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*Cover photograph: Scintillation counter (about 25 cm diameter) prepared at CERN for an experiment at the Saclay 600 MeV electron linac studying molecular processes provoked in liquid hydrogen by muons. The bizarre form comes from the scintillator's role as an anticoincidence counter surrounding a sodium iodide crystal which detects gammas emerging from the hydrogen. The experiment is a CERN/Saclay collaboration which uses the linac so as to take advantage of the time structure of the electron beam. (Photo CERN 15.7.77)*

# Gauge theories with the lid, partially, off

In the brief coverage of gauge theories and their relevance to 'forbidden' muon decays, which appeared in our March issue, we did not trace their evolution in much detail nor did we do justice to the work of the many physicists who have participated in their development. This fuller account enables us to fill in some of the gaps and to indicate why gauge theories have such an important role in particle physics.

The oldest gauge theory is the theory of electromagnetism, which is formulated in terms of the electric field and of the magnetic field obeying Maxwell's equations. It is convenient in using the theory to introduce the electric potential (and a corresponding vector potential for the magnetic field) in terms of which the corresponding electric field is obtained by differentiation.

While the fields are directly observable, only differences of potential have a physical meaning. Therefore the equations of Maxwell determine only potential differences and not absolute values of electric potentials. Another way to say this is that the equations remain invariant if one changes all the potentials for example by adding to them the gradient of an arbitrary 'gauge' function. Such a change is called a 'gauge transformation' and Maxwell's equations are said to be 'gauge invariant'.

The principle of gauge invariance remains valid when considering the interaction of the electromagnetic field with charged particles, such as electrons or protons. In that case the phase of the wave function of the charged particle must also be changed by an amount proportional to the same gauge function. Quite generally gauge invariance requires the presence of a vector field (the gauge field) in the theory.

The word gauge to denote these transformations comes from a suggestion once made by Hermann Weyl that

the change in the electromagnetic potentials should correspond to a change in the standard of length, which he assumed could vary from point to point. This picture is now known to be incorrect and Weyl himself recognized that the gauge transformations are instead connected with changes in the phase of the wave functions of charged particles. The name, however, stuck and is now used to denote any transformation characterized by arbitrary functions, as opposed to transformations depending on a finite number of parameters. A rotation, for example, would not be called a gauge transformation because it is characterized by only three parameters (three angles).

Invariance of the laws of physics under transformations, both of the gauge type and of the type depending on a finite number of parameters, is very important. Clearly, it restricts the form of the physical laws themselves and also makes it possible to deduce all sorts of properties of the solutions of the equations, even without actually finding those solutions.

The simple gauge transformations of electrodynamics were generalized in 1954 by Chen Ning Yang and Robert Mills and, independently, by R. Shaw. The constituents of the atomic nucleus, proton and neutron, can be considered as two possible states of the same particle — the nucleon. If one neglects relatively weak effects, in particular those due to the electric charge, protons and neutrons have the same interactions. The equations governing their behaviour are then invariant under a transformation, called an isospin rotation, which transforms the proton into the neutron and vice versa. The word spin in isospin is used because of the analogy with the spin of the electron (or of any particle having spin one-half) — just as the spin can have one of two orientations, up or down, so the isospin is capable of two orientations, one corresponding to the

*A proton will attract an electron with the same force whether the force is measured under 'normal' conditions or in a laboratory raised to a high constant potential. The theory of electromagnetism, historically the first of the gauge theories, reflects this since it says something only about potential differences. This changing of the circumstances in which the proton-electron measurement is carried out is one example of a gauge transformation and the laws which govern the proton-electron attraction are said to be gauge invariant.*

neutron and the other to the proton.

Yang and Mills had the idea that the isospin orientation, and therefore the parameters of an isospin rotation, should be allowed to depend on position and time. In other words, they made the isospin rotations into transformations depending upon arbitrary functions (gauge transformations). Just as in the case of electromagnetism, this requires the introduction of a potential described by a vector gauge field.

