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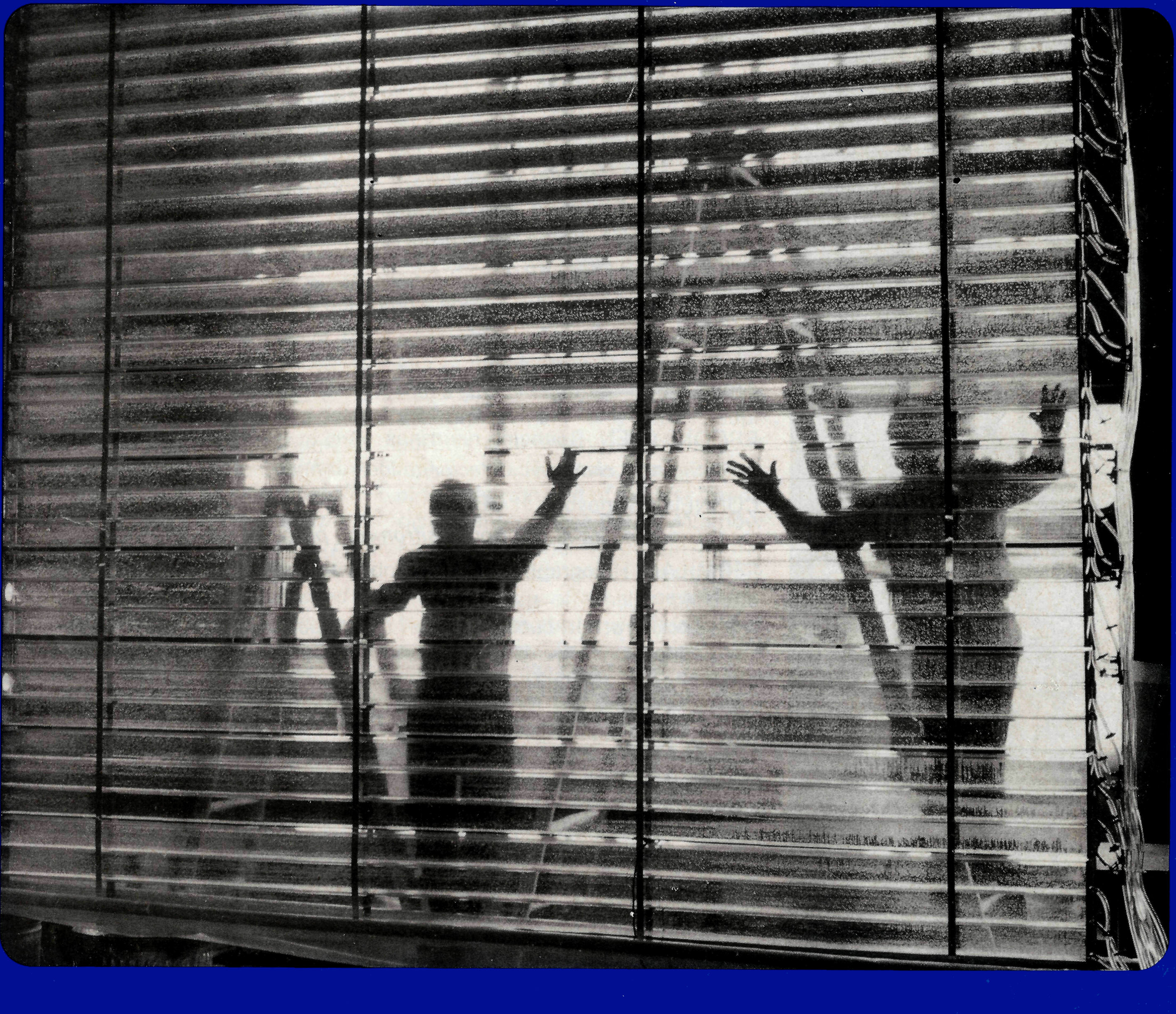

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Around the Laboratories

Physics monitor

Cover photograph: Brookhaven technicians commune with the clear acrylic calorimeter tubes which now form the heart of the new neutrino detector scheduled to begin physics this year. For a full report on this new experiment which will look, among other things, for neutrino oscillations, see page 12. (Photo Brookhaven)

The goal of theoretical physics

'Is the end in sight for theoretical physics?' This was the question posed by Stephen Hawking in his inaugural lecture as incumbent of the prestigious Lucasian Chair of Mathematics in the University of Cambridge. Among his many other accomplishments, Hawking has successfully brought together ideas from particle physics, from general relativity and from thermodynamics (see October 1977 edition, page 334) which have greatly influenced thinking on the origin of the Universe.*

We are publishing the text of the lecture in two parts, the first dealing with the motivations for constructing unified theories in physics, and going on to describe current efforts to unify the electroweak picture with that of quark dynamics. As an influential physicist not directly involved with particle research, Hawking's views on particle theory make interesting reading. In the second part, to be published in our March issue, Hawking goes on to cover the subject of gravity, where his pronouncements always provide substantial food for thought.

'I want to discuss the possibility that the goal of theoretical physics might be achieved in the not too distant future, say, by the end of the century. By this I mean that we might have a complete, consistent and unified theory of the physical interactions which would describe all possible observations.

Of course one has to be very cautious about making such predictions: we have thought that we were on the brink of the final synthesis at least twice before. At the beginning of the century it was believed that everything could be understood in terms of continuum mechanics. All that was needed was to measure a certain number of coefficients of elasticity, viscosity, conductivity etc. This hope was shattered by the discovery of atomic structure and quantum mechanics. Again, in the late 1920s Max Born told a group of scientists visiting Göttingen that 'Physics, as we know it, will be over in six months.' This was shortly after the discovery by Paul Dirac of the equation which governs the behaviour of the electron. It was expected that a similar equation would govern the proton, the only other supposedly elementary particle known at that time. However, the discovery of the neutron and of nuclear forces disappointed these hopes. We now know that neither the proton nor the neutron are elementary but that they are made up of smaller particles. Nevertheless, we have made a lot of progress in recent years and there are some grounds for cautious optimism that we may soon see a complete theory.

Even if we do achieve a complete unified theory, we shall not be able to make detailed predictions in any but the simplest situations. For example, we already know the physical laws that govern everything that we experience in everyday life: as Dirac pointed out, his equation was the basis of 'most of physics and all of chemistry'. However we have been able to solve the equation only for the very simplest system, the hydrogen atom consisting of one proton and one electron. For more complicated atoms with more electrons, let alone for molecules with more than one nucleus, we have to resort to approximations and intuitive guesses of doubtful validity. For macroscopic systems consisting of 10^{23} particles or so, we have to use statistical methods and abandon any pretence of solving the equations exactly. Although in principle we know the equations that govern the whole of biology, we have not been able to reduce the study of human behaviour to a branch of applied mathematics.

Paul Dirac, who discovered the equation which describes the behaviour of the electron. He has pointed out that this equation is the basis of 'most of physics and all of chemistry'.

What would we mean by a complete and unified theory of physics? Our attempts at modelling physical reality normally consist of two parts:

1. A set of local laws that are obeyed by the various physical quantities. These are usually formulated in terms of differential equations.
2. Sets of boundary conditions that tell us the state of some regions of the Universe at a certain time and what effects propagate into it subsequently from the rest of the Universe.

Many people would claim that the role of science was confined to the

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* 'Is the end in sight for theoretical physics?' by Stephen Hawking, published by Cambridge University Press.

first of these and that theoretical physics will have achieved its goal when we have obtained a complete set of local physical laws. They would regard the question of the initial conditions for the Universe as belonging to the realm of metaphysics or religion. In a way this attitude is similar to that of those who in earlier centuries discouraged scientific investigation by saying that all natural phenomena were the work of God and should not be inquired into. I think that the initial conditions of the Universe are as suitable a subject for scientific study and theory as are the local physical laws. We shall not have a complete theory until we can do more than merely say that 'Things are as they are because they were as they were.'

The question of the uniqueness of the initial conditions is closely related to that of the arbitrariness of the local physical laws: one would not regard a theory as complete if it contained a number of adjustable parameters such as masses or coupling constants which could be given any values one liked. In fact it seems that neither the initial conditions nor the values of the parameters in the theory are arbitrary but that they are somehow chosen or picked out very carefully. For example, if the proton-neutron mass difference were not about twice the mass of the electron, one would not obtain the couple of hundred or so stable nuclides that make up the elements and are the basis of chemistry and biology. Similarly if the gravitational mass of the proton were significantly different, one would not have had stars in which these nuclides could have been built up and if the initial expansion of the Universe had been slightly smaller or greater, the Universe would either have collapsed before such stars could have evolved or would have expanded so rapidly that stars would never have been formed by gravitational condensation.

Some people have gone so far as to elevate these restrictions on the initial conditions and the parameters to the status of a principle, the Anthropic Principle, which can be paraphrased as 'Things are as they are because we are'. According to one version of the principle there is a very large number of different separate universes with different values of the physical parameters and different initial conditions. Most of these universes will not provide the right conditions for the development of the complicated structures needed for intelligent life. Only in a small number, with conditions and parameters like our own universe, will it be possible for intelligent life to develop and to ask the question 'Why is the Universe as we observe it?' The answer is, of course, that if it were otherwise there would not be anyone to ask the question.

The Anthropic Principle does provide some sort of explanation of many of the remarkable numerical relations that are observed between the values of different physical parameters. However, it is not completely satisfactory: one cannot help feeling that there is some deeper explanation. Also, it cannot account for all the regions of the Universe. For example, our solar system is certainly a prerequisite for our existence as is an earlier generation of nearby stars in which heavy elements could have been formed by nuclear synthesis. It might even be that the whole of our galaxy was required. But there does not seem any necessity for other galaxies to exist, let alone the million million or so of them that we see, distributed roughly uniformly throughout the observable Universe. This large-scale homogeneity of the Universe makes it very difficult to hold an anthropocentric view or to believe that the structure of the Universe is determined by anything so peripheral as some complicated molecular structures on a minor planet orbiting a very average star in the outer suburbs of a fairly typical spiral galaxy.

If we are not going to appeal to the Anthropic Principle, we need some unifying theory to account for the initial conditions of the Universe and the values of the various physical parameters. However, it is too difficult to think up a complete theory of everything all at one go (though this does not seem to stop some people; I get two or three unified theories in the mail each week). What we do instead is to look for partial theories that will describe situations in which certain interactions can be ignored or approximated in a simple manner. We first divide the material content of the Universe into two parts, 'matter' particles such as quarks, electrons, muons etc., and 'interactions' such as gravity, electromagnetism etc.

The matter particles are described by fields of half-integer spin and obey the Pauli Exclusion Principle which prevents more than one particle of a given kind from being in any state. This is the reason that we can have solid bodies that do not collapse to a point or radiate away to infinity. The matter particles are divided into two groups, the hadrons, which are composed of quarks, and the leptons, which comprise the remainder.

The interactions are divided phenomenologically into four categories. In order of strength they are: the strong nuclear forces which interact only with hadrons, electromagnetism which interacts with charged hadrons and leptons, the weak nuclear forces which interact with all

Murray Gell-Mann seen here lecturing at CERN on the 'Grand Unification' of the different forces in physics. In the audience is (top left) Stephen Hawking, whose own ideas on the subject are stimulating.

(Photo CERN 263.3.79)

hadrons and leptons and finally, the weakest by far, gravity which interacts with everything. The interactions are represented by integer-spin fields which do not obey the Pauli Exclusion Principle. This means that they can have many particles in the same state.

In the case of electromagnetism and gravity, the interactions are also long-range which means that the fields produced by a large number of matter particles can all add up to give a field that can be detected on a macroscopic scale. For these reasons they were the first to have theories developed for them, gravity by Newton in the seventeenth century and electromagnetism by Maxwell in the nineteenth century. However these theories were basically incompatible because the Newtonian Theory was invariant if the whole system was given any uniform velocity whereas the Maxwell Theory defined a preferred velocity, the speed of light. In the end it turned out to be the Newtonian Theory of Gravity which had to be modified to make it compatible with the invariance properties of the Maxwell Theory. This was achieved by Einstein's General Theory of Relativity which was formulated in 1915.

The General Relativity Theory of Gravity and the Maxwell Theory of Electrodynamics were what is called Classical Theories — they involved quantities which were continuously variable and which could, in principle at least, be measured to arbitrary accuracy. However a problem arose when one tried to use such theories to construct a model of the atom. It had been discovered that the atom consisted of a small positively charged nucleus surrounded by a cloud of negatively charged electrons. The natural assumption was that the electrons were in orbit around the nucleus like the Earth is in orbit around the Sun. However the Classical Theory predicted that the electrons would radiate electromagnetic waves. These waves would carry away energy and would cause the electrons to spiral into the nucleus, producing a collapse of the atom.

This problem was overcome by what is undoubtedly the greatest achievement in theoretical physics this century, the discovery of the Quantum Theory. The basic postulate of this is the Heisenberg 'Uncertainty Principle' which states that certain pairs of quantities, such as the position and momentum of a particle, cannot be measured simultaneously with arbitrary accuracy. In the case of the atom this meant that in its lowest energy state the electron could not be at rest in the nucleus because, in that case, its position and velocity would both be defined exactly. Instead the electron would have to be smeared out with some probability distribution around the nucleus. In this state the electron could not radiate energy in the form of electromagnetic waves because there would be no lower energy state for it to go to.

In the 1920s and 1930s quantum mechanics was applied with great success to systems such as atoms or molecules which have only a finite number of degrees of freedom. Difficulties arose when people tried to apply it to the electromagnetic field which has an infinite number of degrees of freedom, roughly speaking, two for each point of space-time. One can regard these degrees of freedom as oscillators, each with its own position and momentum. The oscillators cannot be at rest because then they would have exactly defined positions and momenta. Instead each oscillator must have some minimum amount of what are called 'zero point fluctuations' and a non-zero energy. The energies of the zero point fluctuations of all the infinite number of degrees of freedom would cause the apparent mass and charge of the electron to become infinite.

In the late 1940s, a procedure called renormalization was developed to overcome this difficulty. It consisted of the rather arbitrary subtraction of certain infinite quantities to leave finite remainders. In the case of electrodynamics, it was necessary to make two such infinite subtractions, one for the mass and the other for the charge of the electron. This renormalization procedure has never been put on a very firm conceptual or mathematical basis, but it has worked quite well in practice. Its great success was the prediction of a small displacement, the Lamb Shift, in some lines in the spectrum of atomic hydrogen. However it is not very satisfactory from the point of view of a complete theory because it does not make any predictions of the values of the finite remainders left after making infinite subtractions. Thus we would have to fall back on the Anthropic Principle to explain why the electron has the mass and charge that it does.

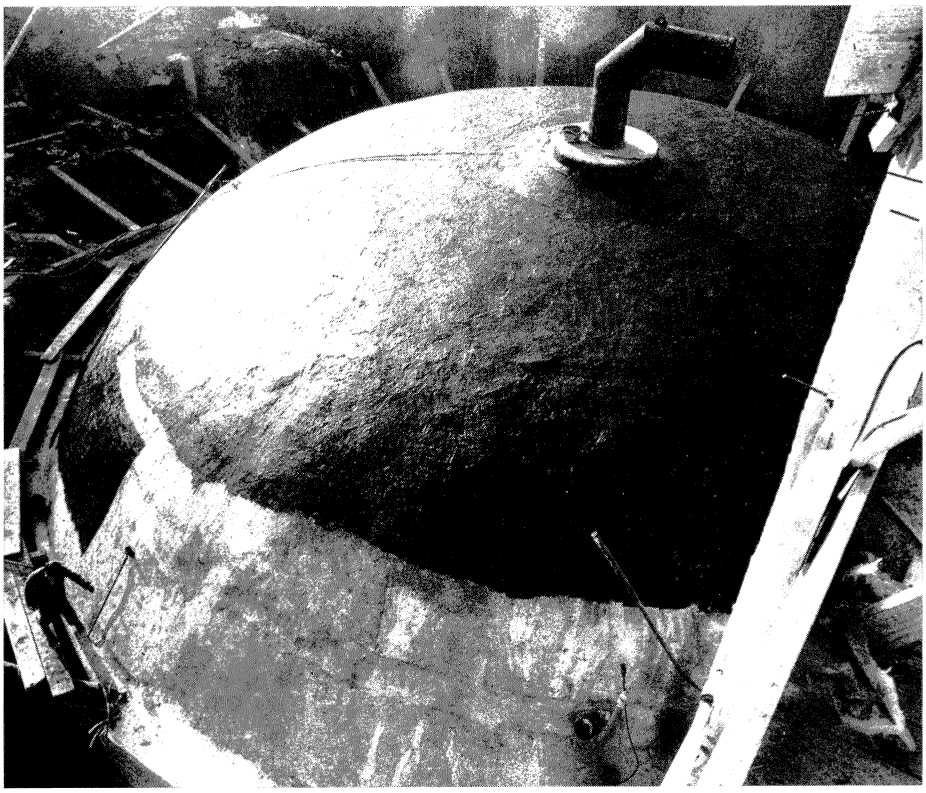
During the 1950s and 1960s it was generally believed that the weak and strong nuclear forces were not renormalizable and would require an infinite number of infinite subtractions to make them finite. There would be an infinite number of finite remainders which were not determined by the theory. Such a theory would have no predictive power because one could never measure all the infinite number of parameters. However, in 1971 't Hooft showed that a unified model of the electromagnetic and weak interactions that had been earlier proposed by Salam and Weinberg was indeed renormalizable with only a finite number of infinite subtractions. In the Salam-Weinberg theory the photon, the spin-1 particle that carries the electromagnetic interaction, is joined by three other spin-1 partners called W^+, W^- and Z^o.

At very high energies these four particles are all predicted to behave in a similar manner. At lower energies a phenomenon called 'spontaneous symmetry breaking' is invoked to explain the fact that the photon has zero rest mass whereas the W^+, W^- and Z^o are all very massive. The low energy predictions of this theory have agreed remarkably well with observation and this led the Swedish Academy in 1979 to award the Nobel prize to Salam, Weinberg and to Glashow, who had also constructed similar unified theories.

The success of the Salam-Weinberg theory led to the search for a similar renormalizable theory of the strong interactions. It was realized fairly early on that the proton and other hadrons such as the pion could not be truly elementary particles, but that they must be bound states of other particles called quarks. These seem to have the curious property that, although they can move fairly freely within a hadron, it appears to be impossible to obtain just one quark on its own; they always come either in groups of three (like the proton or neutron) or in pairs consisting of a quark and antiquark (like the pion). To explain this, quarks were endowed with an attribute conveniently called 'colour'. The idea is that quarks come in three 'colours', red, green and blue, but that any isolated bound state such as a hadron has to be 'colourless', either a combination of red, green and blue like the proton, or a mixture of red and antired, green and antigreen, and blue and antiblue like the pion.

The strong interactions between the quarks are supposed to be carried by spin-1 particles called gluons rather like the particles that carry the weak interaction. The gluons also carry colour and they and the quarks obey a renormalizable theory called quantum chromodynamics or QCD for short. A consequence of the renormalization procedure is that the effective coupling constant of the theory depends on the energy at which it is measured and decreases to zero at very high energies. This phenomenon is known as asymptotic freedom. It means that quarks inside a hadron behave almost like free particles in high energy collisions so that their interactions can be treated successfully by perturbation theory.

The predictions of perturbation theory are in reasonable qualitative agreement with observation but one cannot yet really claim that the the-

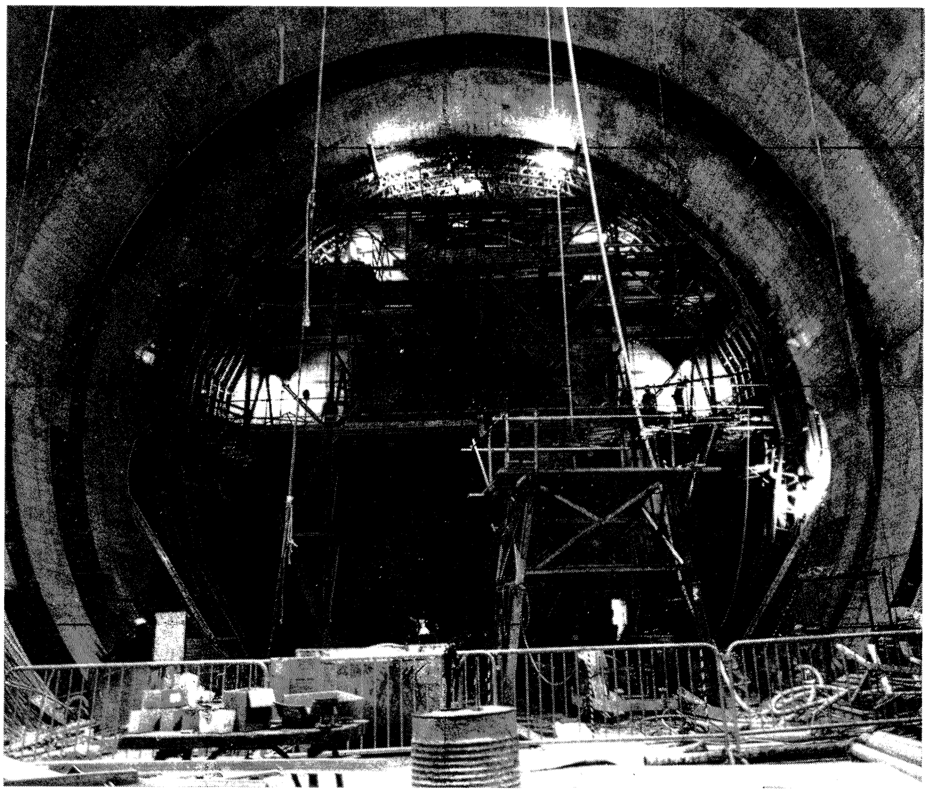


The cupola which roofs over the experimental area at the CERN SPS housing apparatus for the UA1 experiment to study high energy collisions of protons and antiprotons. High on its agenda of priorities is a search for the intermediate bosons of weak interactions, long predicted but so far not seen.

