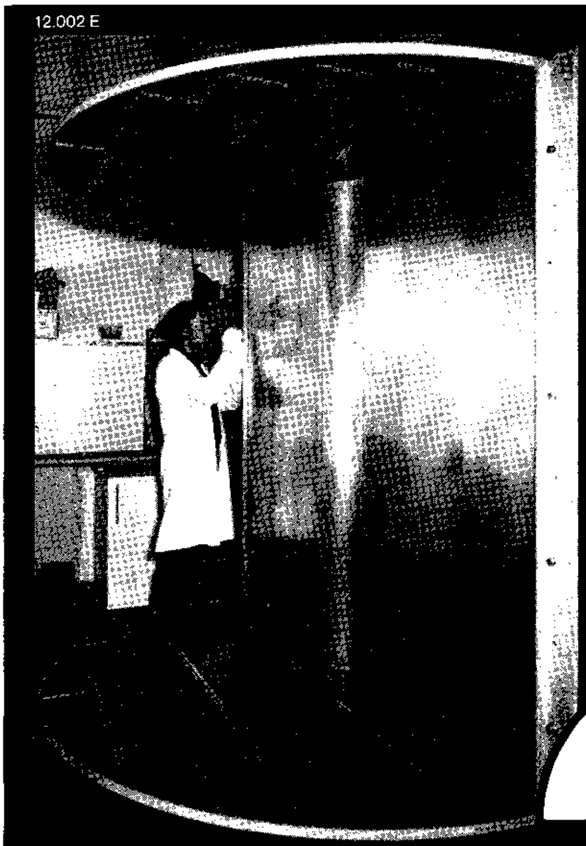

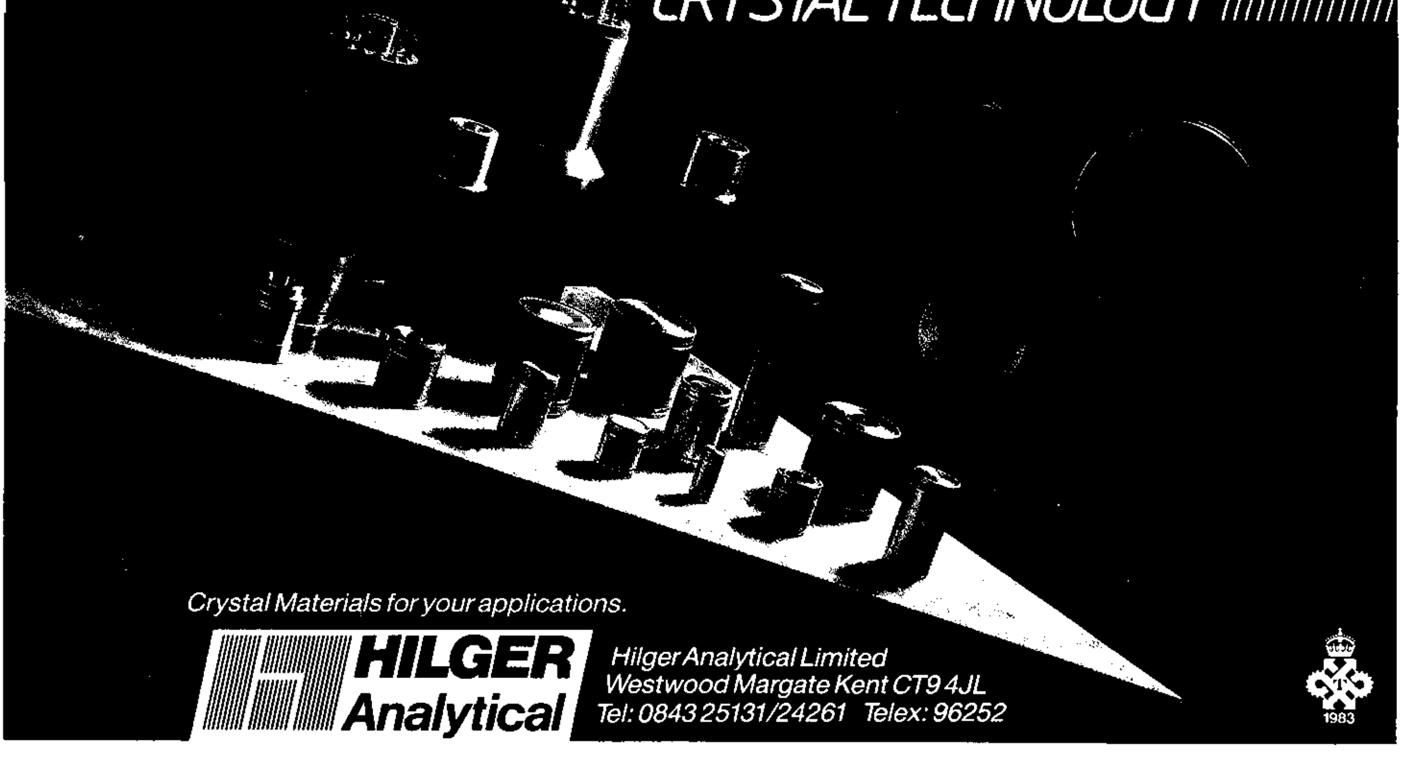

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