In general, performing two rotations in space one after the other gives a different rotation as a result, depending upon the order in which the two rotations are performed; the same is true for two isospin rotations. This is acknowledged by saying that the isospin transformations form a non-Abelian group — in Abelian groups the result is independent of the order. The corresponding gauge theory is called a non-Abelian gauge theory.

There was no immediate flow of physics from the work of Yang and Mills but this pioneering contribution has been the starting point for much of the work which came later, although the present physical interpretation of what Yang and Mills were considering is somewhat different.

After the work of Yang and Mills, a number of attempts were made at formulating a unified theory of weak and electromagnetic interactions. The idea was not new — the very first weak interaction theory, Enrico Fermi's theory of beta decay, was based on an analogy with electromagnetism. Later, this analogy was made even more precise by introducing the idea of the intermediate boson. In the same way that electromagnetic interactions between charged particles come out as a result of photon exchanges, so weak interactions between particles could be understood as resulting from exchanges of something else (given the name intermediate vector boson).

The main defect of this theory was that, although the basic phenomenology was correctly described, it was impossible to make more refined predictions because calculations of higher order corrections resulted in infinities. This is to be contrasted with the theory of electromagnetism, where there exists a well defined procedure for calculating higher order corrections without encountering infinities — the renormalization method, which allows theoretical predictions to be made (and verified experimentally) with very high accuracy. A striking example is that of the CERN measurement of the anomalous magnetic moment of the muon where agreement between theory and experiment is to one part in a hundred million.

The difference between the two theories was of a technical nature, but very important. The electromagnetic theory is a renormalizable theory; the weak interaction theory was, at this stage, a non-renormalizable theory. The natural goal was the formulation of a renormalizable unified theory of the electromagnetic and the weak interactions based on a (non-Abelian) gauge principle but, for a long time, it was not clear that it could be done.

Since the weak interactions are short range, the exchanged in-

termediate vector boson must have mass. This is the basic reason for the incurable divergences of the theory, which gave the infinities in the calculations, and it turned out that a very clever trick had to be used in order to circumvent the problem.

In a theory which is strictly gauge invariant, the vector gauge bosons have zero mass. It is now known that such a theory is renormalizable, but it took many years of very difficult theoretical work before this was shown by Gerard 't Hooft. Among other things, it needed the formulation of the correct rules of calculation for non-Abelian gauge theories, analogous to the Feynman rules in electrodynamics.

Richard Feynman himself discovered the first new complication which appears in non-Abelian gauge theories (and in the theory of gravitation) — the need for additional diagrams (ghost loops) to guarantee unitarity. A host of theoreticians — B. De Witt, L. Fadeev, E. Fradkin, S. Mandelstam, V. Popov, M. Veltman and many others concentrated on developing the mathematical formalism and calculational techniques. Gerard 't Hooft's successful work was especially influenced by that of Martin Veltman, who had been working on the problem for a long time and who was his thesis advisor in Utrecht. Later his results were elucidated and formalized by B.W. Lee, A. Slavnov, J.C. Taylor, J. Zinn-Justin, and others.

These important mathematical developments can be applied to the case when the vector gauge bosons have mass as in the weak interactions because the mass of the bosons can be generated through a spontaneous breaking of the gauge symmetry by the so-called Higgs mechanism. This possibility was described in the work of P. Higgs, P. Anderson, R. Brout, F. Englert, G. Guralnik, C. Hagen, T. Kibble, and others.

It turns out that the spontaneous breaking of the symmetry does not

*The electromagnetic interaction takes place via the exchange of gauge particles known as photons. They are massless and the electromagnetic force therefore has infinite range. In the same way, the weak interaction is believed to take place via the exchange of gauge particles known as intermediate vector bosons ( $W^+$ ,  $W^-$  or  $Z^0$ ). However, these should be heavy particles (probably about 70 GeV) since the weak force has a very short range. But if the gauge particles have mass, refined calculations on the weak interaction do not give sensible answers. To remedy the situation, another type of particle (the so-called Higgs bosons), has to be introduced. Then it is the fact that the gauge particles carrying the weak interaction (the  $W$ s and  $Z$ ), which are without mass, effectively swallow some of the Higgs bosons which give them their mass. The other Higgs bosons may be detected by experiments.*

spoil the renormalizability of the theory. The masses of the vector bosons are related to other parameters of the weak interaction theory and, in the present models, they come out in the 50 to 100 GeV range. These particles are among the tantalizing fruits which are expected to fall to the next generation of high energy machines.