(Photo CERN 387.11.80)

Setting the scene for the hunting of the elusive intermediate bosons of weak interactions, which according to current theory should soon be within reach. This underground cavern at the CERN SPS will shortly house several of the experiments being prepared to exploit high energy proton-antiproton colliding beams.

(Photo CERN 189.12.80)



ory has been experimentally verified. At low energies the effective coupling constant becomes very large and perturbation theory breaks down. It is hoped that this 'infrared slavery' will explain why quarks are always confined in colourless bound states but so far no-one has been able to demonstrate this really convincingly.

Having obtained one renormalizable theory for the strong interactions and another one for the weak and electromagnetic interactions, it was natural to look for a theory which combined the two. Such theories are given the rather exaggerated title of 'Grand Unified Theories' or GUTs for short. This is rather misleading because they are neither all that grand, nor fully unified, nor complete theories in that they have a number of undetermined renormalization parameters such as coupling constants and masses. Nevertheless they may be a significant step toward a complete unified theory. The basic idea is that the effective coupling constant of the strong interactions, which is large at low energies, gradually decreases at high energies because of asymptotic freedom.

On the other hand, the effective coupling constant of the Salam-Weinberg theory, which is small at low energies, gradually increases at high energies because this theory is not asymptotically free. If one extrapolates the low energy rate of increase and decrease of the coupling constants, one finds that the two coupling constants become equal at an energy of about 10^{15} GeV. The theories propose that above this energy the strong interactions are unified with the weak and electromagnetic interactions but that at lower energies there is spontaneous symmetry breaking.

An energy of 10^{15} GeV is way beyond the scope of any laboratory experiment: the present generation of particle accelerators can produce centre-of-mass energies of about 10 GeV and the next generation will produce energies of 100 GeV or so. This will be sufficient to investigate the energy range in which the electromagnetic forces should become unified with the weak forces according to the Salam-Weinberg theory but not the enormously high energy at which the weak and electromagnetic interactions would be predicted to become unified with the strong interactions. Nevertheless there can be low energy predictions of the Grand Unified Theories that might be testable in the laboratory. For example, the theories predict that the proton should not be completely stable but should decay with a lifetime of order 10^{31} years. The present experimental lower limit on the lifetime is about 10^{30} years and it should be possible to improve this.

Another observable prediction concerns the ratio of baryons to photons in the Universe. The laws of physics seem to be the same for particles and antiparticles. More precisely, they are the same if particles are replaced by antiparticles, right-handed is replaced by left-handed and the velocities of all particles are reversed. This is known as the *CPT* Theorem and it is a consequence of basic assumptions that should hold in any reasonable theory. Yet the Earth and indeed the whole solar system is made up of protons and neutrons without any antiprotons or antineutrons. Indeed such an imbalance between particles and antiparticles is yet another *a priori* condition for our existence; for if the solar system were composed of an equal mixture of particles and antiparticles, they would all annihilate each other and leave just radiation.

From the observed absence of

such annihilation radiation we can conclude that our galaxy is made entirely of particles rather than antiparticles. We do not have direct evidence about other galaxies but it seems likely that they are composed of particles and that in the Universe as a whole there is an excess of particles over antiparticles of about one particle per 10^8 photons. One could try to account for this by invoking the Anthropic Principle but Grand Unified Theories actually provide a possible mechanism for explaining the imbalance.

Although all interactions seem to be invariant under the combination of *C* (replace particles by antiparticles), *P* (change right-handed to left-handed) and *T* (reverse the direction of time), there are known to be interactions which are not invariant under *T* alone. In the early Universe, in which there is a very marked arrow of time given by the expansion, these interactions could produce more particles than antiparticles. However, the number they make is very model-dependent, so that agreement with observation is hardly a confirmation of the Grand Unified Theories.'

Synchrotron Radiation Source in action

The world's first large purpose-built high energy source of synchrotron radiation is now in action at the Daresbury Laboratory. Known as the SRS (Synchrotron Radiation Source), the 2 GeV electron storage ring, which produces the radiation, has its roots in the developments made in the early 1970s to use the radiation emerging from the 5 GeV high energy physics electron synchrotron, NINA. This demonstrated the potential applications of synchrotron radiation research in the U.K. and, when it became clear that NINA would be prematurely retired, a proposal was made to build a dedicated radiation source using many of the systems which would be left over from NINA. These systems included power supplies and some beam transport equipment together with suitable buildings. But the most important resource surviving from NINA days was the experience at the Laboratory in all aspects of accelerator design and operation and in computerized data handling.

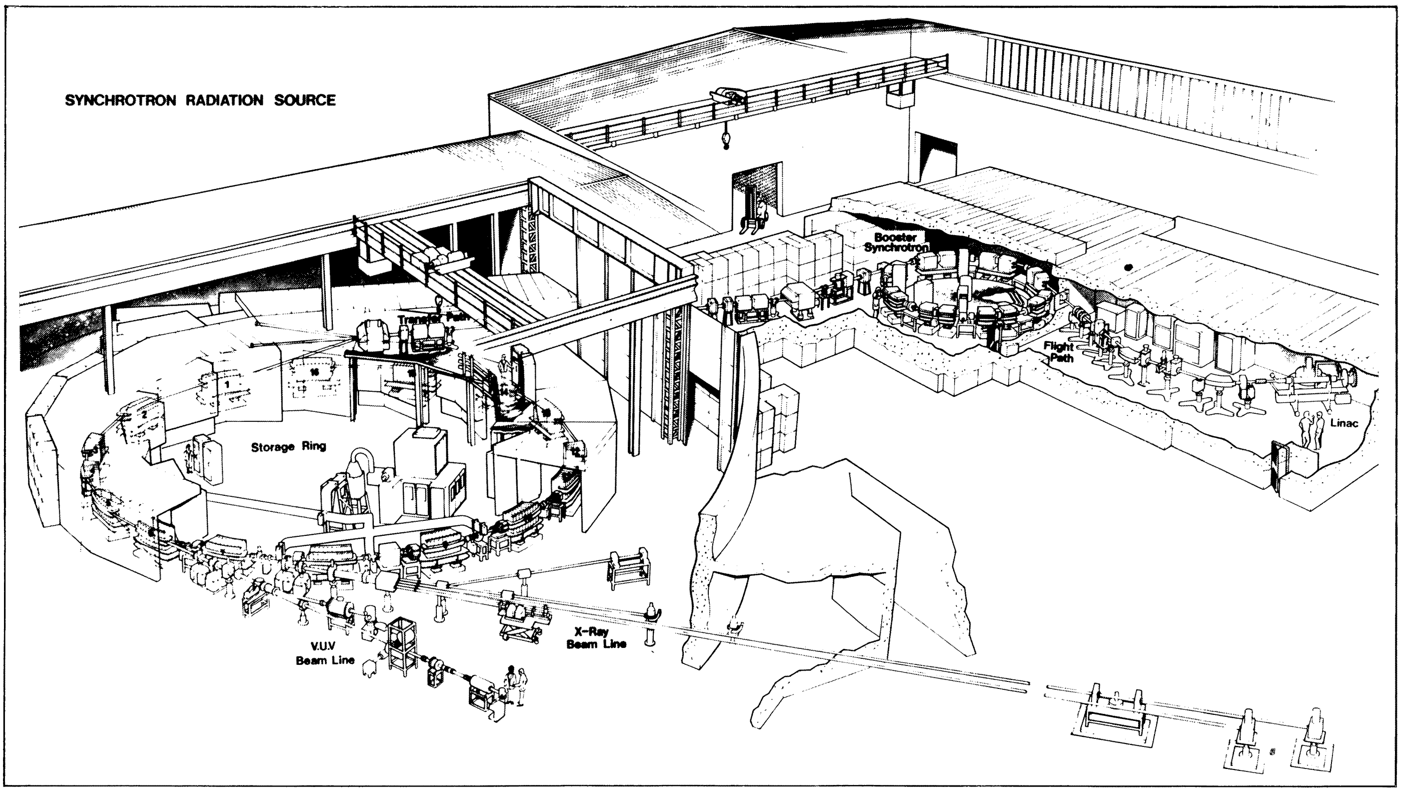
In 1975 approval was given for the construction of a 2 GeV electron storage ring together with its injection accelerators, namely a 12 MeV linac and a 600 MeV booster synchrotron. The storage ring has been built in the building which originally held NINA power supplies, and the injectors in the former experimental hall for high energy physics. As a consequence of this layout, construction of the storage ring could not start until the NINA shutdown in 1977, although in the meantime the linac and booster were rapidly put together and came into operation in 1978. The storage ring was ready in the summer of 1980.

The linac has a travelling wave structure operating at a frequency of 3000 MHz. The electron gun is a triode and, with 500 MHz applied to

During the inauguration ceremony of the Synchrotron Radiation Source at Daresbury Laboratory on 7 November, a bronze plaque was unveiled by Mark Carlisle, UK Secretary of State for Education and Science, seen here (second from right) congratulating Sir Geoffrey Allen, Chairman of the UK Science Research Council, with (right) Daresbury Director Alick Ashmore and (left) project head Jerry Tompson.

(Photo Daresbury)

Drawing of the Synchrotron Radiation Source at Daresbury indicating the locations of the electron linac, the 600 MeV Booster Synchrotron, the SRS storage ring itself and several radiation beamlines. The Daresbury SRS is the first large purpose-built facility for synchrotron radiation research to come into action.



the grid, the beam is prebunched to assist subsequent capture in the booster. Depending on the desired output current, the final energy of the linac may be selected between 10 and 15 MeV. It is normally set for 12 MeV which results in an analysed pulse current of 30 mA within a momentum spread of ± 0.5 per cent. The repetition rate is 10 Hz to match that of the booster.

The booster uses combined function magnets. The repetition rate of 10 Hz allows the magnets to be powered by means of a resonant, White-circuit supply and also matches the rate at which injection can be made into the ring. This rate is low enough to permit an all-metal vacuum chamber to be used without the accelerated beam being perturbed by the effects of eddy currents. Under normal conditions, the booster accelerates 25 mA to 600 MeV but, after fine tuning, over 40 mA has been measured. The electrons are distributed uniformly around the orbit in 53 bunches. As a prime number, this is an unusual harmonic number for an accelerator, but in conjunction with the harmonic number of 160 in the storage ring it allows many bunch-filling sequences to be used.

The storage ring is a separated function lattice of eight normal cells without long straights or inserts. At 2.0 GeV the field in these magnets is 1.2 T which produces a synchrotron radiation spectrum whose critical wavelength is 3.9 angströms. The storage ring has been designed for a maximum stored current of 1 A at which level the total synchrotron radiation power will be 250 kW. At present only half the r.f. power is installed which limits the current to about 350 mA at 2 GeV.

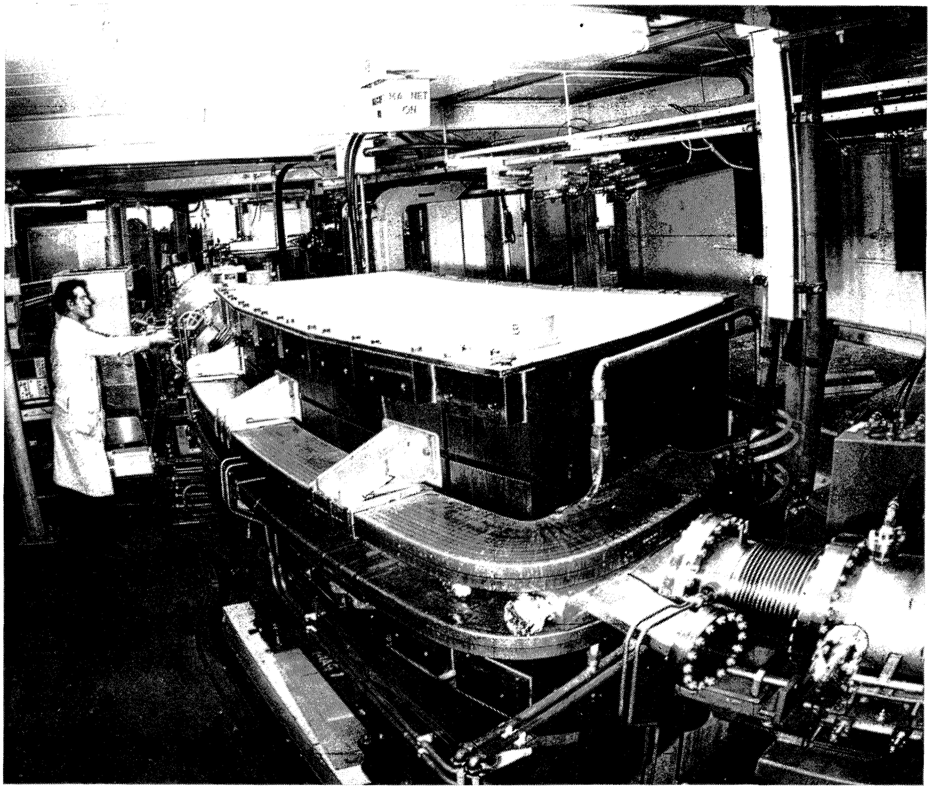
The first electrons were injected into the storage ring at the end of June 1980 and three days later the beam was successfully stored at the injection energy of 600 MeV. Since then the storage ring has been run for accelerator studies a few days a week over ten weeks. The remaining time has been used for further installation and construction work, particularly connected with the beamlines and experimental hall.

The maximum observed stored current is 200 mA, evenly distributed over the 160 r.f. buckets; no work has been done yet to establish the reason for the limitation. Injection has been successfully made at a rate of 10 Hz with high efficiency and an accumulation rate of 50 mA/s.

The beam lifetime up to now is about thirty minutes, limited by the average vacuum pressure of 3×10^{-8} torr. This was with the vacuum chamber unbaked and with none of the distributed ion pumps in opera-

A section of the 2 GeV electron storage ring of the SRS. An exit port for synchrotron radiation adjoining a bending magnet can be seen in the foreground.

(Photo Daresbury)



tion. During November the whole chamber was baked in situ to 200°C which resulted in a considerable reduction in base pressure and enabled the distributed pumps to be switched on.

The stored electrons have been accelerated above the 600 MeV injection energy while increasing the fields in all the magnets, a process which is carried out by the computer control system. The maximum energy which has been achieved is 1.4 GeV with only one r.f. cavity in operation. There are a total of four single cell cavities in the storage ring and the remaining three are being brought into operation.

Initially the SRS will supply two synchrotron radiation beamlines, one for vacuum ultraviolet physics equipped with two experimental stations, and the other for X-ray research equipped with four experimental stations (two being dual-purpose). It is planned to open up other beam ports as finances permit, up to a maximum of about twelve. The first stage of the plan is to have twelve independent stations, fed from six ports, operational by about May 1982.

All accelerators are modified and refined to meet the changing demands of their users and the SRS will be no exception. In the immediate future, single bunch option will be developed to allow various bunch separation patterns to be filled, thus catering for the users who need their radiation in discrete pulses separated by well-defined dark spaces. Also imminent is a high field superconducting wiggler magnet which will generate hard X-rays in its 4.5 T field. This magnet is being assembled and is due for installation towards the end of 1981.

Another possible development, which is being studied, would be to install extra quadrupoles to increase the unit cell number from 8 to 16. This would lead to a reduction in the beam emittance by over an order of magnitude and, if it were carried out in a few years, would ensure that the SRS remained competitive with even the second generation of purpose-designed synchrotron radiation sources.

The SRS has been completed close to programme and within its financial target of 5.4 million pounds. Experiments are now starting and some fifty UK groups are preparing to start work at the machine.

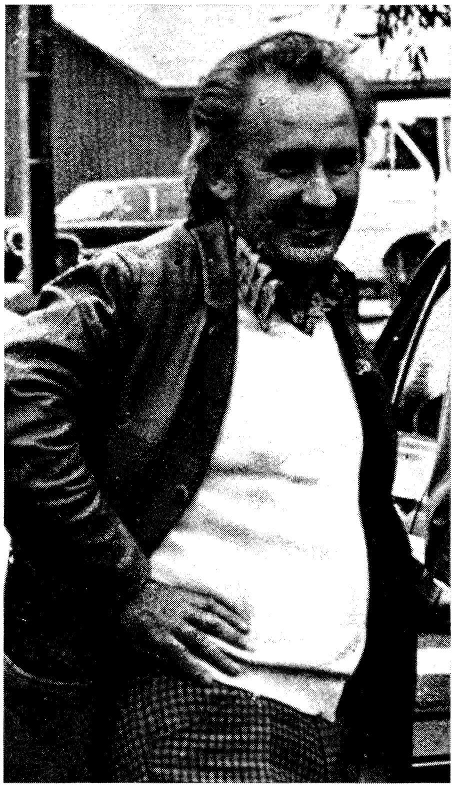
ECFA prepares for LEP

The European Committee for Future Accelerators had its 28th Plenary Meeting in November and prominent on the agenda was preparation for the proposed large electron-positron storage ring, LEP.

It was decided to organize a 'General Meeting on LEP' in the first half of this year with the aims of informing the high energy physics community of the status of the machine design (giving the opportunity to comment on the parameters of the experimental halls and all other features which affect the use of LEP by physicists) and of discussing the participation by physicists and engineers in the Member States in the building of LEP components. In this context ECFA strongly endorsed a resolution of the CERN Scientific Policy Committee:

'The Scientific Policy Committee stresses that the research programme for LEP should not be prematurely frozen. Should LEP be approved in June 1981, a call for experimental proposals will be sent out towards the end of 1981. The first selection of experiments will be made by an appropriate committee towards the end of 1982. The Scientific Policy Committee urges that special attention be given to ensuring that small groups and young physicists are given every opportunity to take part in LEP experiments.'

It is hoped that the 'General Meeting on LEP' will take place at Villars-sur-Ollon in the Swiss Alps in the first week of June. A Working Group has been set up to prepare for the meeting with the following members: J. Mulvey, H. Boggild, F. Bonaudi, M. Bourquin, W. Braunschweig, J. Buon, R. Cashmore, M. Davier, P. Duinker, T. Ekelöf, J.H. Field, A. Klovning, F. Pierre, P. Strolin, G. Weber, G. Wolf and Ch. Redman (Secretary).



New ECFA chairman John Mulvey (left), who succeeds Marcel Vivargent (right).

This Group will work in contact with the LEP Project Committee at CERN which will put forward all the problems they feel should be discussed by the community. The Group will use the community as the source of data to solve these problems. Anyone may contact Group members to raise any other issues considered important.

To help the interchange of ideas on LEP design, especially as it affects the performance of experiments, the Project Committee itself is holding two or three open meetings at CERN. Each meeting is intended to concentrate on a limited number of topics and they will be useful in preparing for the General Meeting in June. The first of these meetings was held on 23 January, and included discussion of the choice of intersection regions for the first four experimental areas.

Among other topics discussed at the November ECFA Meeting, Bryan Montague presented prospects for polarized beams in LEP. This is a possibility which must be confronted at the start because if it is decided to aim for polarized beam, there are implications for the machine design. There was a call for all physicists who have an interest in LEP experiments with polarized beams to make their interest known so that the decision on polarization can be taken early.

E. Lillestøl covered progress in the ECFA Working Group on Data Processing Standards in High Energy Physics. This also is related to experimentation at LEP where standardization would greatly ease the participation of national groups in big collaborations. Sub-groups are now tackling specific topics (see November 1980 issue, page 340).

Gus Voss reported on the status of the proposed electron-proton ma-

Around the Laboratories

chine, HERA, at the DESY Laboratory (see May 1980 issue, page 99). The project is now being evaluated along with several other major proposed scientific facilities in the Federal Republic of Germany by a committee set up by the Government. The committee is expected to report in March and if its recommendation is favourable, the Government can then be approached for finance. All other preparatory steps in terms of local authorizations, approval by the Hamburg authorities and, of course, continuing development of the design, are under way.