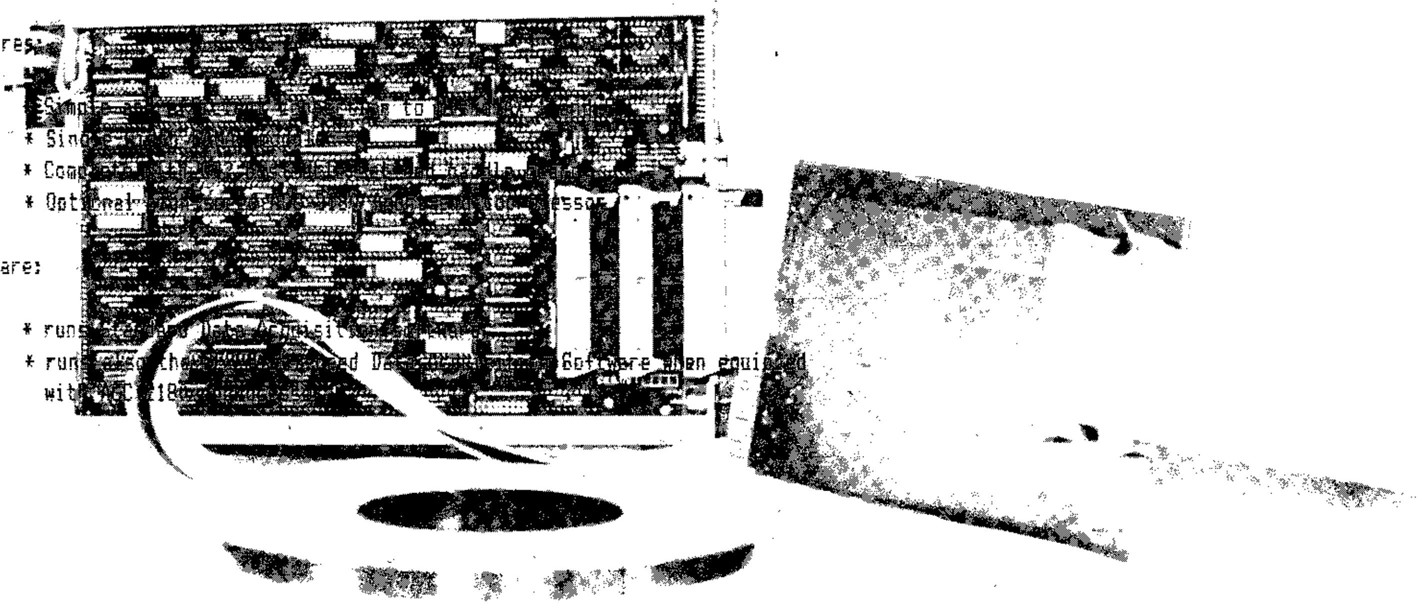

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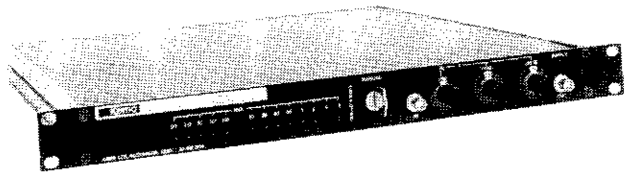