Before the mathematical methods had been fully developed and renormalizability demonstrated, Steven Weinberg and Abdus Salam came up, in 1967 and 1968, with their now famous model which links the intermediate vector bosons with the photon, bringing the electromagnetic and weak interactions under one umbrella. The Weinberg-Salam model is the culmination of the work of many people, notably J. Schwinger, S. Glashow, S. Bludman, and J. Ward.



Sheldon Glashow, for instance, had almost been there some years before, but his model was lacking the ideas on spontaneous symmetry breaking, which Weinberg, Salam and Ward fed in.

Originally, the model described only the weak and electromagnetic interactions of leptons (the electron and its neutrino, the muon and its neutrino) and it was not known how to extend it to include the interactions of the hadrons (the strongly interacting particles). Eventually, this became clear after Glashow, J. Iliopoulos and L. Maiani showed that the properties of the weak and electromagnetic currents of the hadrons could be correctly described in a model with four quarks (the so-called GIM mechanism). With the inclusion of the GIM picture, the Weinberg-Salam model became very fruitful. It forecast the existence of the neutral current type of weak interaction, which was later discovered by the Gargamelle collaboration at CERN, and its validity has been further rubbed home by the discovery of the  $J/\psi$  particle at Brookhaven and Stanford and by the subsequent bonanza of excited states and charmed particles.

At the time, in the late 60s, Weinberg and Salam did not have the mathematical formalism needed to show that their model was renor-

malizable (although they suspected that everything would be all right). Because of this, the initial Salam-Weinberg ideas lay dormant for some time. It was only after 't Hooft's work on renormalization became known that interest welled up again.

An important contribution was made by C. Bouchiat, J. Iliopoulos and P. Meyer and by D. Gross and R. Jackiw, who showed that certain particularly disagreeable infinities (those due to the so-called triangle anomalies of S. Adler, J. Bell and R. Jackiw) could be cancelled between leptons and quarks.

So here, at last, was a complete picture of weak interactions which was renormalized and could in principle allow the calculation of any physical quantity. Then came the discovery of neutral currents and since then gauge theorists have hardly had time to look back. Models based on spontaneously broken gauge invariance have mushroomed into a major industry.

Gauge theory ideas can be applied to any force field, gravitational, electromagnetic, weak or strong and therefore hold out the promise of unifying our conception of all the forces in Nature. With renormalizability clearly established, calculations can be made to any level of accuracy. The language of gauge theories is flexible enough to accommodate all the experimental surprises of recent years.

At the moment, the burning topic is the prediction that the weak interactions are mediated by the charged vector bosons —  $W^+$  and  $W^-$  for charged current interactions and the  $Z^0$  for neutral current interactions — with masses in the 70 GeV region. Every proposal for the next generation of accelerators or storage rings has the finding of these bosons as one of the major physics justifications.

It is a criterion of a good theory that it not only absorbs the knowledge which has already been gathered in experiments but also predicts what

*Combining the ideas of gauge particles and of Higgs bosons enables sensible calculations to be made for the weak interaction in an analogous way to the electromagnetic interaction. Through the introduction of the quark model, the unified picture of the weak and the electromagnetic interactions can be applied to the strongly interacting particles, the hadrons. Such seemingly disparate phenomena as an electric spark, the swing of a compass needle, the radioactive decay of a nucleus, features of the burning of the sun... all can then be explained by the same theory.*

future experiments should find. Variations of the gauge theory can move the  $W$  and  $Z$  masses from 70 GeV but they should not be far away. Their discovery, which should take place within the next ten years, will be crowning glory of more than two decades of work in high energy physics theory. If they do not exist the present theoretical picture is definitely wrong.