At the ECFA Meeting, John Mulvey of Oxford University was elected Chairman of ECFA, taking office from 1 January. He succeeds Marcel Vivargent of the LAPP Laboratory at Annecy whose considerable efforts as Chairman of ECFA in the cause of LEP have been a major contribution to the strong support generated for the project within the European high energy physics community. He initiated several working groups on LEP, including the new one announced at the beginning of this article. He also introduced into ECFA's deliberations very thorough reporting of the decisions in the various CERN Committees which has helped ECFA in formulating its own policies. John Mulvey now leads ECFA with the experience behind him of chairing the ECFA Working Group which examined the high energy physics activities and resources of Europe and emerged with a very thorough report (see March issue 1980, page 11). He was also Director at CERN for several years before returning to Oxford University in 1976.

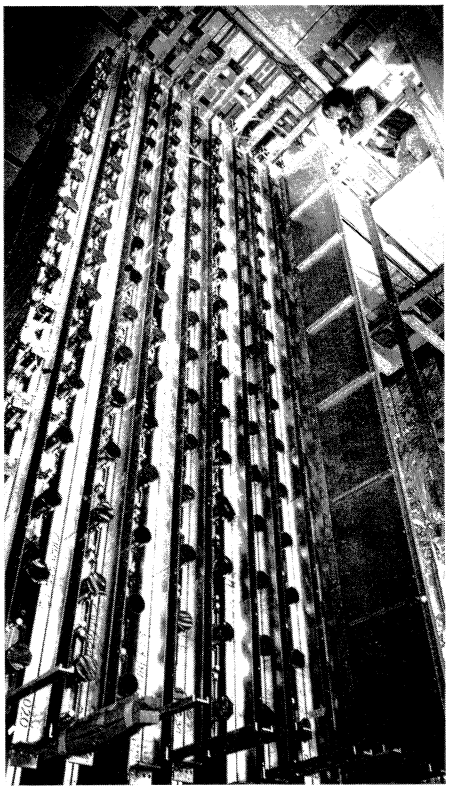
BROOKHAVEN
Bouncing neutrinos

During the past year a massive and heavily instrumented new electronic detector has been taking shape at Brookhaven. Its primary purpose is to investigate with high precision the elastic scattering of neutrinos from electrons and protons. A wide range of other reactions will also be looked at, including a search for neutrino oscillations (see page 21).

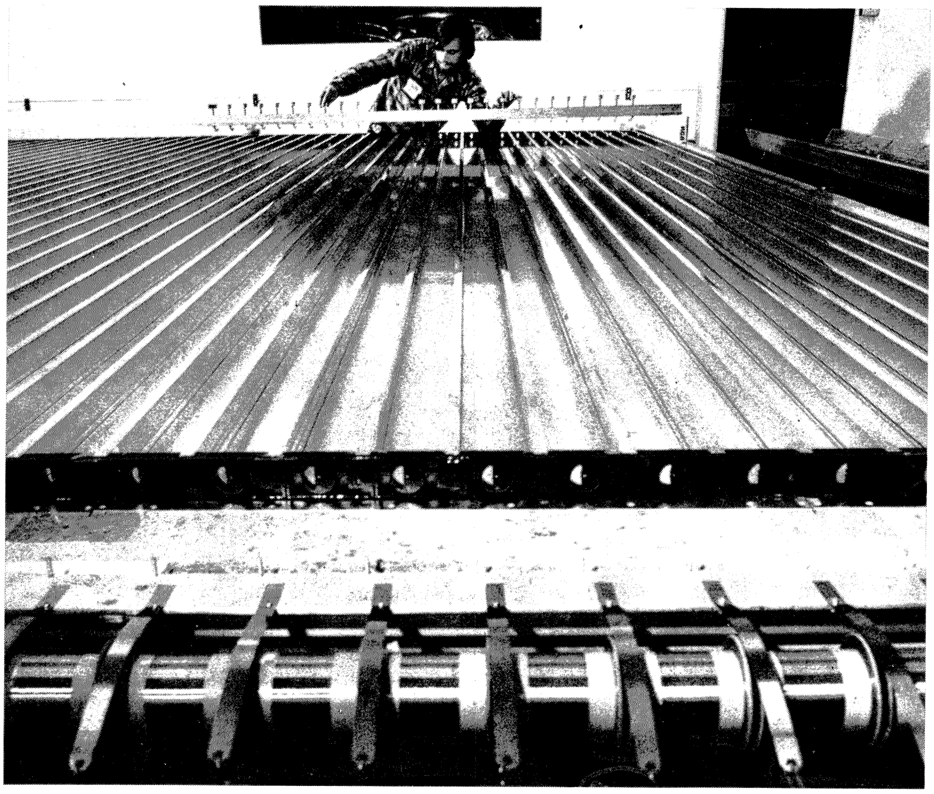
The new detector represents a major step forward in both size and complexity from the early electronic experiments at the Brookhaven Alternating Gradient Synchrotron (AGS). It is being constructed by a consortium of physicists from Brookhaven, Brown University, the University of Pennsylvania, the State University of New York at Stony Brook, KEK, Osaka University and INS-Tokyo. A key design goal was to have almost all of the detector 'live', recording all energy deposition by charged particles as well as serving as a target. Most of the mass (170 tons in 128 modules) is in the form of liquid scintillator which gives good energy resolution and low multiple scattering. The liquid is contained in 4-metre-long acrylic tubes which also serve as light-pipes to carry the scintillation light to phototubes at each end. The width of each tube in the beam direction is only 7.5 cm, meaning that protons can be detected down to about 300 MeV and that an electron can be tracked through a distance of three modules, on average, before it begins to shower. This latter feature is important for precise measurement of the electron scattering angle.

The tracking is done by proportional drift tubes sandwiched between the calorimeter modules. They measure charged particle locations to a precision of 0.5 mm. The tubes also provide dE/dx measurements. This information, together with the good angular resolution of the drift tubes, will be used to distinguish elastically scattered electrons from other charged particles and photon conversions.

Brookhaven's new neutrino detector in the assembly stage. Liquid calorimeter modules interspersed with proportional drift tube planes will provide a fine-grained 'live' target, recording energy deposition by charged particles.



The AGS is ideally suited for the study of neutrino elastic scattering. The neutrino beam peaks near 1 GeV, with useful flux up to about 5 GeV. The yield of neutrino on electron scattering events per ton of detector is approximately the same from this beam as that from higher energy accelerators, since the higher repetition rate of the AGS compensates for the lower cross-section. The hadronic reactions of neutrinos at this energy have low multiplicity and are well understood, with the result that the background for the electron scattering signal is expected to be only 10 per cent. About two events per day are anticipated,



Tensioning sense wires in the proportional drift tube planes for the new Brookhaven neutrino detector. This is well-suited to study elastic neutrino scattering from both protons and electrons.

(Photos Brookhaven)

which should yield a measurement of the Weinberg angle with high precision (±0.01) and no systematic error. The same advantages associated with low energy apply *a fortiori* with respect to the neutrino on proton elastic scattering, since the cross-section for that channel does not rise linearly with energy but quickly approaches a maximum.

Construction of the detector has proceeded smoothly and testing of components has been highly successful. After an initial test run, physics data-taking runs with 80 modules in place are scheduled for March and May. The full apparatus is expected to be complete by the fall. One of the interesting results anticipated from these first data runs is related to neutrino oscillations. A measurement of the ratio of neutral current to charged current event rates as a function of energy will set a low limit for any transition between muon and electron neutrinos. A charged particle spectrometer will be added downstream of the detector to provide a measure of the neutrino flux by normalizing with high precison to the charged current event rate.

CORNELL
B mesons at CESR

Indirect evidence for the production and decay of mesons containing the new b-quark ('beauty') flavour has been observed at CESR by both experimental groups, CLEO and CUSB. The properties of the fourth upsilon (see June 1980, page 151) and of the decays observed appear to be in agreement with predictions of the 'standard' theory of electroweak interactions. The best evidence comes from the number of high energy leptons in the observed events at the fourth upsilon resonance. A significant increase in the number of leptons per event at the resonance indicates a new weak decay channel and thus the production of a new 'flavour' that can only decay by flavour-changing weak decays.

Both groups have observed a dramatic increase in the production of electrons above 1 GeV. (The spectrum of electrons and muons from the decay of lighter hadrons such as D mesons is weighted towards lower energies.) The total hadronic cross-section shows a 50 per cent increase over the continuum at the resonance, while the electron yield increases by almost a factor of four. The muon cross-section measured by CLEO shows a similar increase, in agreement with the electron numbers. The branching ratio for naked beauty B mesons to decay into electrons is 13 per cent (CLEO), 15 per cent (CUSB), and into muons is 9 per cent (CLEO), all of these being consistent with each other within experimental errors.

The CLEO detector has also observed a significant increase in the kaon yield at the resonance. Data from the time-of-flight counters are used to select charged kaons, and neutral vees from the drift chamber are identified as neutral kaons, giving a combined rate of about 1.6 kaons per B decay. This indicates that the B decays predominantly to charmed mesons, which then decay predominantly to strange mesons (kaons). This mode of decay is expected to dominate, according to the Kobayashi-Maskawa scheme utilizing six quark flavours. (This scheme, of course, also postulates the existence of a sixth 'top' quark which has so far eluded detection at PETRA.)

The CUSB detector, which is designed to be sensitive to low energy photons, has not observed a clear signal of 50 MeV photons at the resonance. Such a signal would be expected from the decay of excited B mesons which are thought to be 50 MeV heavier than their ground-state counterparts. The absence of a 50 MeV photon peak indicates that the fourth upsilon resonance is less than 100 MeV above the beauty threshold, since the CUSB detector is sensitive enough to see at least one of the two 50 MeV photons expected from the production of excited B mesons.

FERMILAB Holographic track chamber workshop

An informal workshop was held at Fermilab in November on holographic track chambers, with emphasis on high resolution bubble and streamer chamber vertex detectors for fixed-target Tevatron experiments. About 85 experimenters participated, with approximately equal numbers interested in applications to hadron/photon interactions and to neutrino/beam dump studies.

The possibility of holography offering advantages over conventional photography of bubble chambers by providing direct three-dimensional recording, as well as high spatial resolution over much larger depths of field, was explored in the late 1960s. Optics scientists in Britain, the United States, and Japan participated in these investigations. Holographic recording of spark and streamer chamber track residues was demonstrated in the early 1970s in the Soviet Union. However it is chiefly in the last two years that extensive practical interest has developed in holographic track recording, principally for studies of short-lived charmed hadrons and of heavy leptons (see June 1980 issue, page 154).

Tests at CERN with the small BIBC bubble chamber have demonstrated well the possibilities of using holographic techniques with bubble chambers.

At the workshop it appeared that the goal for many experimenters is to achieve with practical chambers an order of magnitude improvement in spatial resolution with holograms as compared to conventional photographs. It was emphasized by Leon Lederman in his welcoming address that the realization of higher spatial resolution detectors is both important for increased physics capabilities in Tevatron experiments and would in many cases also allow the use of smaller and more economical apparatus.

In the first session T. Jeong (Lake Forest) provided background and demonstrations of a variety of general holographic techniques. C. Fisher (Rutherford) reviewed limitations of conventional high resolution track chambers and spectrometers, leading to recent European developments and proposals for several varieties of small holographic bubble chambers. P. Lecoq (CERN) showed reconstructed images from the first high resolution bubble chamber holograms, taken earlier this year at the CERN SPS with the Berne freon mini-chamber (BIBC). Videotape test results with eight micron bubble diameter tracks were particularly dramatic. Image resolution of this quality appears to be needed for efficient observation of decay vertices for particles with lifetimes down to 10^{-13} s.

The second session provided additional technical perspectives on the limits for holographic techniques by F. Eisler (CUNY), and on the characteristics of the required lasers for practical holographic track chambers by R. Milburn (Tufts). Aspects of high resolution photography and holography of streamer chambe tracks were reviewed by J. Sandweiss (Yale), and of big bubble chambers by H. Bingham (Berkeley). Designs of two novel holographic freon bubble chamber proposal were described by I. Pless (MIT). On design featured a very small ultrasonic chamber for hadronic interactions, aiming at about 5 micron bubble size, the other a 36 inc chamber for Tevatron beam dum experiments, aiming at about 30 m cron bubbles resolution. Both designs featured classical in-line hol graphic optics with the addition o auxiliary lenses, providing imag magnification for the small chamb and demagnification for the larg chamber for similar 70 mm film fo mats.

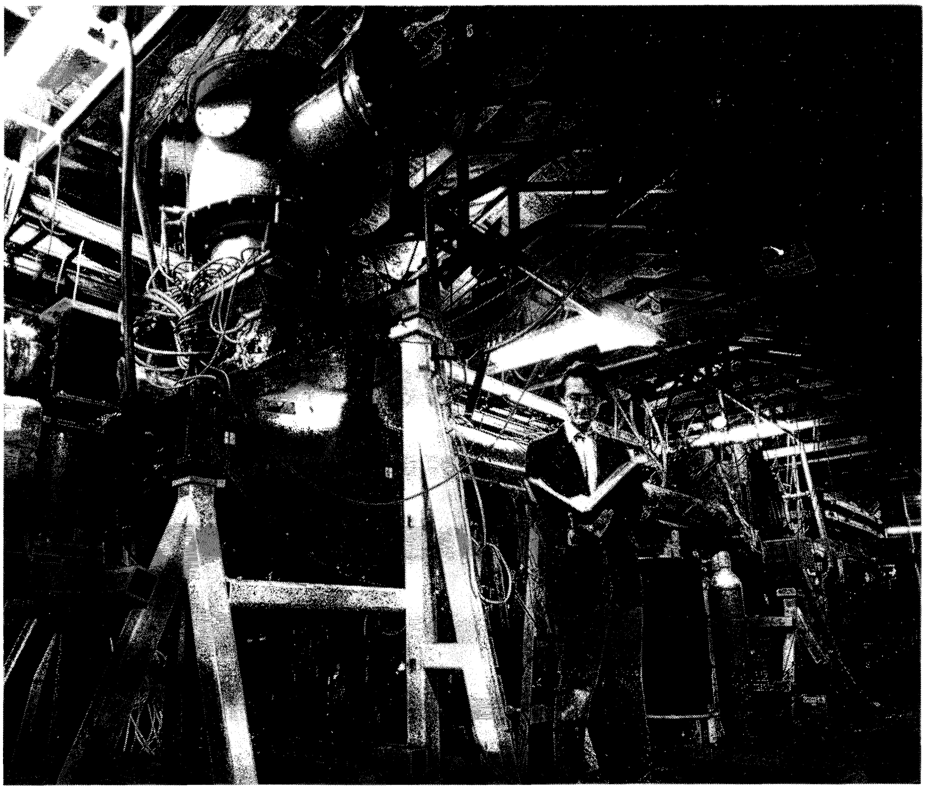
Two parallel sessions were he one on possible holographic mi detectors for hadron/photon inte actions and the other on big hol graphic bubble chambers for neut no/beam dump experiments. The sessions stimulated lively in a dience participation and int changes of new ideas.

C. Fisher, assisted by the 'big chambers' chairman V. Peterson (Hawaii), emerged with an idealized big cylinder holographic chamber geometry with internal spherical mirrors at the ends, resembling the optics in some forms of astronomical telescopes. It was later learned that T. Kitagaki and others in Japan had recently come to similar conclusions for a possible design of a proposed MIT Tohoku beam-dump holographic chamber. For the 15 ft chamber, thoughts were aired on laser speckle problems, liquid turbulence and magnetic field optical polarization effects, which may be serious for holographic methods using bright-field Scotchlite and off-axis reference beam illumination. Possible alternate solutions were suggested, including the introduction of a suitable laser beam inside the chamber independent of the camera lens assembly. This might also allow for dark-field Scotchlite illumination and more nearly in-line image holograms.

In the mini-detector session, chaired by J. Sandweiss, it was generally agreed that the holographic optics posed only minor problems for small transparent chambers. The main discussions centred on chamber types, duty factors, beam rates, laser and triggering logic requirements, as well as a brief look at the associated problems of scanning and data reduction if millions of holograms are to be taken. C. Roos (Vanderbilt) pointed out the axial optics and high field solenoid features of the HYBUC bubble chamber as an attractive rapid cycling holographic target chamber for development and use with Tevatron spectrometers. R. Plano (Rutgers) described an idea for a continuously operating small holographic bubble chamber, using the Bernoulli principle for establishing an appropriate pressure drop for sensitivity together with velocity flow for removing old bubbles.

Fermilab's electron cooling system installed in the cooling ring. Peter McIntyre, leader of the group that built the system, is in the foreground.

(Photo Fermilab)



A similar idea for continuous cloud chamber operation had been discussed by R. Schluter (Northwestern) during the previous evening's social gathering. (A. Hervé at CERN is at work on a continuously sensitive Bernoulli bubble chamber, making use of leftover Gargamelle liquid pumping facilities.) On the streamer chamber side, L. Voyvodic (Fermilab) discussed recent preprints from a joint Dubna/Leningrad team who reported holographic recording of tracks in a pressurized hydrogen avalanche chamber. He speculated on possible holographic streamer/cloud chambers if these holographic techniques were combined with an avalanche-nucleated diffusion cloud chamber method reported several years ago by a group in Tbilisi.

The workshop ended with overviews on directions for future efforts for prospective Tevatron holographic track chambers by V. Peterson and J. Sandweiss, with additional theory-oriented comments by J. Bjorken (Fermilab). After describing his estimates for the copious abundance of Tevatron-produced charm and bottom quarks, Bjorken stressed that their effective study with suitable detector systems may well bring about a richness of physics comparable to the discoveries that have been provided in the past by intensive and detailed studies of strange particles.

Cooling scenario study week

A study week was held in November to consider antiproton cooling in the Tevatron Phase I colliding beams project. Collaborators from Wisconsin, Argonne and Berkeley participated, as well as visitors from CERN, DESY and Brookhaven.

Heating of the antiproton target during the beam pulse can reduce the antiproton production and several ideas were discussed that could reduce this heating. Possibilities include targeting segments of the proton beam sequentially, stacking the antiprotons from separate segments together after production and some cooling. A scheme invented at an earlier targeting workshop would move the proton beam laterally across the target faster than the shock wave generated by the beam (the total motion is of the order of 1 mm). It may also be possible to target the entire beam on a multiple target system — a sequence of current-carrying targets interspersed with lithium lenses similar to one developed for Fermilab by a group at Novosibirsk. Combinations of these schemes are also interesting and are being explored further.

During the study week, cooling scenarios involving only stochastic cooling were considered. These schemes are not completely different from the CERN AA system, but one of the targeting-injecting systems discussed above is needed, because at Fermilab the initial proton beam comes in units of Main Ring Length and must be segmented to fit in a smaller ring. In addition, any all-stochastic system needs another storage ring to accumulate particles or a shutter system and large aperture like that at CERN.

Electron cooling at higher energies was explored. It was shown that cooling at 380 MeV, the limit of the present ring at Fermilab, is more efficient than at 200 MeV. The interesting possibility of cooling at 1 or 2 GeV was also raised. In this method, a high-voltage power-supply system, such as a Van der Graaff or Cockcroft-Walton, would be used in the production of a suitable electron beam.

One result of the week was that many schemes for targeting and cooling involve precooler rings of similar radius and aperture. The possibility of designing a ring that could accommodate any of these schemes with only small modifications is being explored. The study week showed that a number of scenarios can meet the Tevatron Phase I goal of 10^{30} per cm^2 per s luminosity, with room for improvement.

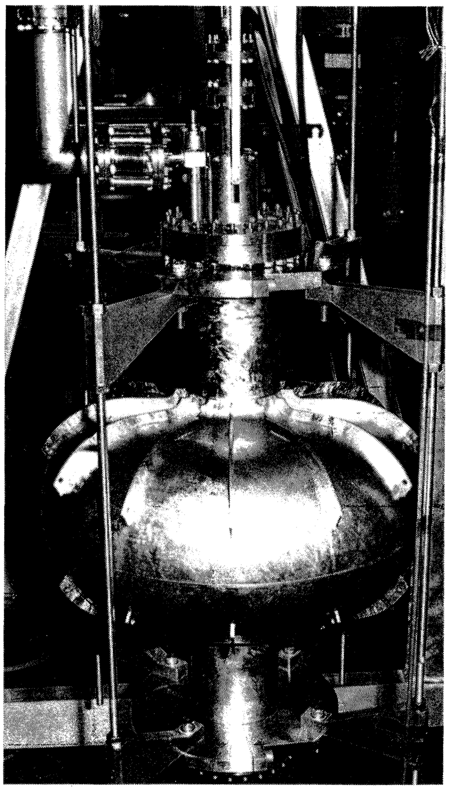
KEK Superconducting cavity tested

The study of superconducting r.f. cavities at KEK was started several years ago by a small group headed by Y. Kojima, and has been stimulated by an exchange of scientists with groups at Karlsruhe and Stanford. Last year the work focused on the development of superconducting cavities for use in the proposed TRISTAN storage ring at KEK. The plan is that around 1985, the conventional cavities in TRISTAN would be replaced by superconducting ones so as to increase the peak energy of the electron and positron beams beyond 35 GeV if a gradient of 3 MV/m can be achieved.