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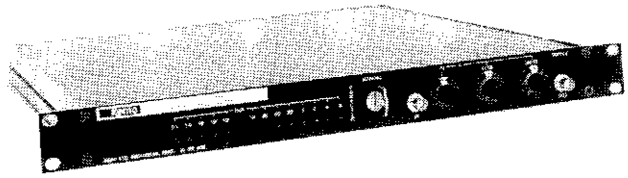

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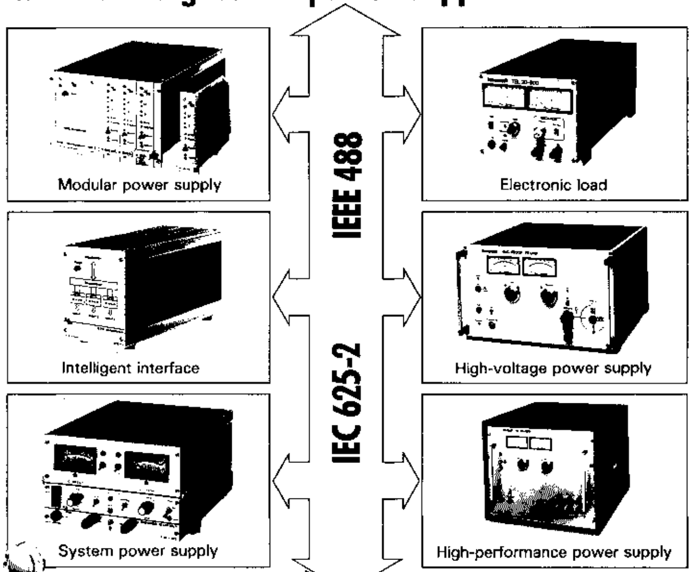

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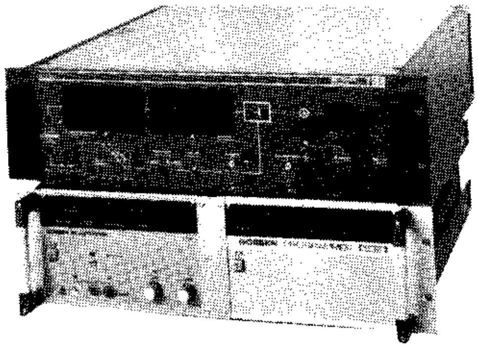

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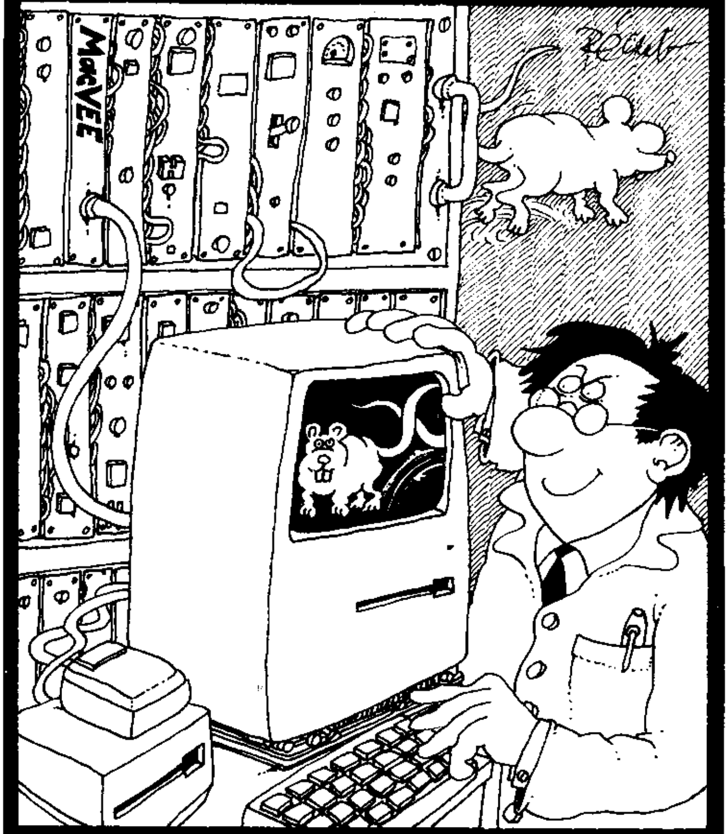