On the other hand, a renormalizable gauge theory implies much more. For instance, all present models require the existence of scalar particles, responsible for the spontaneous symmetry breaking, the so-called Higgs mesons. However difficult it may be experimentally, they, or a suitable theoretically acceptable alternative, must also be found before we can say that the present picture is correct.

*The Higgs bosons are the origin of 'spontaneous symmetry breaking'. Abdus Salam has a personal picture to communicate this abstruse concept. Imagine a banquet where guests sit at round tables. A bird's eye view of the scene presents total symmetry, with serviettes alternating with people around each table. A person could equally well take a serviette from his right or from his left. The symmetry is spontaneously broken when one guest decides to pick up from his left and every one else follows suit.*

# Leptons at Hamburg

*At the end of August the Congress Centre in Hamburg was the scene of the 1977 International Symposium on Lepton and Photon Interactions at High Energies.*

The 1977 International Symposium on Lepton and Photon Interactions at High Energies was held from 25 - 31 August in the Congress Centre at Hamburg. The symposium was sponsored by IUPAP, the German Research Ministry BMFT, the city of Hamburg, and DESY, and attracted 500 physicists from more than thirty countries. It was excellently organized by DESY and in particular by G. Weber and G. Flügge.

The Conference opened with the latest results from electron-positron colliding beam physics which consolidate the amazing series of discoveries made in the past couple of years. Particularly important for the charm model was the discovery of the long awaited F meson by the DASP group on DORIS at DESY some weeks before the Conference (see August issue, page 235). Another important discovery was that of the psi resonance at 3.772 GeV by the DELCO and SLAC /

LBL (Leadglass) groups on SPEAR at SLAC. Because this resonance is just above threshold for charm production it nearly always decays into  $D\bar{D}$  and so provides an almost background free source of D mesons — a happy circumstance which has already been exploited by the SLAC/LBL group who reported on many properties of the D mesons.

Direct electron production continues to provide a key to the new physics in electron-positron annihilations. This was demonstrated beautifully by the results on inclusive electron production of the DELCO group. By looking at the production of an electron plus multiprongs they have been able to draw the most detailed map yet of charm production.

Any mention of direct lepton production leads quickly to the other outstanding result of the past few years — the discovery of the heavy lepton, tau. All the evidence for the ex-

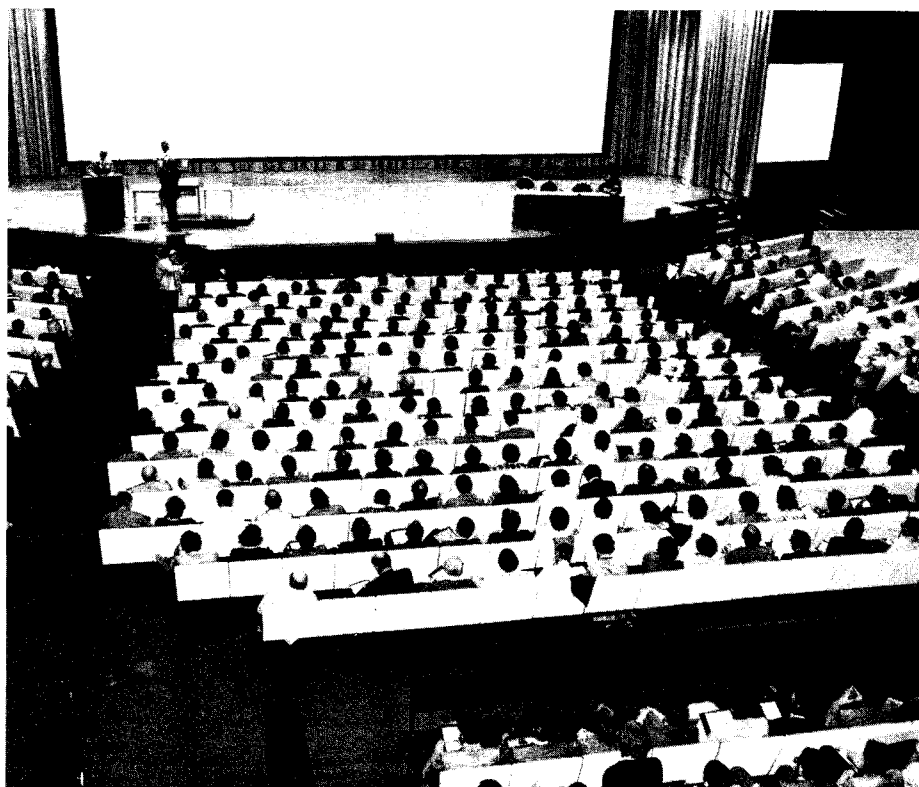
istence of the tau comes from such observations. Martin Perl gave an inspiring review of the experimental situation showing that all experiments that should see a tau signal, do see one and with more or less the properties expected of a sequential heavy lepton. He emphasized, however, that while it is possible with existing data to exclude certain types of lepton, it is going to be very difficult to pin down the parameters of the tau precisely.