A spherical cavity was designed with a frequency of 500 MHz, and a Q-value of 48 000. The peak surface electric field was minimized by adopting an elliptical transition from the beam tube to the endplate. This cavity was made from 2.5 mm thick niobium sheet by spinning with twelve reinforcement ribs welded to each cavity section. The material was of 99.6 per cent purity, the major culprit being tantalum (1700 ppm).

A superconducting r.f. cavity which has been successfully tested at KEK. It is made of niobium and has external reinforcing ribs. The aim is to develop superconducting cavities for use in the proposed TRISTAN electron-positron storage ring.

(Photo KEK)



Prior to welding (all the welds are from inside except for the last one at the beam tube) the individual sections of the cavity have been electropolished, removing 80 microns. After welding, the cavity was stress-relieved at 900°C at a vacuum of about 10^{-5} torr and again electropolished for 20 microns. Wet assembly was accomplished; no high temperature degassing was carried out.

The first measurements in a mu-metal shielded cryostat resulted in a Q-value of 3.4×10^9 at 4.2 K and low field level and of 1.8×10^9 at the maximum accelerating field of 4.1 MV/m. No multipacting and only moderate field emission loading above 3.3 MV/m were encountered while raising the field in the cavity. By lowering the temperature to 2 K the Q-value improved to over 1.1×10^{10}, while the accelerating field gradients remained the same.

It is intended to confirm the results of this successful test with a second cavity of similar geometry. A third one will be equipped with all the necessary features (like main power coupling and higher mode coupling devices) for testing in the photon factory ring or the TRISTAN accumulator ring during this year.

James Bradbury, Applications Group leader at LAMPF, Los Alamos, reporting to the annual LAMPF Users meeting in November. He was able to describe work in cancer therapy, radioisotope production, proton tomography and special instrumentation.

(Photo Los Alamos)

LOS ALAMOS Physics and biomedical reports

Reviews of the physics and applications programme highlighted the fourteenth annual LAMPF Users Group meeting held in November. Director Louis Rosen contrasted the 'adventuresome' and 'bread-and-butter' aspects of the nuclear and particle physics research programme now in full stride at the 800 MeV accelerator.

LAMPF's bread-and-butter is the structure and properties of nuclei and nuclear forces. Rosen discussed new ideas in this traditional field such as monopole isovector excitation (a breathing or compression mode of the nucleus with protons and neutrons out of phase). He also noted that only 20 per cent of the nuclei which we believe it is possible to form have been studied. A better picture of nuclear forces awaits an understanding of the short-range force, modification of the nuclear potential by resonance formation, quark effects, multibody correlations, and the complete spin-isospin analysis. Amongst the recent work mentioned were the experiments on dibaryon resonances using polarized beams and targets.

In particle physics, Rosen cited recent precision experiments on quantum electrodynamics using muons, charge symmetry violation limits with the three gamma decay of the neutral pion, and conserved vector current (CVC) with pion beta decay. CVC has a close connection to unification theories, since it was the first successful theory of unification.

Weak interactions and rare decays form a bridge between established and speculative physics. An example which has produced a new physics result is the neutrino experiment on lepton conservation, which gave a limit on antineutrino oscillations.

Rosen suggested that an experiment with high physics impact is adventuresome if undertaken with odds against producing a positive, measureable effect. A list of such experiments performed or considered at LAMPF includes rare decay modes of the muon, parity violation in the strong interaction, the search for precursors to pion condensation, measurement of the strong interaction shift in pionic atoms, neutrino oscillations, and neutron-antineutron oscillations (where it is not clear whether a suitable beam-stop neutron moderator is practical).

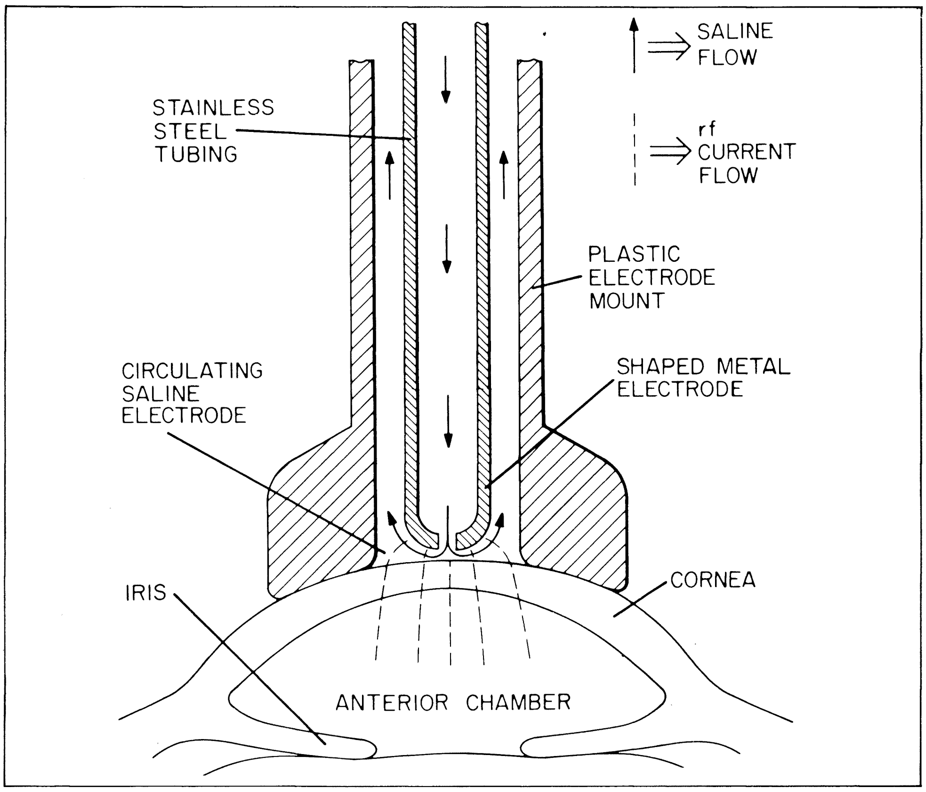
A political topic of high current interest, re-establishment of US-USSR scientific exchange, was also discussed by Rosen. A possible high-level meeting this winter may address this issue.

James Bradbury, Applications Group Leader, reviewed the LAMPF biomedical programme. To date, 175 cancer patients have been given pion therapy and statistically significant trends are being noted. An extensive beam catalogue has been developed with transverse field sizes up to 14 cm x 19 cm and beam range in water up to 23 cm. Total doses are typically 4200 to 4500 rads delivered in 35 fractions over six to seven weeks. Treatment planning involves use of an on-site tomography scanner to determine tissue density and tumour location. Beam delivery may employ a collimator, bolus, and dynamic range shifter.

Ninety-six patients, who almost certainly could not have benefitted from conventional techniques, received treatment. Treated sites included head and neck, brain, prostate, and pancreas. Local control of 45 per cent has been achieved with follow-up from six to forty months. None of the patients with pancreatic carcinoma have local control, but all of the prostate cancer cases have local control. Moderate acute reactions and minimal chronic reactions have generally been observed.

Bradbury also described a very straightforward application of the LAMPF high-intensity beam for radioisotope production for the biological sciences. Many Curies of strontium and bismuth isotopes have been produced and a pricing procedure has been established for commercial sales.

Diagram of the circulating saline electrode developed at Los Alamos in the LAMPF Applications Group for the treatment of extreme refractive error in the eye. It allows r.f. heating of the cornea to correct the error under much more favourable conditions.



A biomedical instrumentation programme has grown up in the Applications Group. One rewarding innovation is a circulating saline electrode (CSE) for vision correction. Extreme cases of refractive error in the eye are often not able to be treated with external lenses. Up to now thermal modification of corneal shape has been an alternative to corneal transplant, but the technique has been limited by surface damage caused in the heating. The CSE permits r.f. heating of the cornea plus epithelial cooling with the circulating saline solution to achieve a more favourable temperature profile.

Bradbury also reported conclusions from the proton computer tomography (CT) experiment, where proton and X-ray CT scans were compared. A well-collimated 230 MeV proton beam was delivered on phantom targets and organ samples. A 32-element range telescope collected range information and a wire chamber recorded position for about 6 x 10^7 protons in a scan. The proton CT reconstructions were computed using a standard filtered back-projection algorithm. The experimenters concluded that the proton scans are remarkably similar to X-ray scans, with somewhat poorer spatial resolution but a five-fold dose advantage. This work was given some prominence in Allan Cormack's 1979 Nobel Prize acceptance speech.

RUTHERFORD
Heavy particle search

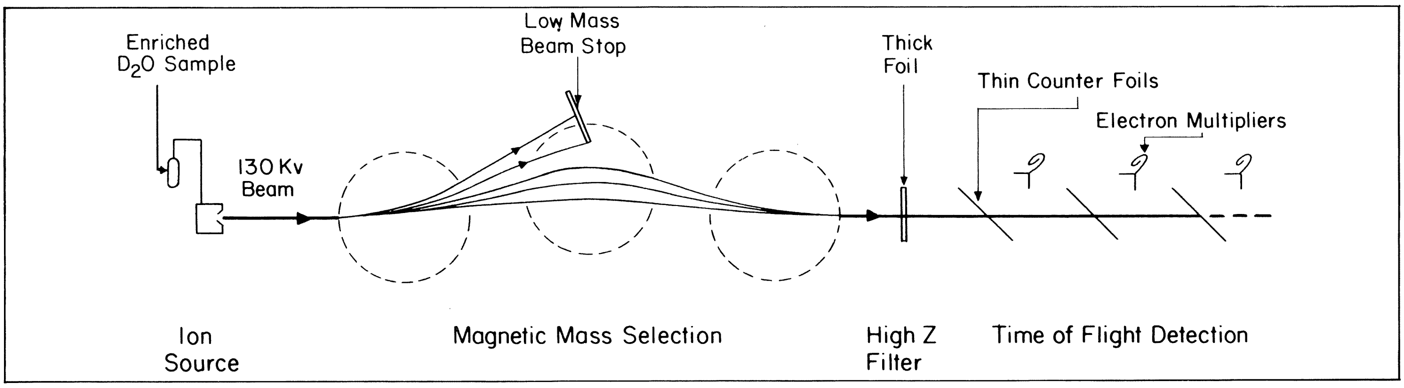
An experiment at the Rutherford Laboratory has set very low limits on the concentration of heavy stable charged particles in water. The experiment was proposed and led by Peter Smith and the team consisted of G.J. Homer, J.D. Lewin, W. Walford and W.A. Smith.

The experiment was based on the principle that if such particles exist, they would be present in matter as a result of either a natural abundance created during the early phase of the Universe (theoretical estimates suggest that this should be rather high — typically 10^{-12} or more, relative to hydrogen) or an accumulated concentration arising from cosmic ray production processes during the lifetime of the earth. In the latter case charge +1 particles in particular would form heavy hydrogen-like atoms X, the majority of which would end up as a minute concentration of HXO in water. Depending on the production process, the expected concentration (after 3.10^9 years) would be in the range 10^{-20} to 10^{-30} for stable particles with masses from 10 to 100 GeV. This mechanism is confirmed by tritium produced by cosmic rays (which has a lifetime of twelve years) being observed as a fairly uniform concentration (about 10^{-17}) of HTO in water.

Inherent uncertainties could account for lower than expected concentrations of X particles from the early Universe, but cosmic ray produced concentrations of the X particles would be inescapable.

Several mass spectrometry experiments to search for such stable charge +1 particles have been carried out, the two most sensitive coming from experiments at Berkeley and at Princeton, which achieved sensitivities in the region 10^{-18} to 10^{-19} for particle masses up to 16 GeV.

In the new experiment, which used time-of-flight techniques to analyse a highly enriched heavy water sample, it was possible to cover a much larger mass range (up



The time-of-flight system used in the Rutherford Laboratory experiment to search for stable heavy charged particles. None were found in water down to extremely low levels of concentration.

to about 1300 GeV) and to reach concentration levels in the region 10^{-29} to 10^{-30}. Since this is below the minimum which would result from cosmic ray pair production of masses up to about 80 GeV, the result provides strong evidence that no stable particles can exist in this mass range.

The production of the enriched water sample was itself a major task, achieved in collaboration with the United Kingdom Atomic Energy Commission (Harwell and Winfrith) by the electrolysis of about six tons of heavy water. Over a three-year period an initial 6000 litres was progressively reduced to 20 microlitres. The increasing tritium concentration was monitored throughout to check the predicted enrichment factors. Since heavy water itself is manufactured from 20 000 times its volume of natural water, the overall enrichment factor was between 10^{11} and 10^{12}.

In 1978, a portion of this sample was examined by conventional mass spectrometry at the Atomic Weapons Research Establishment, Aldermaston, giving a heavy particle concentration limit of about 10^{-22}, but very much lower limits have now been reached by a time-of-flight spectrometer devised in collaboration with J.R.J. Bennett. Heavy water molecules (together with impurities and any DXO) were ionized in a high efficiency ion source and accelerated to 130 kV. The components of the beams were first separated in mass to remove the main heavy water beam and other low mass components. Everything remaining was then recombined into a single beam, which passed through a carbon foil to attenuate impurities of higher charge. Any surviving particles were individually recorded by a time-of-flight channel formed by three thin foils and electron multipliers. From the flight times before and after passage through the central thin foil, events due to residual highly charged ions or scattered deuterium could be distinguished from heavy particle events, which would have a much lower energy loss rate.

Recent accelerator searches for new charged particles, in particular the data from PETRA, provide null results up to a mass of 12 GeV. Accordingly, the time-of-flight system was designed for maximum sensitivity over the range of 12 to 1000 GeV.

The figure (p. 20) shows the sensivity achieved as a function of mass, together with the calculated concentrations from cosmic ray interactions over 3.10^9 years by the Drell-Yan pair production mechanism (assuming pointlike particles) and by typical hadronic production processes. Particles produced by the Drell-Yan mechanism would thus have been seen up to mass 70–80 GeV and particles produced by the hadronic mechanism up to at least 300 GeV.

Also shown is a possible limit on the concentration of masses from 10^3 GeV upwards, obtained from the observation that the density of the enriched sample did not differ significantly from unenriched control samples. This particular limit depends on the additional assumption that the surface water from which the original heavy water was extracted was not gravitationally depleted in heavy particles (gravitational separation would begin to be significant in the mass region 100–1000 GeV). However, provided there is a reasonable degree of mixing in the oceans every 10^8 years, this assumption should be satisfied.

Regarded as a cosmic ray experiment, the quantity of water processed is equivalent to a detector covering 50 m^2 of the earth's surface running for 3.10^9 years. The sensitivity level of 3.10^{-30} is equivalent to one particle in 10 m^3 of water.

Prior to the spectrometer runs, the sample was also tested for quasi-stable heavy particles with lifetimes in the range 10 to 10^{10} years. In this part of the experiment (carried out by Franz Heymann and David Imrie of

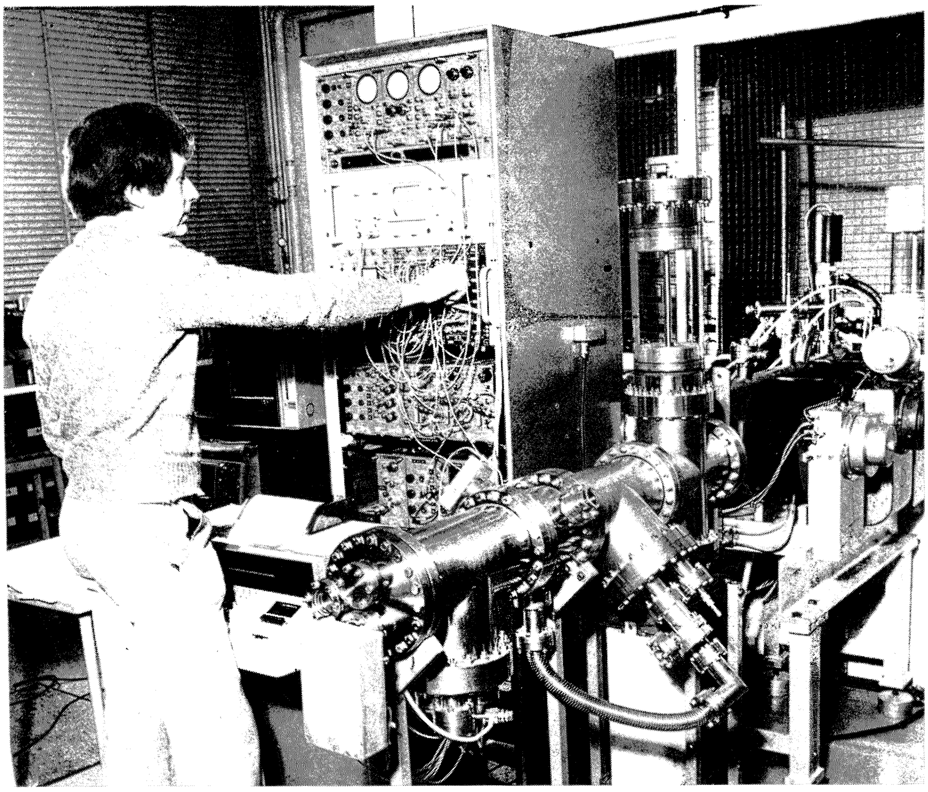
University College and P.T. Trent of Birkbeck College, London) a small spark chamber array was used to detect any high energy decay products emanating from the sample. The experiment was carried out in an underground laboratory to reduce cosmic ray background and no events attributable to particle decays were observed in six months running.

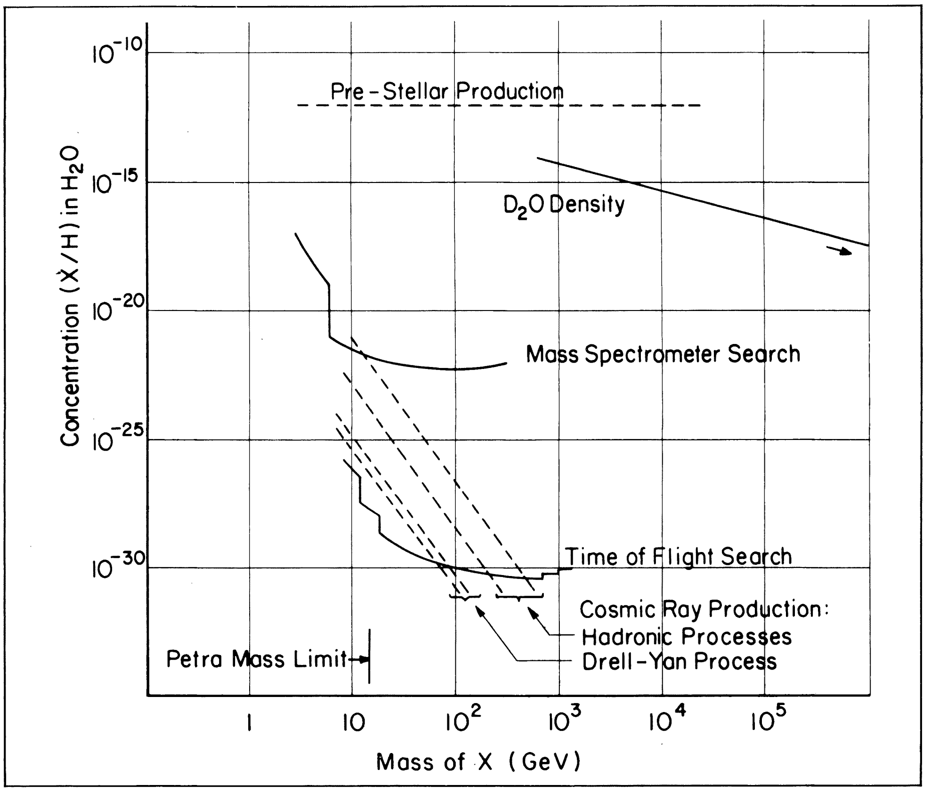
Although all of these experiments were designed primarily for heavy particles of charge + 1, they are also relevant to the possible existence of free fractionally charged quarks which would also be expected to be produced by cosmic rays and to form charged water molecules with fractional charges (HQO). These would have been similarly enriched by the electrolysis and would have been clearly observable in the time-of-flight experiment. However there is greater uncertainty in the likely history of water molecules with net charge, for example in their evaporation mechanism and their response to the earth's electric field, giving rise to a possible deficiency in HQO molecules in the water from which heavy water was extracted. For fractionally charged particles, the results therefore do not necessarily imply a specific concentration limit, but do provide some further evidence against their existence in the form HQO.

In recent years there have been a number of predictions and speculations regarding new stable particles — integrally and fractionally charged quarks, stable heavy leptons and

The time-of-flight apparatus used in the heavy particle search. Comparisons between this experiment and a search made by Lord Rutherford over 40 years ago reflect the tremendous progress which has been made in experimental techniques.