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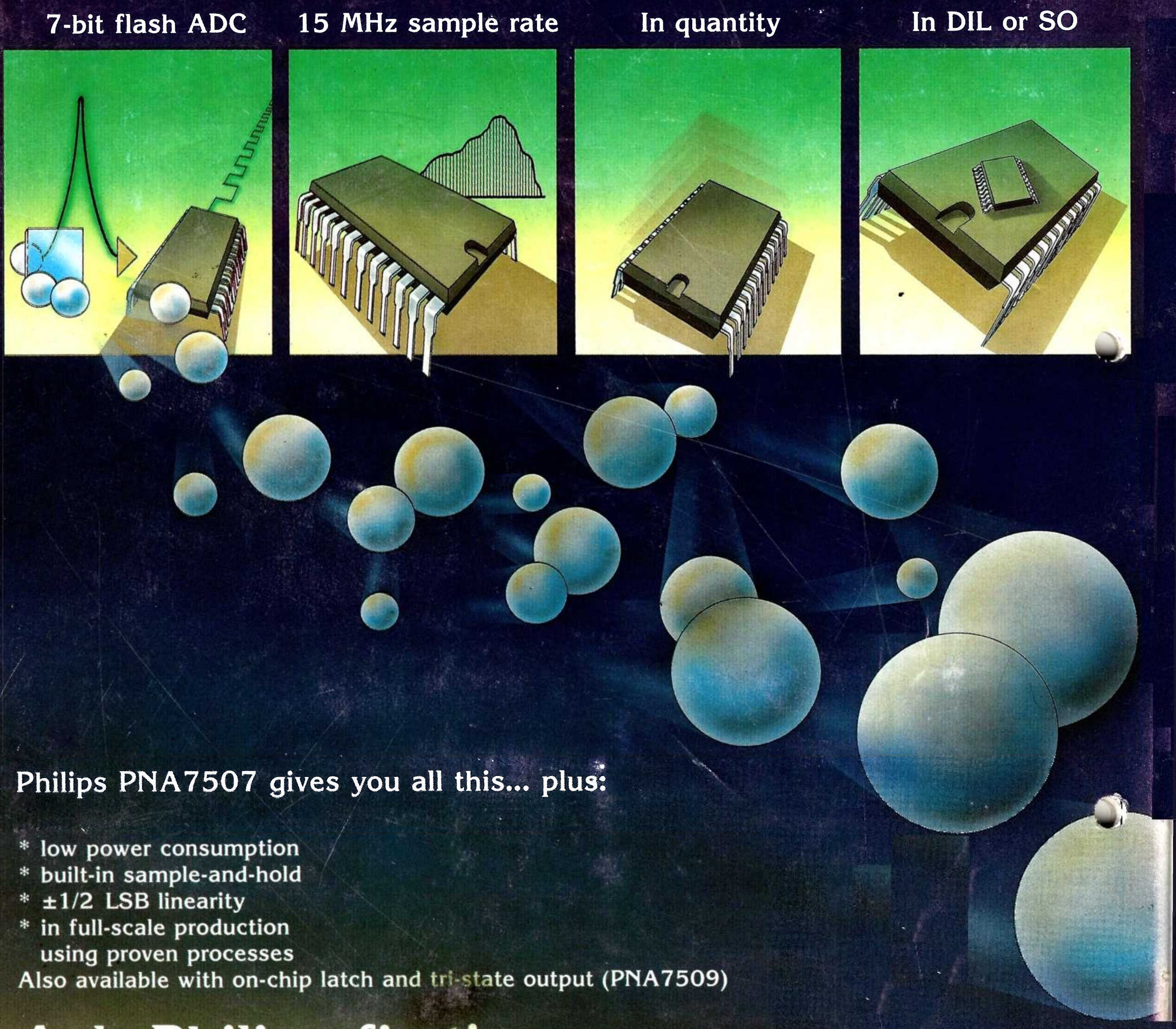
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