In the past year particularly important evidence came from the electron-muon events of the PLUTO group on DORIS and more recently from the SLAC/LBL (Leadglass) group. The events are very clean with only a small contamination from charm particle sources. Further important evidence was the electron momentum spectrum of the two prong events from the DASP group.

The Conference heard about a number of tentative measurements of some tau decay branching ratios. Among these was the possible identification by the PLUTO group of the decay into the  $A_1$  meson and neutrino, with the  $A_1$  decaying into a rho and a pion, which was supported by preliminary results from SLAC/LBL. It is amusing to note that these data are also among the first observations of the  $A_1$  and show that Sakurai was right when he suggested looking, long before the discovery of the tau, for the  $A_1$  in heavy lepton decays.

The only cloud in the picture at the moment is a discrepancy in the pion decay rate as measured by the DASP group but the statistics are small and it is obviously of the utmost importance to repeat this experiment since the validity of standard weak interaction theory is at stake.

Attention in the field of neutrino interactions was, of course, focused on the question of the existence or non-existence of the so-called high  $\gamma$  anomaly (see August issue, page 244). The evidence that the HPWF group





*A welcome buffet in the open air at the end of a tour of the DORIS and PETRA storage rings at DESY.*



gathered in 1974 and 1975 at Fermilab of an excess of events in antineutrino charged current interactions at large lepton energy transfers (high  $\gamma$ ) and high energies had caused a major stir. The simplest explanation required the existence of a fifth quark with a right handed coupling to the weak current which does not fit easily into the otherwise successful theory of weak interactions.

The first results published earlier this year by the CDHS experiment at CERN showed no high  $\gamma$  anomaly and results from other experiments at Fermilab (CITF) and CERN (BEBC) were therefore of particular interest. Neither group can exclude the possibility of a slight energy dependence in the ratio of the neutrino to antineutrino charged current total cross sections and in the sea quark fraction ( $B$ ) but neither group sees an effect anything like as large as that seen in the HPWF experiment.

All groups summarized the interpretation of their results as being compatible with the standard weak interaction four quark scheme with perhaps some evidence for breaking of scale invariance with a magnitude comparable to that seen in deep inelastic electron and muon scattering.

Still with neutrinos — in addition to the original observation by the HPWF group, dilepton events have now been seen in the CERN counter experiment (CDHS) and the BEBC bubble chamber experiments and in the other neutrino experiments at Fermilab. The rates of dilepton production are compatible with each other and with the expectations of models based on charm production and decay.

The status of trimuon production is unchanged. HPWF have now collected twelve events, other experiments have a few examples but are not yet in a position to confirm the observation. What was rather surprising was the absence of any further trimuon results from the CDHS experiment at CERN — the group could report that trimuon

candidates have been seen and that data taking and analysis continue.