(Photo Rutherford)





The sensitivity achieved in the Rutherford Laboratory experiment as a function of particle mass, with the calculated concentrations which could be anticipated from cosmic ray interactions during 3.10^9 years. The dotted lines show theoretical estimates while the solid lines show experimentally measured limits.

Physics monitor

hadrons, and new ultra heavy particles up to 10^{15} GeV in mass. Their apparent absence in the form of hydrogen-like atoms at the low concentration levels achieved in this experiment seems to provide strong evidence against the existence of stable charged particles with masses greater than the proton.

The experiment has an interesting historical parallel. In August 1937, Rutherford's last paper appeared in 'Nature'. It described a search for natural tritium in an electrolytically enriched sample of heavy water using Aston's mass spectrometer. The search was unsuccessful only because tritium is unstable, reducing its concentration to less than 10^{-17} rather than 10^{-9} if it had been stable. Natural HTO was later detected (in the same sample) by counter techniques.

A comparison between the 1937 experiment and the latest measurements is a nice reflection on the evolution of our experimental abilities. Lord Rutherford began with 13 000 tons of water and experimented on 11 ml of heavy water (an enrichment factor of 10^7). The Rutherford Laboratory began with 120 000 tons of water and experimented on 0.02 ml of heavy water (an enrichment factor of over 10^{11}). Lord Rutherford had a detection sensitivity of 10^{-5} and an overall sensitivity of 10^{-12}. The corresponding figures for Rutherford Lab are better than 10^{-17} and 10^{-28}.

The continuing hunt for neutrino oscillations

Last year, evidence from a number of very different experiments sparked off a flurry of interest in the possibility of neutrino 'oscillations'. After the discovery in 1962 that neutrinos come in different kinds, all the evidence had been that these different neutrinos were immutable and could not mix. Then suddenly last year, experiments using low energy neutrinos from fission reactors, together with studies on the beta-decay of tritium, gave preliminary results which pointed to a possible mixing between electron and muon-type neutrinos (see July/August 1980 issue, page 189). Some initial high energy neutrino results from CERN also provided preliminary evidence for such an effect, although a subsequent study using the narrow-band neutrino beam showed nothing out of the ordinary.

In classical neutrino theory, the particle, no matter what species — electron, muon or tau — is massless and travels at the speed of light. This assumption makes the theory neat, but has yet to be proved. The new evidence, as yet still slim, points to the possibility that the different types of neutrino have different masses and therefore travel at different speeds. If so, the composition of a neutrino beam would appear to change as it travels along.

Some of last year's indications for such neutrino oscillations came from a reactor experiment comparing the rates of deuteron dissociation through the charged and neutral weak current. Fred Reines' group obtained a result which was not in agreement with the theoretical predictions using zero mass neutrinos.

In the meantime, other explanations have been proposed which could account for this result. Nuclear binding effects in the deuteron, together with uncertainties in detection efficiencies and in the reactor neutrino spectrum, could mean that the effects seen in the reactor studies are not 'clean'. In addition, results from another reactor neutrino experiment, this time at Grenoble, have given results in agreement with the simple non-oscillating theory.

In the search for neutrino oscillations, experiments which make their measurements at a fixed distance from the source of neutrinos are difficult to analyse as they require a precise knowledge of the neutrino flux — notoriously difficult to quantify with confidence. More reliable indications are expected from experiments which compare readings at different distances from the neutrino source, which should be able to detect any changes in the composition of a neutrino beam.

To try and provide a conclusive answer to the neutrino oscillation question, new experiments are being considered. Ideally, oscillation effects should show up best at long distances from the neutrino source, and at low neutrino energies, but because of the difficulties of working with neutrinos, some optimum solution has to be reached. At CERN the possibility of using a lower energy neutrino beam, derived from the 28 GeV proton synchrotron, is being looked at. This would be the first experiment specifically designed to look for neutrino oscillations in an energy range which favours their detection. The idea is that near the new neutrino source, the CERN / Dortmund / Heidelberg / Saclay collaboration would have detector modules identical to those used in their large WA1 experiment using neutrino beams from the SPS

400 GeV proton synchrotron. The new lower energy neutrinos would also pass through the main WA1 detector some 1000 m downstream, enabling the flux of muon-type neutrinos to be measured in two places. The natural divergence of the neutrino beam over this distance is known, and any oscillations changing the level of muon neutrinos would show up as an additional small effect. Another possibility with the same neutrino beam is to look for transformations of muon-type neutrinos to electron-type neutrinos using a bubble chamber.

A new low energy neutrino experiment is being assembled at Brookhaven (see page 12) which could help shed more light on the question, while further evidence could come from continuing experiments both at reactors and using high energy beams.

Whether successful or not, the search for neutrino oscillations looks as though it will add another interesting chapter to neutrino history, which already includes some of the most important discoveries in particle physics.

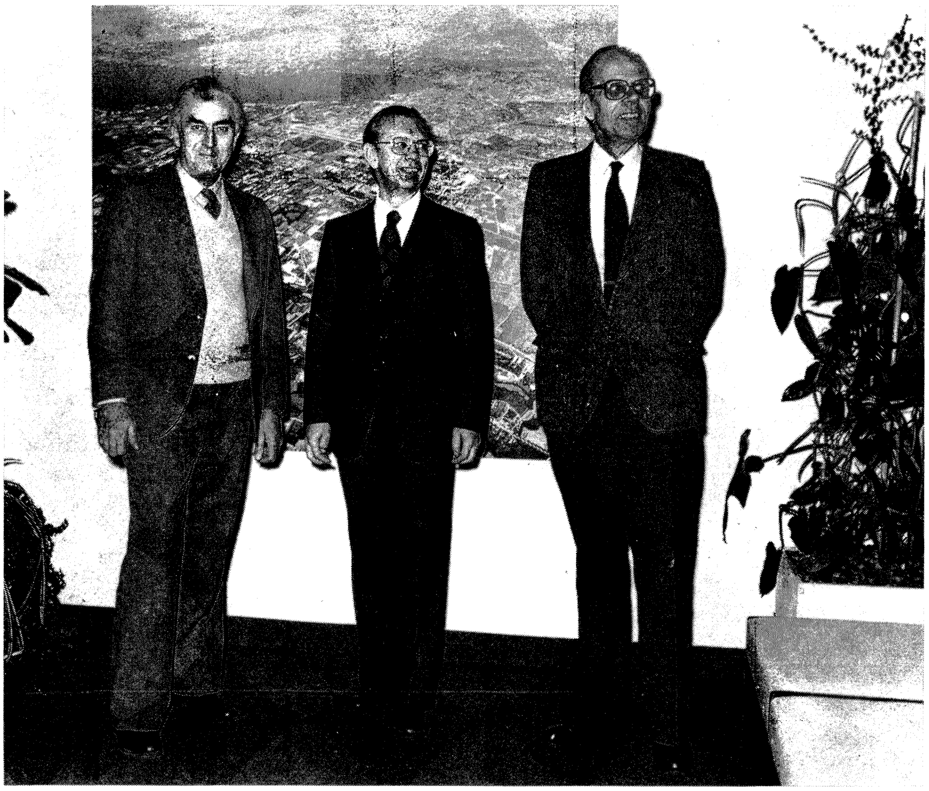
Modules of the CERN / Dortmund / Heidelberg / Saclay high energy neutrino experiment (WA1) at the SPS. Similar modules could be used in a new experiment using a low energy neutrino beam to look for signs of neutrino oscillations.

(Photo CERN 77.6.76)

People and things

On 31 December 1980, the five-year term of office of CERN Executive Director General John Adams (left) and Research Director General Leon Van Hove (right) came to an end. They hand over to Herwig Schopper (centre). In the United Kingdom New Year Honours List it was announced that the former Executive Director General is to receive the accolade of Knight Bachelor, becoming Sir John Adams.

(Photo CERN 504.12.80)



CERN elections and appointments

At the CERN Council session in December, a number of elections or re-elections were made, all for a one-year period. Jean Teillac of France was re-elected as President of Council while Günter Lehr of Germany and Wolfgang Kummer of Austria were re-elected as Vice-Presidents. Karl Nielsen of Denmark was re-elected as President of the Finance Committee and Valentin Telegdi of the Ecole Polytechnique Fédérale in Zurich becomes President of the Scientific Policy Committee. Other new members of this committee are Paul Falk-Vairant of France, Erich Lohrmann of Germany and Donald Perkins of the United Kingdom.

Within CERN, the appointment of Fritz Ferger as ISR Division Leader was extended for three years, while Alan Wetherell becomes Experimental Physics Division Leader and Bastiaan de Raad SPS Division Leader, both for three-year periods.

On people

Volker Soergel has been appointed Director of the DESY Laboratory to succeed Herwig Schopper who became Director General of CERN at the beginning of 1981. Professor Soergel has a distinguished career in nuclear and particle physics, with major contributions particularly in the study of hypernuclei as leader of a team from Heidelberg University. He is also Executive Director of the Physics Institute of the University of Heidelberg. At CERN, he was chairman of the Synchro-cyclotron Experiments Committee in 1975 and has been a Directorate Member since March 1979. At DESY, he served as Chairman of the Scientific Council from 1976 to 1979.

Volker Soergel

It is with deep regret that we have learned of the death of Carlo Franzinetti of Turin University. He was a staff physicist at CERN from 1963 to 1968, and was a very active member of the first large counter neutrino experiments which used massive spark chambers to study neutrino interactions with emphasis on the search for the Intermediate Boson. Following these pioneering experiments, he continued to study neutrino reactions using the 1.5 m heavy liquid bubble chamber and made important contributions in the study of single pion and strange particle production. In 1968, he was appointed to a Professorship at Turin and there he collaborated with the Milan group using the Gar-

gamelle bubble chamber. He was also very interested in the 1960s in starting a muon physics programme at CERN but had to wait until the start of the SPS, where he participated with a group from Turin in the European Muon Collaboration. In the intervening period, he carried out a successful experiment to measure the proton form factors in the time-like region. He was an excellent researcher and teacher, with a very good insight into basic physical processes, and he was always enthusiastic that CERN should undertake experiments of a fundamental nature. He was a man of high integrity, and will be sadly missed in the community of European particle physics.

Collaboration agreement between Italian INFN and the Sinic Academy of Sciences

Following an official invitation of the Academy of Sciences of the People's Republic of China, Antonino Zichichi, President of the Italian Institute of Nuclear Physics (INFN), visited China in October.

During his stay Zichichi, the first Italian high energy physicist to be officially invited by the Sinic Academy of Sciences, delivered a series of lectures and visited the Research Centres and Laboratories of the Academy in Peking, Chekiang, Shanghai and Canton. At the end of the visit, he signed a bilateral agreement for scientific collaboration between INFN and the Academy with Tsien San-Tsiang, President of the Sinic Academy of Sciences.

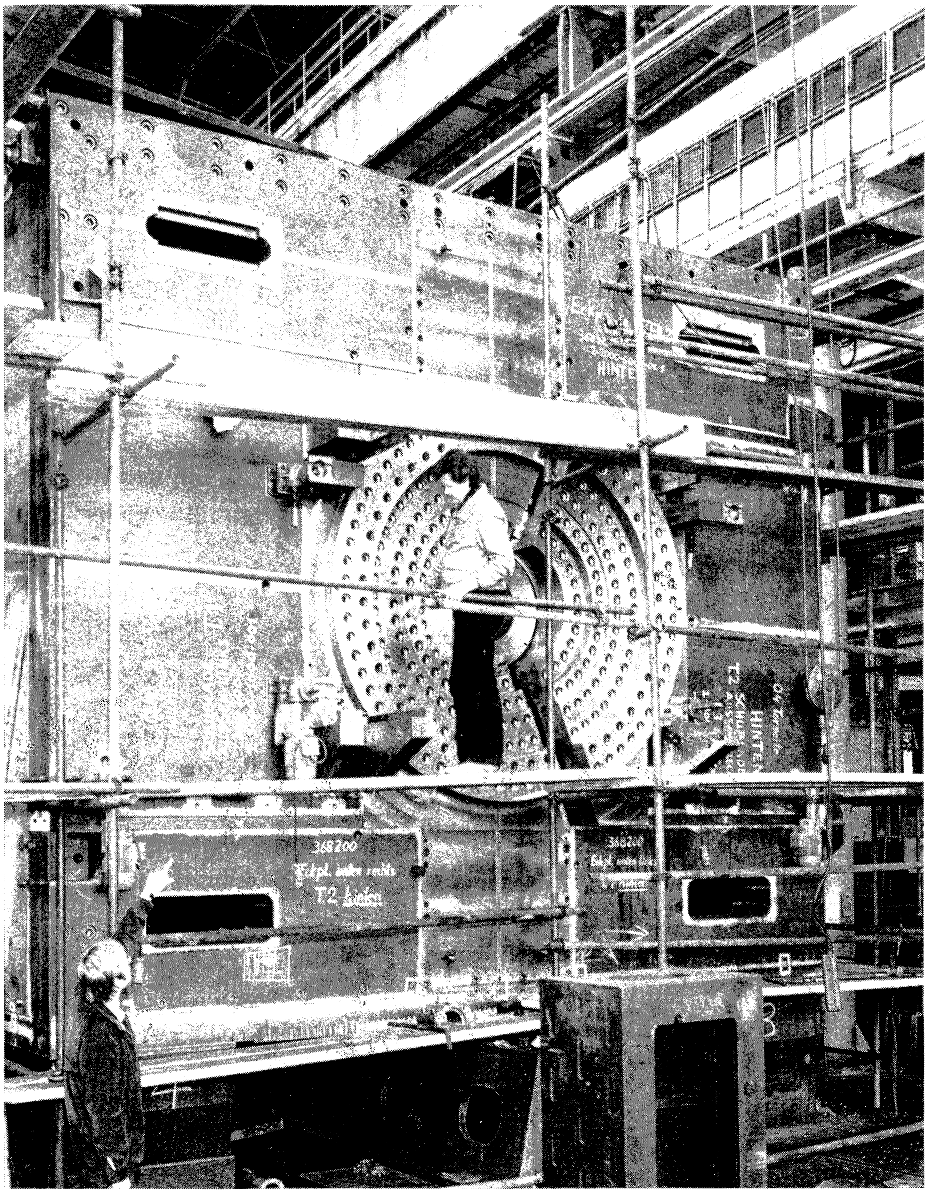
Going into history

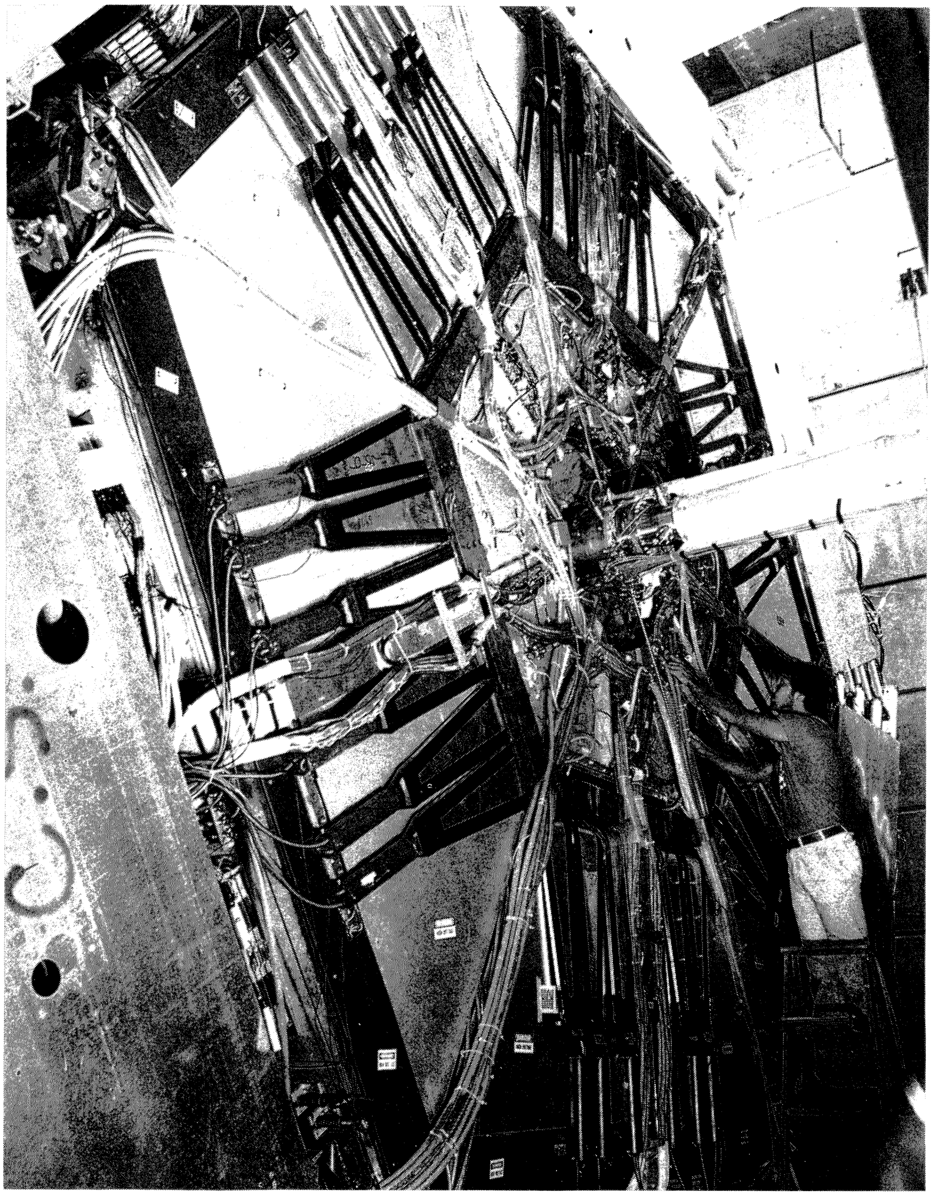
In 1979, the CERN Committee of Council invited Armin Hermann of the University of Stuttgart to carry out a feasibility study, financed by the Volkswagen Foundation, on the writing of a history of CERN. On the basis of its findings, and a recommendation of the CERN History Advisory Committee, the Committee of Council has now authorized the history study which will be carried out by three European Science historians, led by Professor Hermann based at CERN. The study will be financed outside the CERN budget and it is intended to produce the history within the next five years.

The study will cover the events which led to the setting up of CERN in the early 1950s and continue through the early years of the Organization to at least 1963. Alfred Günther will be the coordinator between CERN and the historians and the Scientific Information Service has set up Historical Archives to bring together documen-

A new experiment being prepared for the DORIS electron-positron storage ring at DESY. Seen here is the end view of the magnet yoke for the ARGUS detector of a DESY / Dortmund / Heidelberg / Lund / Moscow / South Carolina collaboration, which will be installed towards the end of the year. The holes are for the light guides of the end-cap counters.

(Photo DESY)





The central section of the 'Big Mac' detector at intersection region 4 of the PEP electron-positron storage ring at SLAC. The PEP vacuum pipe, the solenoid magnet, the shower detectors, light pipes from the trigger counters and parts of the outer drift chamber can be seen. Latest news from PEP is that luminosity is pushing 10^{31} per cm^2 per s. 'Mini-beta' projects are under discussion to push the luminosity higher at some interaction points.

(Photo Joe Faust)

tation which will be of use in compiling the history of CERN.

Urged on by the American Institute of Physics, several of the high energy physics Laboratories in the USA have fairly recently launched 'history' projects. At Brookhaven, science historian Alan Needell began to examine archival needs in 1977 and last year a History Committee was set up under the chairmanship of John Binnington. Bob Wilson set up a History Committee at Fermilab in 1977 and Lillian Hoddeson joined as part-time historian/archivist a year later. The Laboratory has a lecture series on the history of accelerator physics. At Berkeley, Vicki Davis has been in place since 1978 as archivist and a History Committee has been set up. At Argonne, Helen Harman and Don Wood have been gathering data for a written history of the Laboratory.

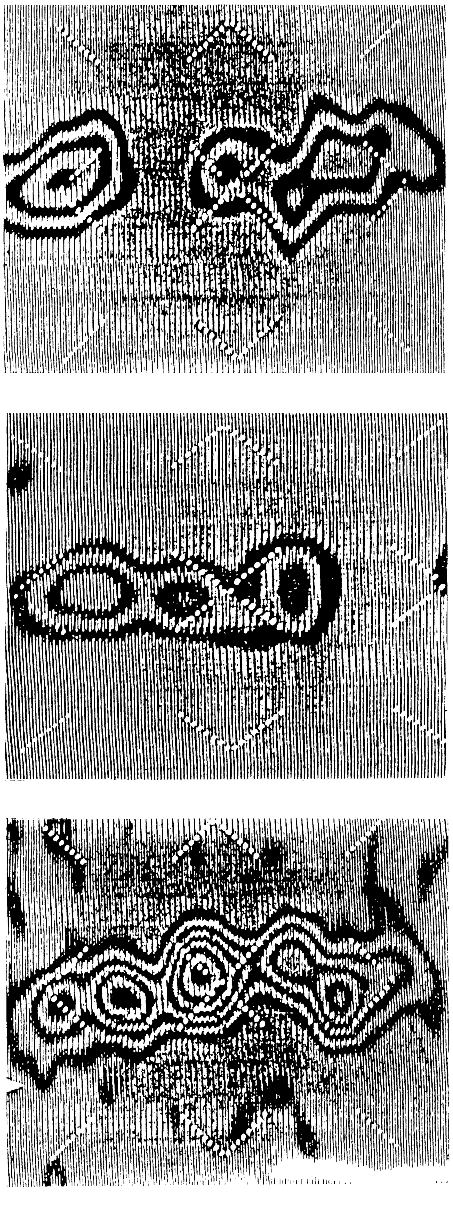
'Technical' visitors to CERN

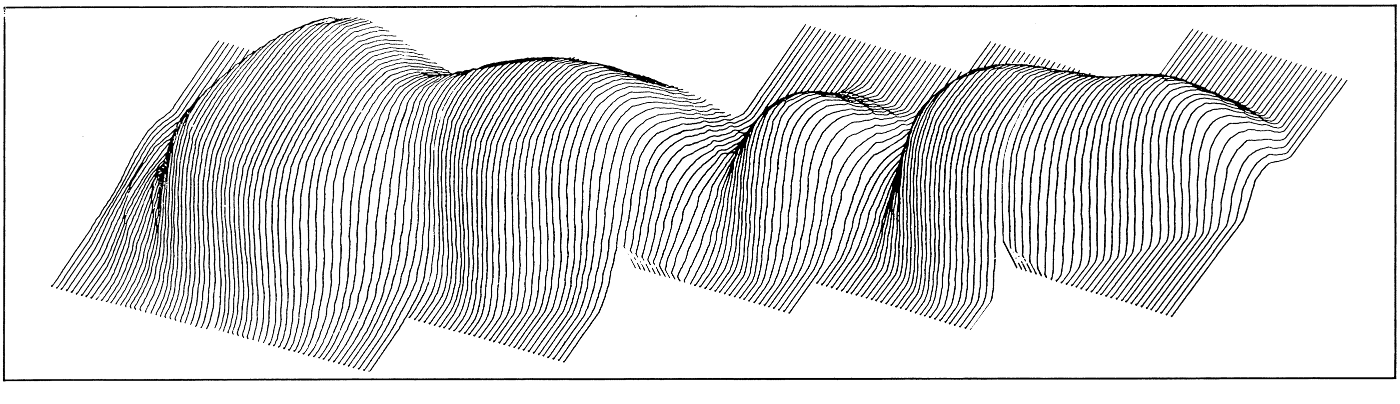
A few years ago the National Norwegian CERN Committee proposed that CERN might open its doors also to visitors from technical fields in the Member States. The idea is that visitors spending up to a year working in a CERN group, which is doing some front-line work in a technological field, will benefit personally and will carry further expertise back to the home country.

Two visitors, financed from Norway, have now had short stays at CERN. Arild Jansen, the computer manager from the University of Oslo, spent a month in the Data Handling Division working in the computer centre. Erik Hoff-Hansen, from the Norwegian Central Institute for Industrial Research, spent three months in the SPS Division working on advanced computer control systems.

100 GeV e^+e^- workshop at Cornell

A two-day workshop was held at Cornell in November to introduce the high energy physics community to the design of a new 50 GeV electron-positron storage ring aimed at neutral intermediate boson physics. This new storage ring is being considered as the next effort at Cornell. Potential users of such a facility were invited to Cornell to participate in the first of a series of workshops on experiments, detectors and experimental services. Early involvement of the user community is sought so that machine design may be tailored as closely as possible to experimental needs. The storage ring design is optimized with the use of superconducting r.f. cavities to reach a centre-of-mass energy of just over 100 GeV and a peak luminosity of 3×10^{31} per cm^2 per s. The workshop was attended by





A Bologna / CERN / Frascati collaboration working at the CERN SPS has searched 200 000 neutrino interactions for signs of fractionally-charged quarks, which would show up as tracks with low ionization. Scanning was assisted by automatic devices which produced the pictures seen here. Charged particle tracks show up as a series of blobs on the film from the large avalanche chamber. The PEPR computer-assisted measuring device at Frascati produced these images of the blobs, each of which is in reality about 800 microns across. The analysis can be extended to produce a density profile of the blobs along a track (below).

about. 150 physicists from the USA and Canada. Chris Quigg from Fermilab and Stan Brodsky from SLAC gave elegant previews of the physics waiting to be explored at 100 GeV.

Meetings

The 5th High Energy Heavy Ion Study will be held at the Lawrence Berkeley Laboratory from 18–22 May. The Study will consist of a fairly relaxed schedule of talks and discussions, with the focus on recent experimental and theoretical results concerning heavy ion collisions from 20 MeV/nucleon up to colliding beam and cosmic ray energies. Particular emphasis will be placed on defining the new directions of research which will be opened up with the completion of the Bevalac upgrading to GeV/nucleon uranium beams. Further information can be obtained by contacting Lee Schroeder, Building 70-257, Lawrence Berkeley Laboratory, Berkeley, California 94720, USA.

The 1981 CERN-JINR School of Physics will be held at Hanho, Finland from 6–19 June. The aim of these schools, of which this will be the seventh in the series organized by CERN in collaboration with Dubna, is to teach various aspects of high energy physics, and especially theoretical physics, to young experimental physicists mainly from the Member States of the Laboratories. Further information can be obtained from Miss D. Caton, Scientific Conference Secretariat, CERN, CH-1211 Geneva 23, Switzerland or A.I. Romanov, Joint Institute for Nuclear Research, Head Post Office, P.O. Box 79, 101000 Moscow, USSR.

More on proton scattering

A very thorough polarization experiment for the direct determination of the amplitude in proton-proton elastic scattering has been carried out at the SIN cyclotron. At medium energy, these spin dependent amplitudes are large and of the same magnitude as the spin-independent amplitudes. The direct determination, at several angles and several energies, of the five complex scat-

Seasonal activities at CERN: (above) the traditional childrens' Christmas Party, and (below) Theory Division's Christmas Show, fast becoming traditional.

(Photos CERN 216.12.80 and 539.12.80)

tering amplitudes without using any model such as a phase-shift analysis is a longstanding problem. The problem has become even more interesting in the light of the possible existence of dibaryon resonances.

An experimental programme on proton-proton scattering is presently being conducted at SIN by Geneva University. Fifteen different polarization parameters have been determined at 579 MeV between 60° and 90°. These data give the scattering amplitudes up to an overall phase.

DORIS workshop

A workshop is being held at DESY on 10-11 February to discuss the physics with the 2 × 5 GeV electron-positron DORIS storage ring and potential DORIS improvements. The latest experimental results on heavy quark systems including the B-mesons will be presented together with the theory. Those wishing to participate should contact H. Schröder at DESY.

More carbon ions

Following improvements in the ion source of the CERN 600 MeV synchro-cyclotron, the operational intensity of the $^{12}C^{4+}$ *ion beam at an energy of 85 MeV/nucleon has been doubled since the previous run a year ago, to reach* 5×10^{11} *ions per s. The first carbon ion beam was obtained in August 1979 (see November 1979 issue, page 355).*

Accelerator Conference Proceedings

The proceedings of the 11th International Conference on High Energy Accelerators held at CERN from 7-11 July 1980 have now been published. Edited by W.S. Newman, *the single 940-page volume contains over 120 invited and contributed papers and summaries of panel discussions. It can be obtained from the publishers Birkhäuser Verlag, Elisabethenstrasse 19, CH-4010 Basel (also at Boston and Stuttgart) at the price of SFr 174, DM 186 or $112.*

Interregional use of accelerators

As an appropriate 'Goodwill to all men' message in this first issue of the New Year we reproduce the guidelines proposed by the International Committee for Future Accelerators for the 'interregional utilization of major regional experimental facilities for high energy particle physics research'. This is one of the themes that ICFA has pursued for several years and it has been presaged for example by recommendations of the Fermilab Physics Advisory Committee and of the European Committee for Future Accelerators (see March 1980 issue, page 12).

ICFA made its proposal considering that, in the future, major experimental facilities for high energy particle physics research (notably the large particle accelerators and colliding beam machines) are likely to be few in number. There will probably be only one of each type covering very high energies and the machines will be located in different regions of the world. Nevertheless experimental physicists from all regions may wish to gain access to any of these machines in order to pursue their particular interests. ICFA proposed that the regional Laboratories operating these facilities should adopt a common policy toward experimental physicists from other regions. The guidelines proposed are as follows:

1. The selection of experiments and the priority accorded to them are the responsibility of the Laboratory operating the regional facility.

2. The criteria used in selecting experiments and determining their priority are:
(a) scientific merit
(b) technical feasibility
(c) capability of the experimental group
(d) availability of the resources required.

3. It is expected that teams from other regions will normally wish to join with local regional teams to form experimental groups in proposing and carrying out experiments using a regional facility. The national or institutional affiliations of the teams should not influence the selection of an experiment nor the priority accorded to it.

4. The availability of the resources needed for the experiment are examined at the time of selection of the experiment. The contributions of each team and of the operating Laboratory to an experiment are the subject of agreements drawn up between the operating Laboratory and the authorized leaders of the teams in the experimental group. When appropriate, realization of the proposals approved may be effected within the framework of bilateral and multilateral agreements in force or newly reached arrangements.

5. Operating Laboratories should not require experimental groups to contribute to the running costs of the accelerators or colliding beam machines nor to the operating costs of their associated experimental areas.

6. It is expected that averaged over a reasonable period of time the application of guideline 2. above will lead to a balanced use of the major new facilities by the regions concerned. However, if at any time an operating Laboratory finds that the participation of teams from other regions in their experimental programme is becoming excessive, the operating Laboratory may be obliged to limit that participation. Any such action should be accompanied by discussions with the relevant authorities of the regions concerned and consultations with the other operating Laboratories subscribing to the guidelines.'

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The Lawrence Berkeley Laboratory is a multi-purpose research laboratory funded by the Department of Energy. Its Physics, Computer Science, and Mathematics Division conducts a multimillion dollar research program, chiefly in high-energy physics. The Associate Director and Head of the Division has primary responsibility for the leadership and management of this program under the general direction of the Laboratory Director. Candidates must have had significant experience as practicing high-energy physicists and be of the general calibre of persons holding senior tenure positions in major research institutions. Appointed as a permanent Staff Senior Scientist, the successful applicant would be expected to serve in the administrative role of Associate Director and Head of Division for an initial term of 3 to 5 years, subject to renewal for further terms by mutual agreement.

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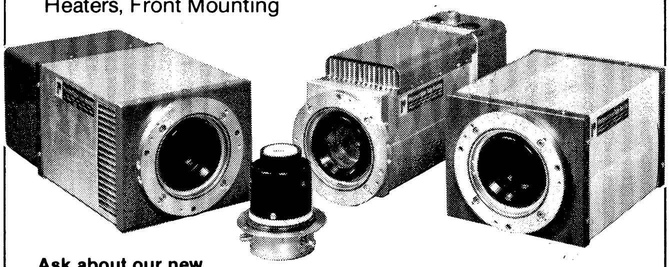

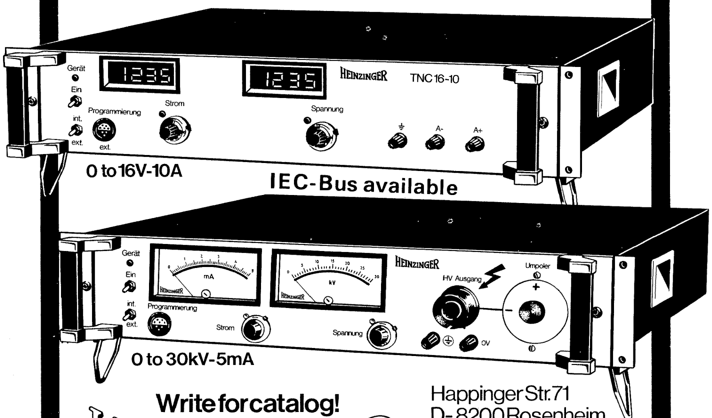
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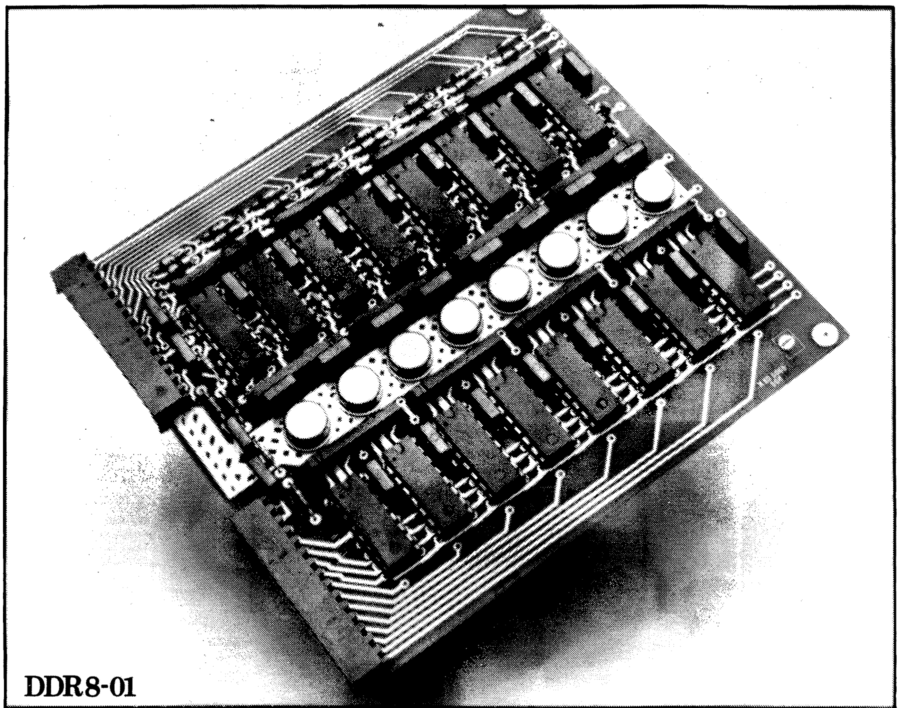

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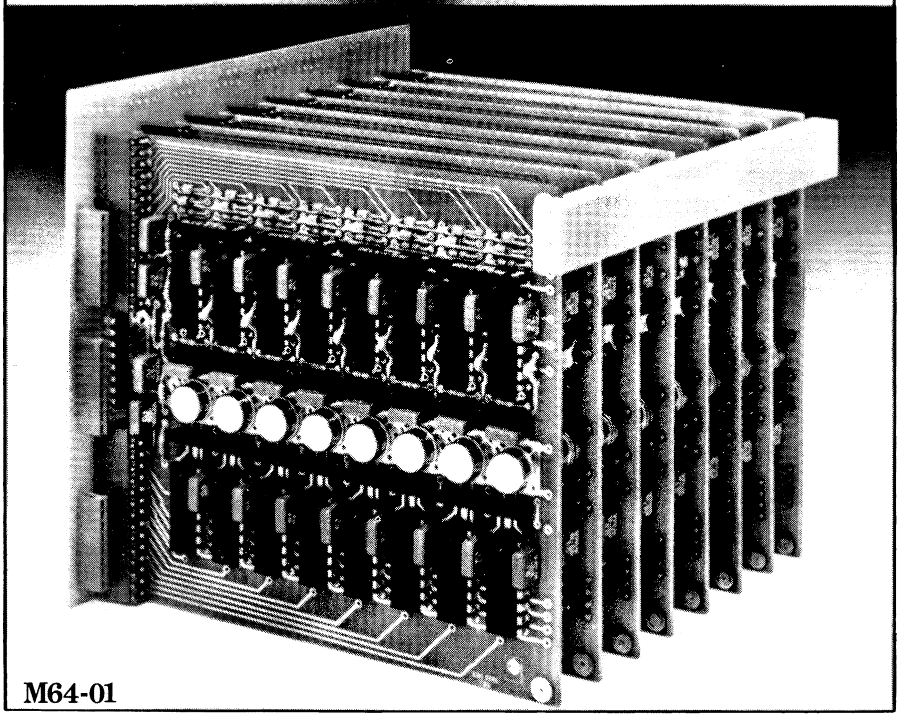

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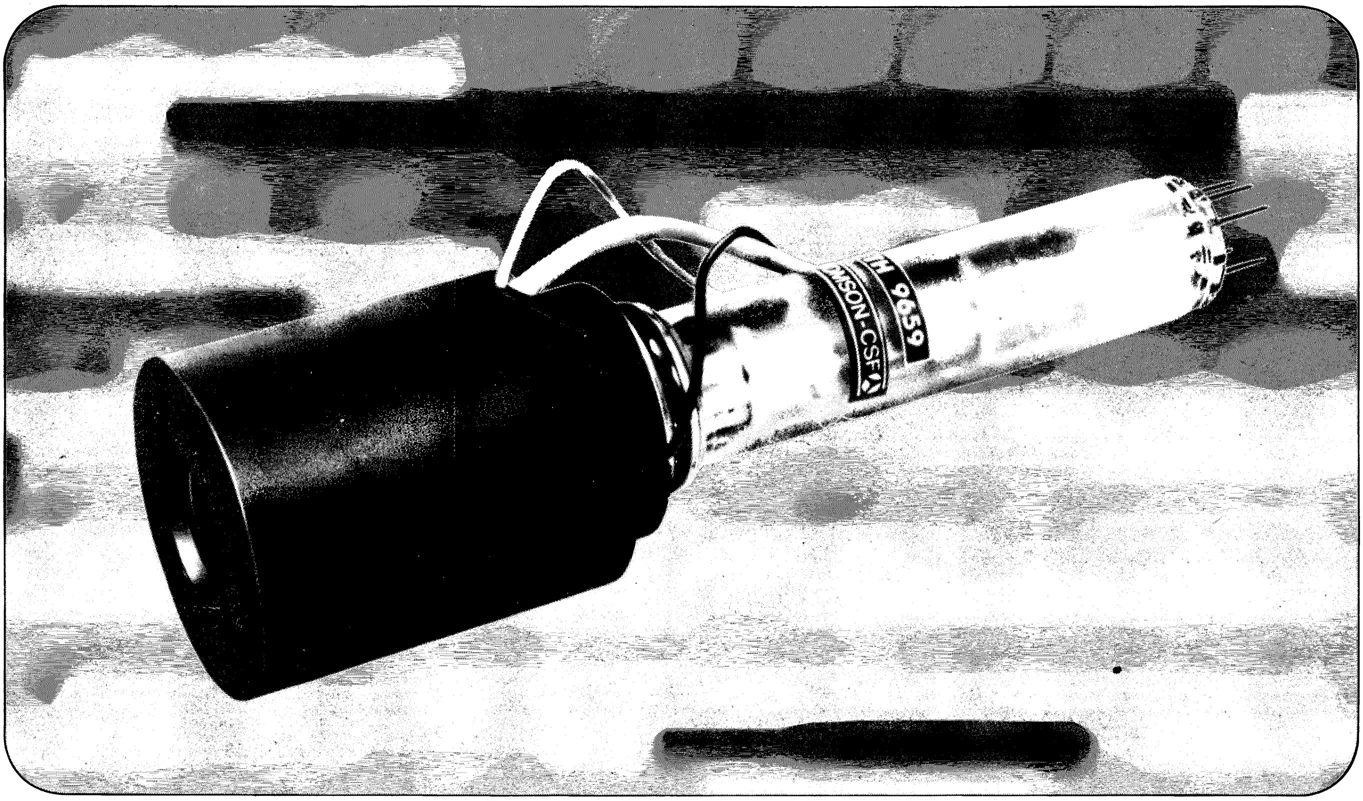
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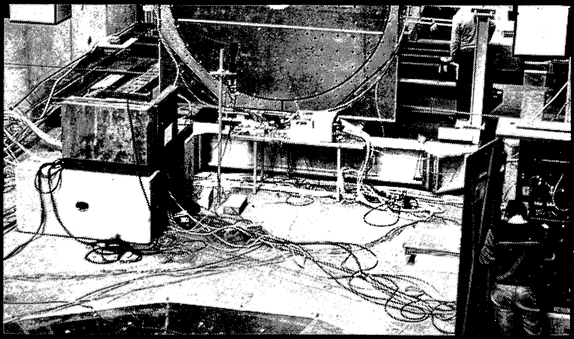

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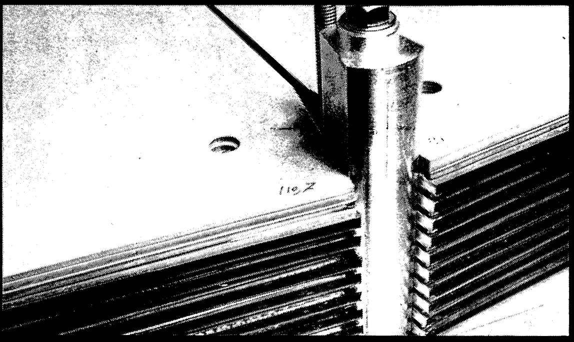

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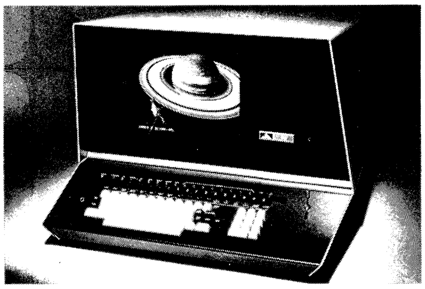

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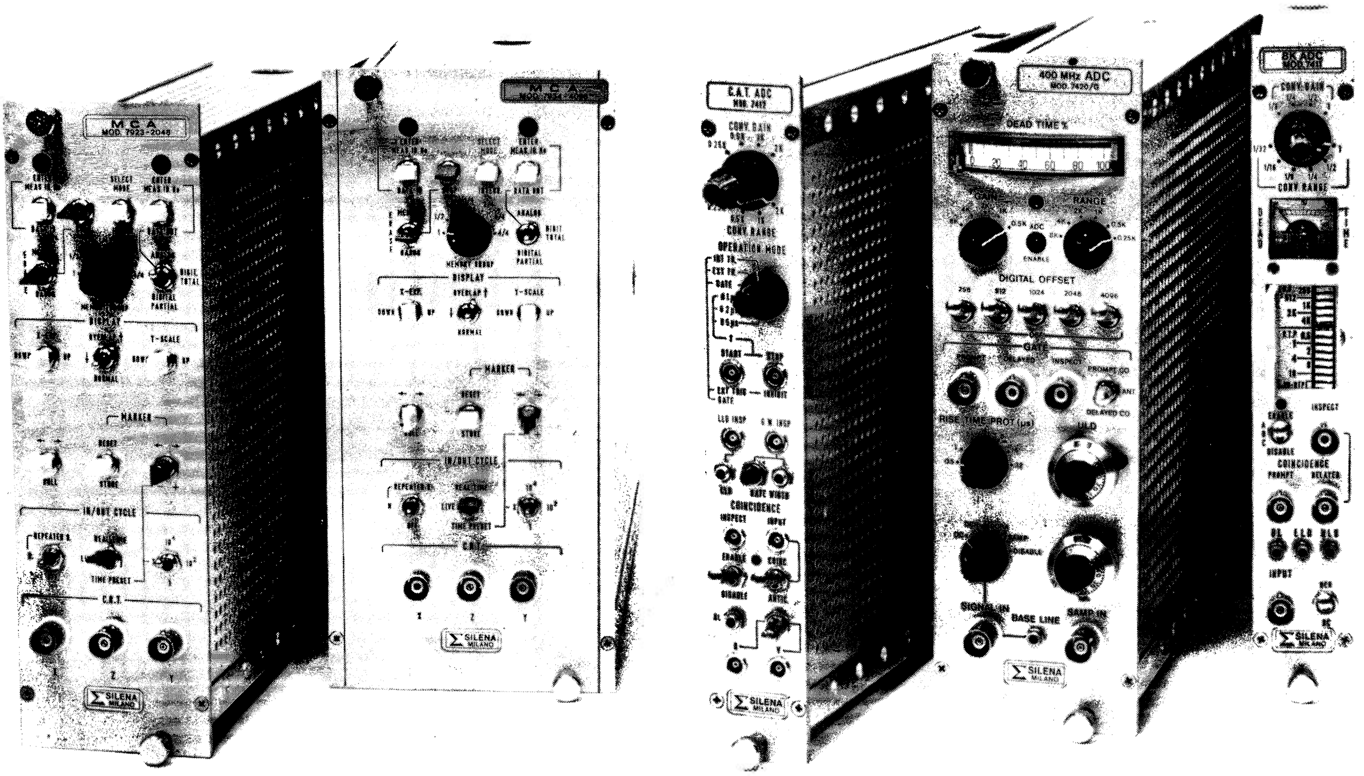

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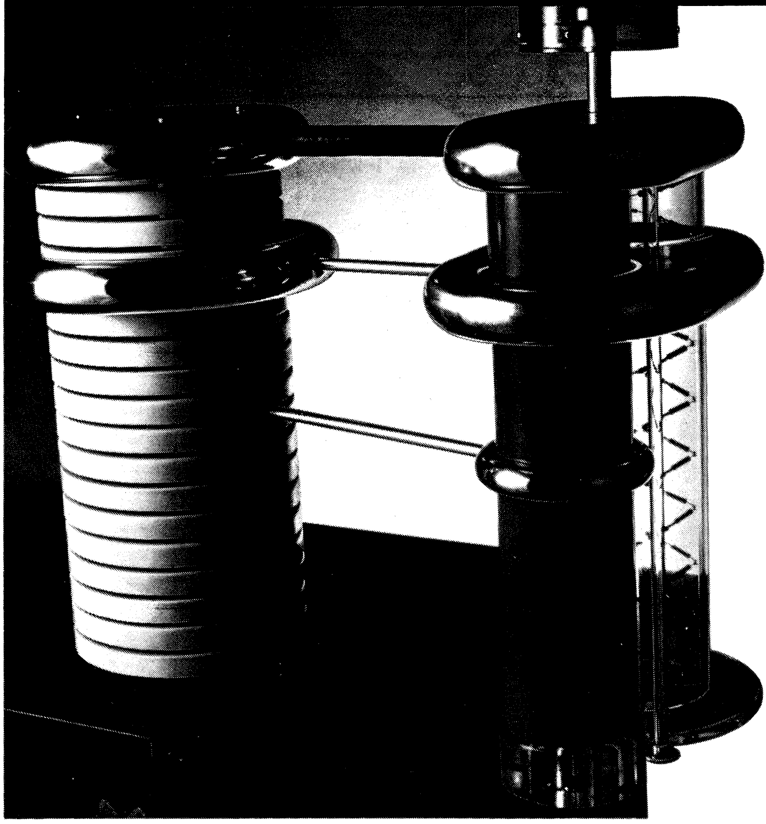

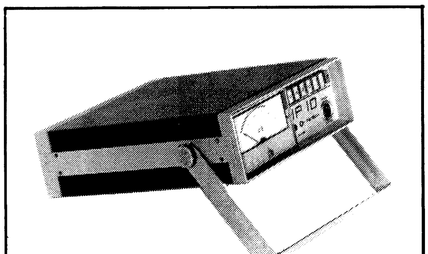
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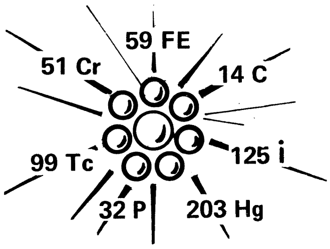
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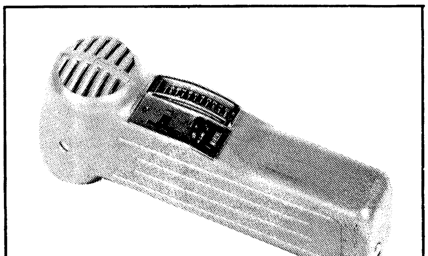

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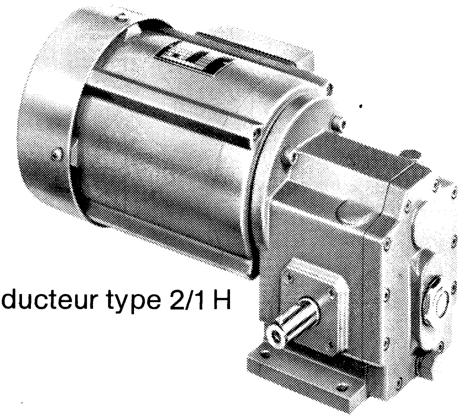

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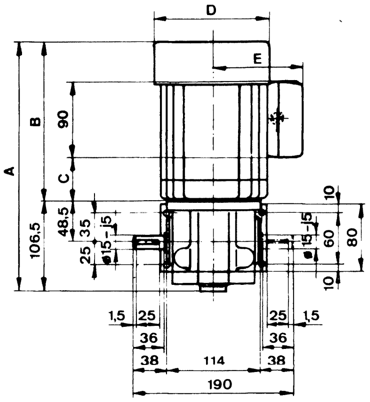

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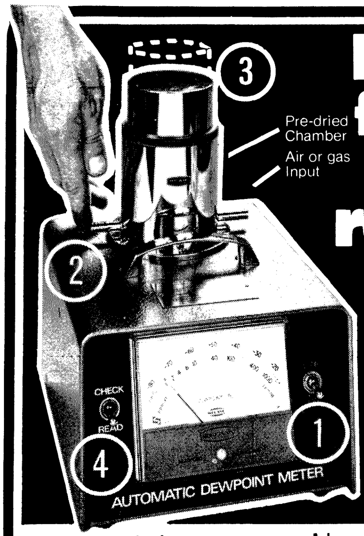

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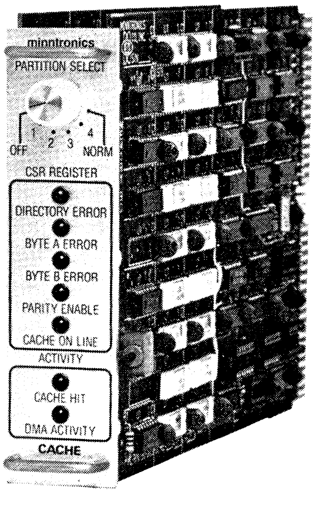

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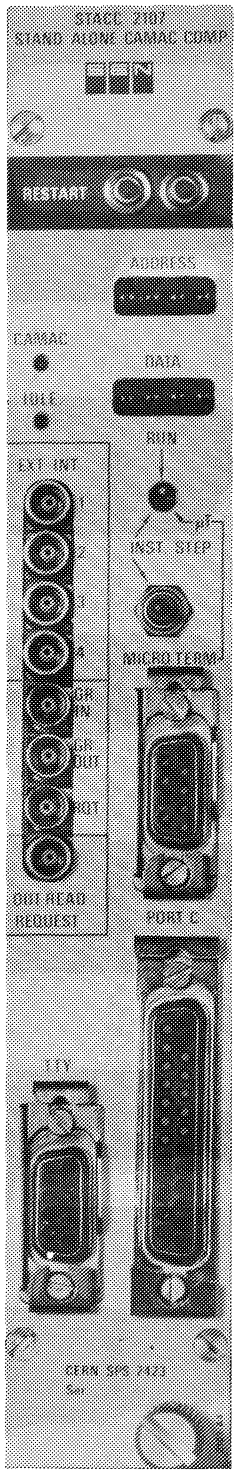

- ★ **Powerful 16 bit microprocessor**
- ★ **High speed CAMAC operations**
- ★ **CAMAC stations treated as memory addresses**
- ★ **16 K – 16 bit RAM memory of which upto 12 K can be replaced by EPROM**
- ★ **Teletype and two RS 232 C interfaces**
- ★ **Allows Auxiliary Crate Controllers connection for multi-processing application**
- ★ **Only two units wide**
- ★ **Powerful high-level interpreter either EPROM resident or floppy-disc resident with disc file support**
- ★ **Software compatible with ACC 2099/ACC 2103**

GENERAL DESCRIPTION

The STACC 2107 (Cern SPS 2423) is a new microprocessor based unit using the 16 bit texas TMS 9900 microprocessor.
It provides autonomous computing power at the CAMAC level for stand-alone systems.
A link to a host computer is provided through RS232C I/O ports.
The CPU card contains the CPU, the dual port RAM memory, the TTY interface and the I/O bus connectors. The control station card contains the N/L drivers, the EPROM section, the two RS232C interface and a programmable LAM grader.
Debugging of programs is made easy with a front panel data/address display and a step by step push button.

For ease and efficiency of programming, CAMAC stations accessed as if they were memory addresses of the TMS 9900's 32 K word address-range, addresses below 16 K are always interpreted as references to the physical memory, whereas those above 16 K are interpreted as addresses and functions of CAMAC stations.
A console for program control and I/O can be connected through a serial port (current loop) on the front panel.
A floppy disc can be attached to one of the RS232C ports.
Inputs for up to 4 real time signals are provided on the front panel.

SOFTWARE

The standard software consists of a high level NODAL interpreter which is very similar to Basic but provides much more flexible I/O and contains a line editor. This interpreter is supplied either on EPROM or as a floppy disc if the STACC 2107 is used with a floppy disc drive connected to one of the RS232C attachments.

A debugger-loader is also available for assembly written programs.
The debugger allows the user to examine and/or modify RAM memory, to insert a break-point and to start execution of programs stored in RAM or ROM.

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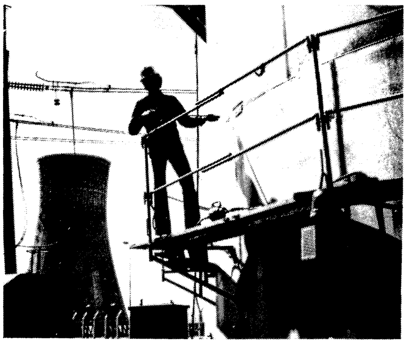

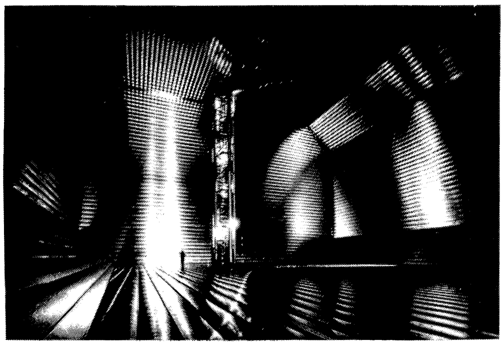

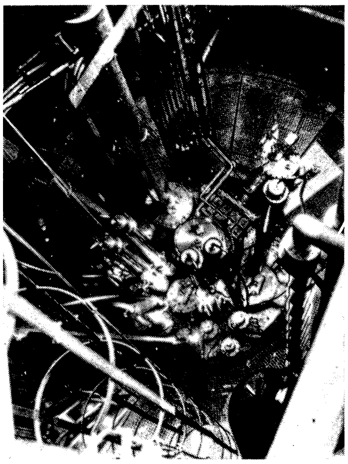

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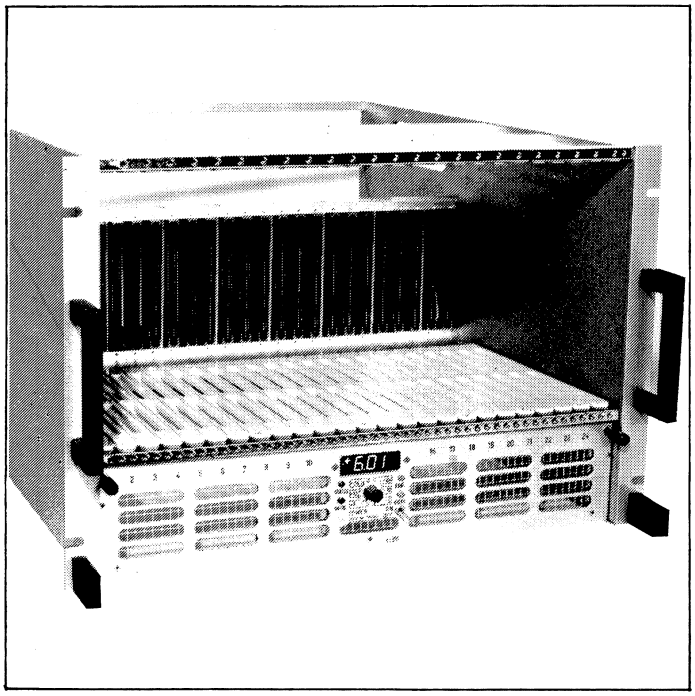

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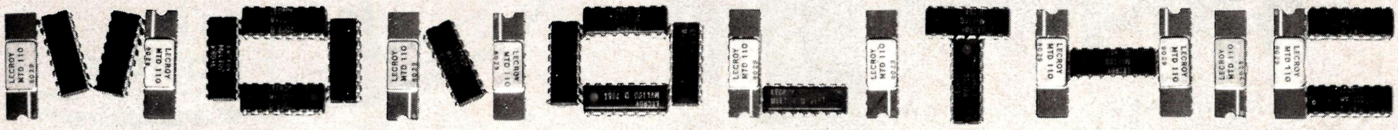

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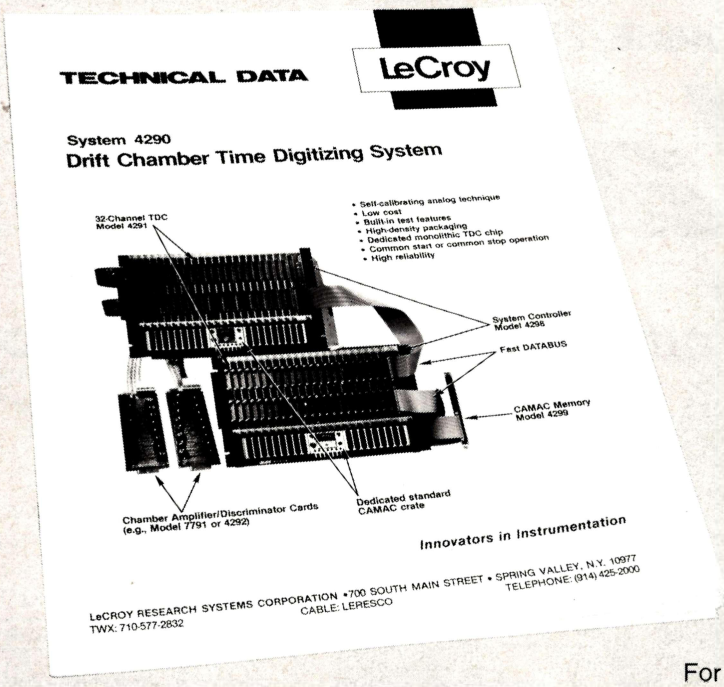

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System 4290
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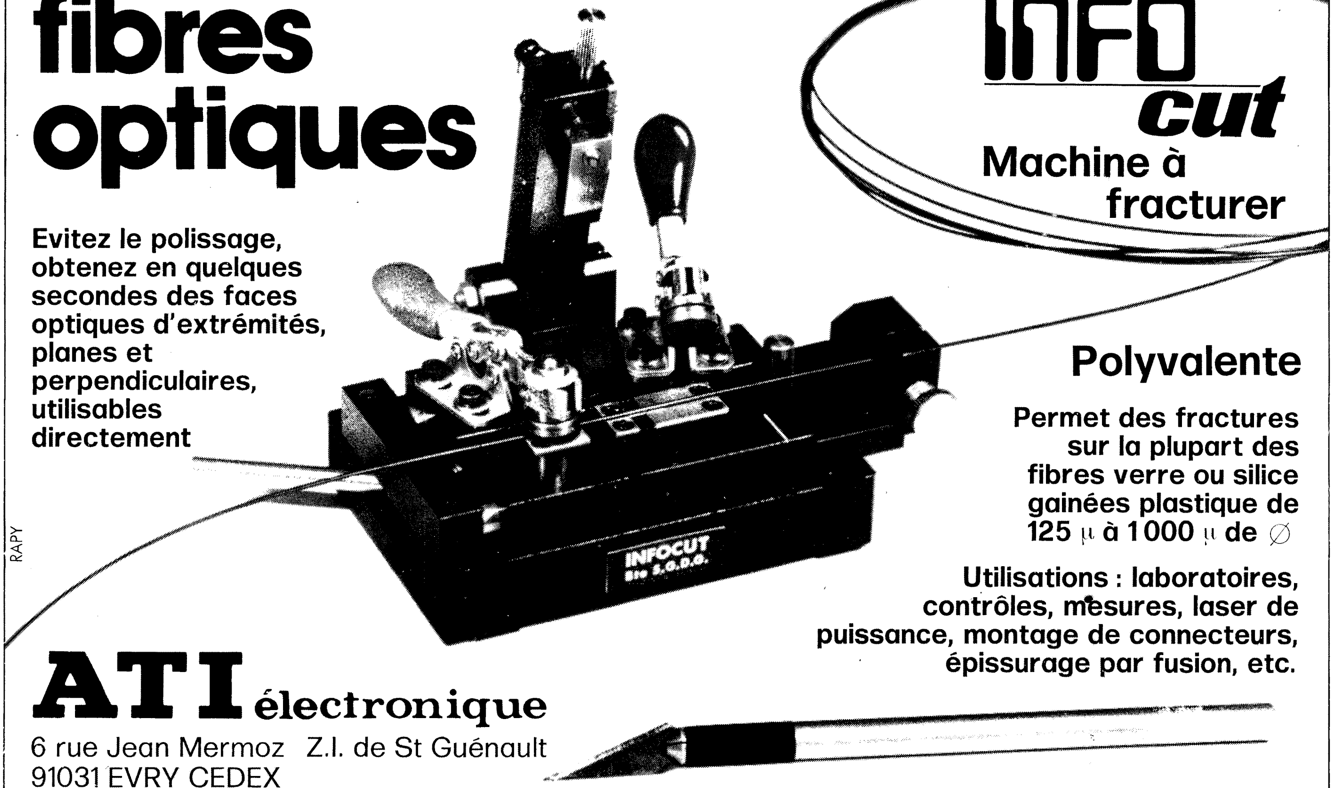
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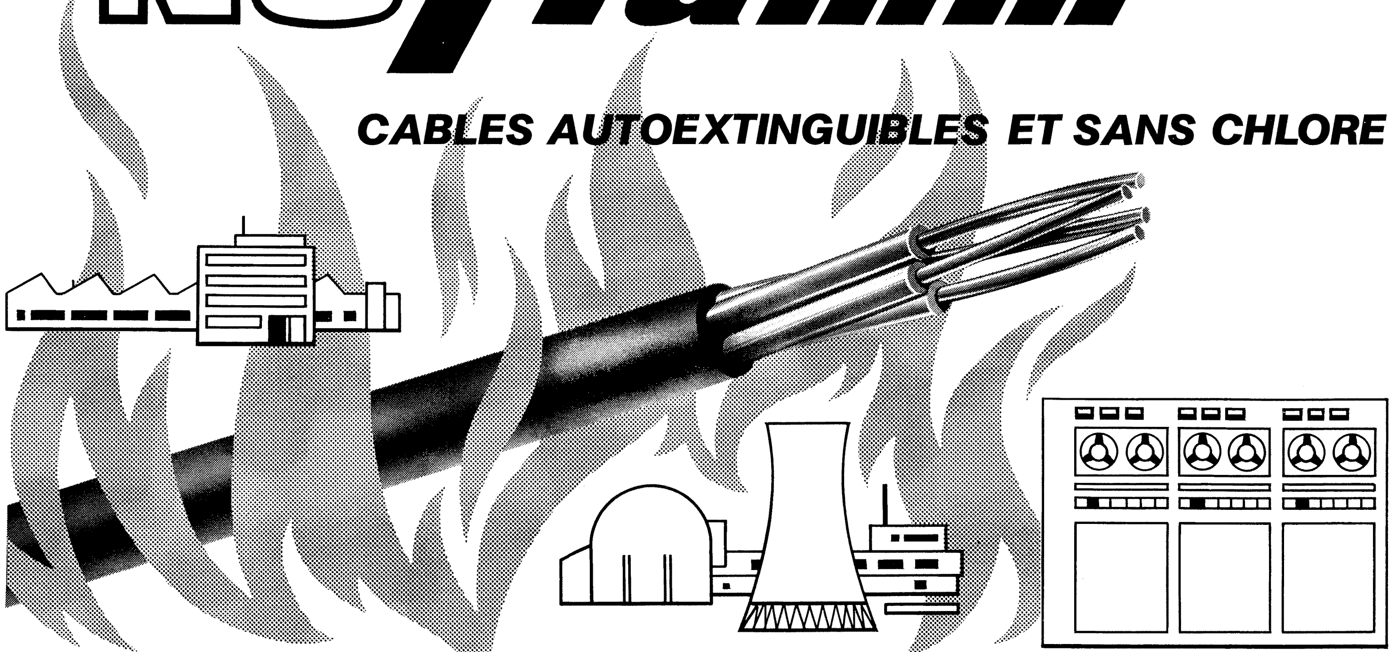

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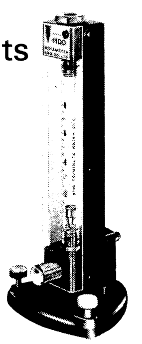

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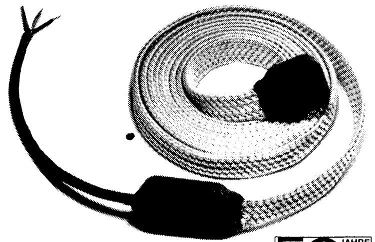

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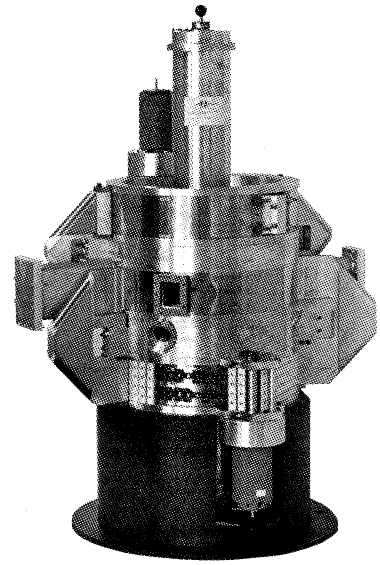

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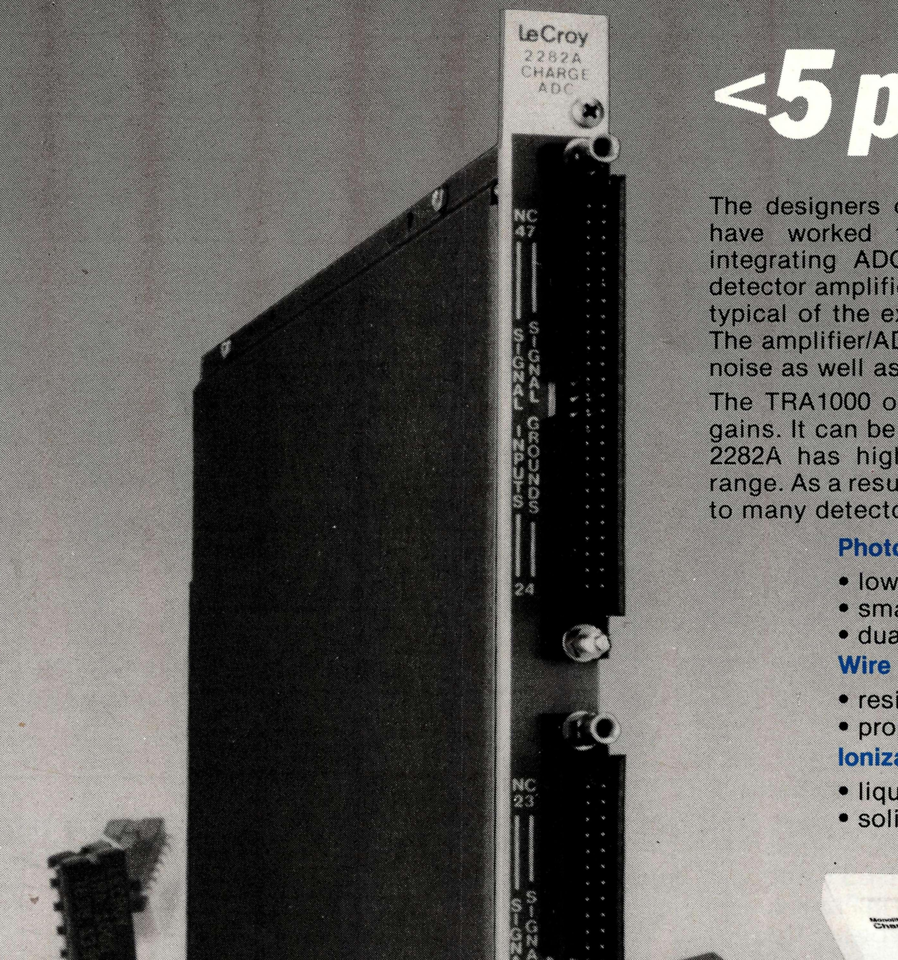

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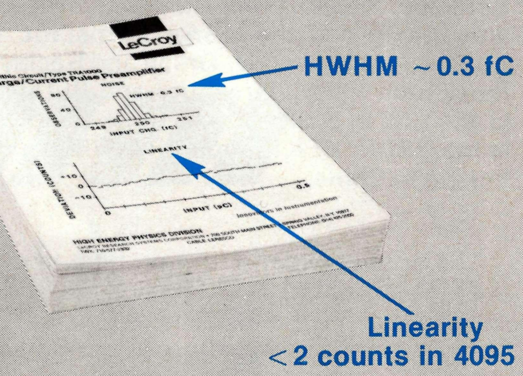

Contact your local LeCroy representative for complete details. A technical brochure is available on **System 2280** describing three different ADC's and the data preprocessing scheme. The data sheet on the **TRA1000** gives complete information and test results on 14 ADC/amplifier configurations.

2282A Multichannel ADC
48 ADC's per #1 CAMAC
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TRA1000 Monolithic Transimpedance Amplifier
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charge-to-voltage operation

LeCroy

Headquarters: 700 S. Main St., Spring Valley, N.Y. 10977. Offices: Chicago, (312) 626-6726; New England, (603) 483-8755; New York, (914) 425-2000; Palo Alto, (415) 856-1806: Geneva, Switzerland, (022) 98 97 97; Heidelberg, W. Germany, (06221) 28192; Hamburg. W. Germany, (040) 54 2713; Orsay, France 907.38.97; Botley, Oxford, England.
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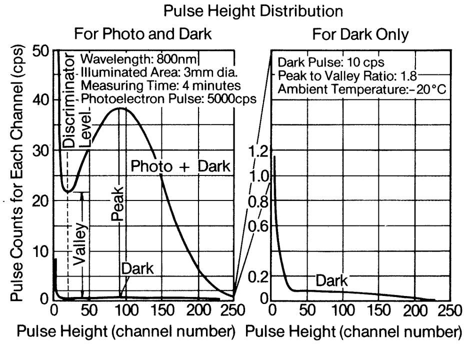
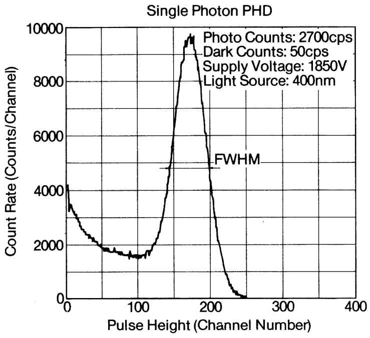
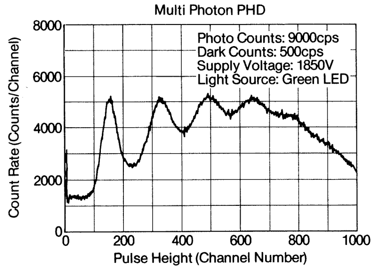
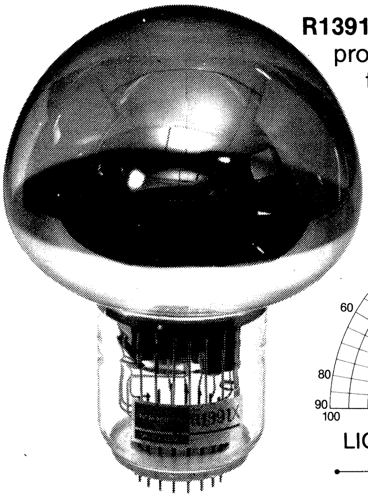
R943
02

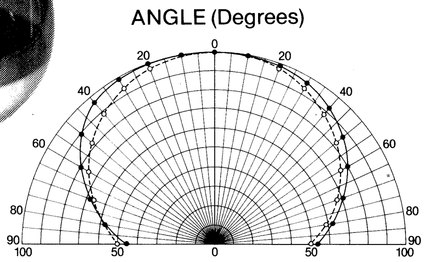

Pulse Height Distribution
For Photo and Dark
For Dark Only
Wavelength: 800nm
Illuminated Area: 3mm dia.
Measuring Time: 4 minutes
Photoelectron Pulse: 5000cps
Dark Pulse: 10 cps
Peak to Valley Ratio: 1.8
Ambient Temperature: -20°C
Discriminator Level
Valley
Peak
Photo + Dark
Dark
Pulse Counts for Each Channel (cps)
Pulse Height (channel number)
0
10
20
30
40
50
100
150
200
250
0.2
0.6
0.8
1.0
1.2

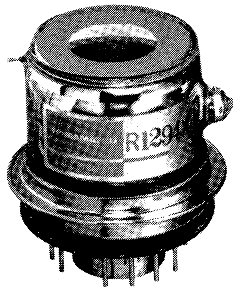

R1262X

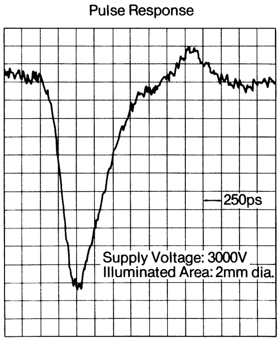

Single Photon PHD
Photo Counts: 2700cps
Dark Counts: 50cps
Supply Voltage: 1850V
Light Source: 400nm
FWHM
Count Rate (Counts/Channel)
Pulse Height (Channel Number)
0
2000
4000
6000
8000
10000
100
200
300
400

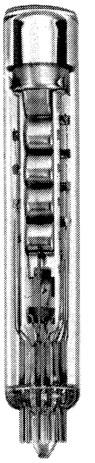

Multi Photon PHD
Photo Counts: 9000cps
Dark Counts: 500cps
Supply Voltage: 1850V
Light Source: Green LED
Count Rate (Counts/Channel)
Pulse Height (Channel Number)
0
2000
4000
6000
8000
200
400
600
800
1000

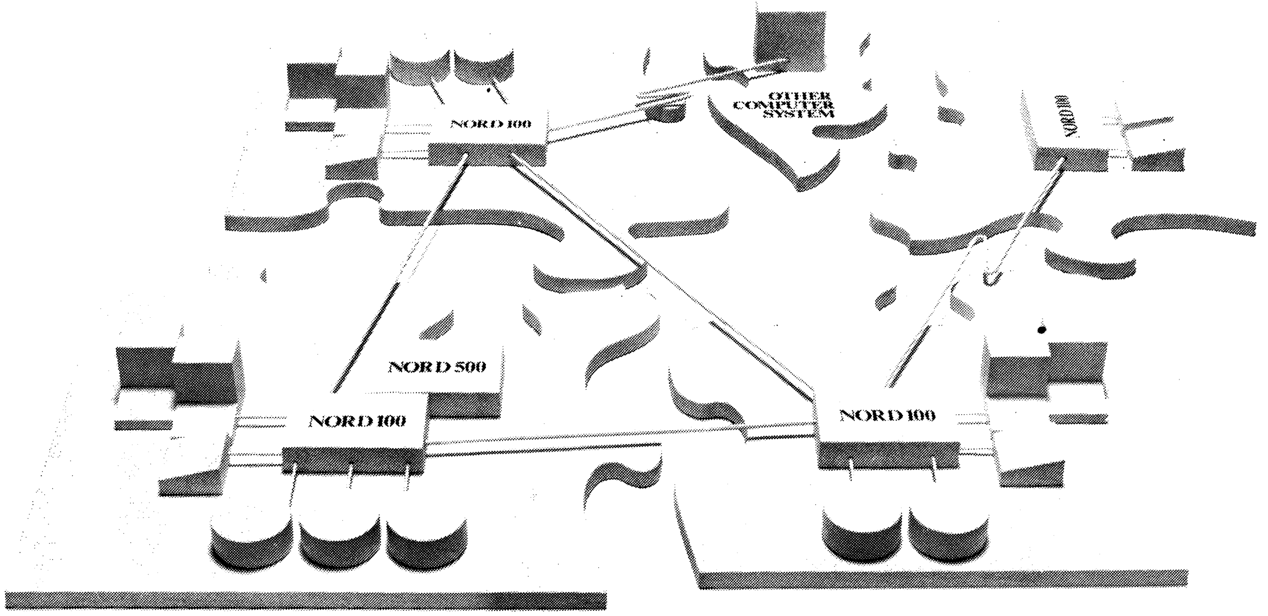

R1391X

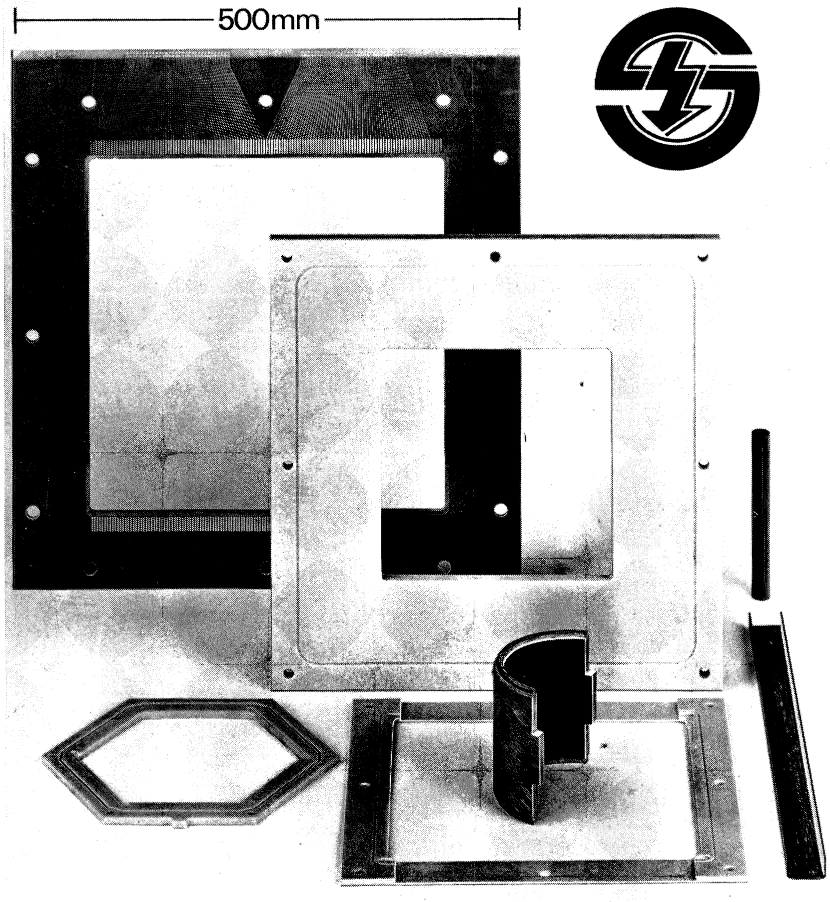

ANGLE (Degrees)
0
20
40
60
80
90
100
50

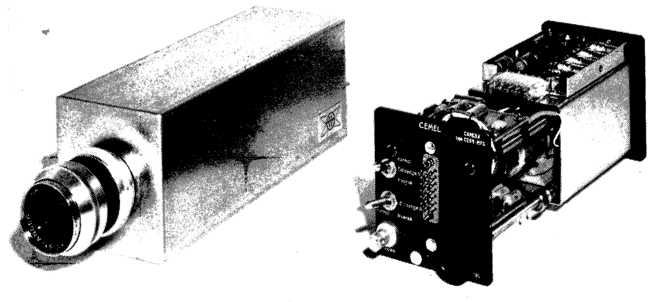

R1294

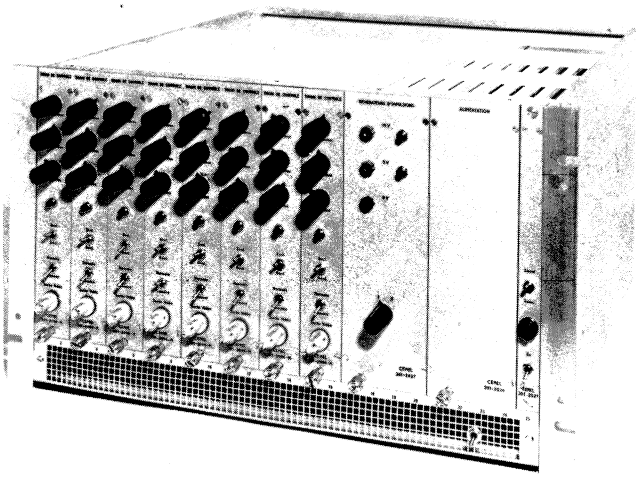

Pulse Response
250ps
Supply Voltage: 3000V
Illuminated Area: 2mm dia.




NORD 100
OTHER COMPUTER SYSTEM
NORD 100
NORD 500
NORD 100
NORD 100


500mm





OCTOBER 1980
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EIMAC 8973 tetrodes helped bring fusion power a step closer at Princeton.

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On August 5, 1978 scientists at Princeton University Plasma Physics Laboratory succeeded in heating a form of hydrogen to more than 60 million degrees Celsius and produced the highest temperature ever achieved in a TOKAMAK device—four times the temperature of the interior of the sun, thus bringing fusion power a step closer for mankind.

EIMAC tetrodes for switching and regulating.

Four EIMAC super-power 8973 (X-2170) tetrodes were used to control and protect the four sensitive neutral beam sources in this scientific achievement. The next experiment in this series (PDX) will also utilize EIMAC 8973 tetrodes to control the neutral beam sources. The EIMAC 8973 is also being used at Oak Ridge National Laboratory, another major research facility involved in the Department of Energy's program to develop practical fusion power. The 8973 is a regular production tube designed for high power switching and control by EIMAC division of Varian.

January 1980

EIMAC 8973 provides over one megawatt CW power output at 78 MHz with 14 dB stage gain.

For information

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Offices throughout the world.

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