The discussion session on neutrino physics was dominated by the confrontation between the HPWF and CDHS experiments — high  $\gamma$  seems to incite high flood pressure. Despite sometimes heated exchanges, the understanding of the high  $\gamma$  discrepancy was not much advanced. Obvious questions were whether the discrepancy exists in the measured data, as far as it can be compared, and if so how much and whether the analysis procedures employed can enhance or suppress a possible effect.

These points were taken up by Barry Barish in his summary talk on neutrino results. He emphasized how difficult neutrino experiments are and in particular how errors can multiply due to the inherent poor resolution of the apparatus. He showed that although the  $\gamma$  distributions from the CDHS and HPWF experiments agree qualitatively, fits to determine the antiquark  $B$  parameter differ by factors of 2 or 3. Drawing together the results of all relevant experiments he declared that there is no high  $\gamma$  anomaly.

The remaining experimental results on the once dominant themes of electron production and photoproduction were dealt with in a single morning. New information was presented on the magnitude of scale breaking from the experiments at Fermilab and further interesting work remains to be

done in this field. Another thorny question, of perhaps less fundamental importance, is that of the precise  $q^2$  dependence of the nuclear shadowing effect.

The evidence for the new vector meson at about 1100 MeV found in the Bethe-Heitler interference experiment at DESY has improved. There are also indications of more states at higher energies and it will be interesting to see how these results tie in with the many possible new states found below 3 GeV in the electron-positron colliding beam experiments reported to the Conference from the groups at Adone in Frascati and DCI in Orsay.

A week-end break was devoted to lighter pursuits, allowing time for a proper digestion of the experimental results before the theoretical papers of the second half of the Conference. A tour of DESY stimulated a good appetite for a very pleasant buffet and an excursion by special train to Lübeck and the Baltic coast provided a most relaxing day.

Business started again with the most exciting and important result of all. Leon Lederman, in a characteristic talk, presented the results of the experiment at Fermilab showing a clear enhancement at 9.5 GeV (see August issue, page 223). This has now been resolved into two narrow peaks and rough estimates give the mass of Upsilon as 9.4 GeV and Upsilon prime



Getting away from it all. The Conference participants took an excursion to the Baltic sea and are pictured leaving their special train at the old Hansestadt Lübeck for a sightseeing tour.

(Photos DESY)

as 10 GeV. With the demise of the high  $\gamma$  anomaly in antineutrino charged current scattering, the Upsilon's are now providing the most provocative indication that there are more than four types of quark in nature. The results from the first electron-positron machine to reach the 9.5 GeV energy region will be eagerly awaited!

An interesting change from the usual fare at high energy meetings was an elegant report by Patrick Sandars on the experiments looking for weak interference effects in atomic transitions. The experiments are miniatures by high energy physics standards but extremely sensitive; to quote Sandars, 'A fingerprint in the wrong place can produce a bigger optical rotation than Weinberg and Salam combined'.

The only experimental groups sufficiently advanced to be able to present results were from Washington (Seattle) and Oxford looking for optical rotation in bismuth vapour. Both find a null result which is of the order of six standard deviations from the expected rotation assuming the standard Weinberg-Salam theory. However, Sandars emphasized that the calculation involves a non-trivial atomic physics part which, although very carefully done, may ignore certain many-body effects.

Attempts to understand these are in progress and preliminary results indicate that the expected rotation may be reduced by up to a factor of two.

This is still not enough to remove the disagreement with theory and the failure to observe parity violation in these atomic physics measurements remains the biggest cloud in particle physics at present. Further experiments looking for weak interference effects in hydrogen are in progress.

The theoretical sessions were dominated by gauge theories, quantum chromodynamics (QCD) and quark models. Among many excellent talks, Steve Weinberg gave a breathtaking overview of the status of gauge theories in weak interactions. He showed how the requirements of generalized gauge invariance and renormalizability already restrict the possible theories very considerably and how many critical experiments already in progress in atomic, nuclear and particle physics will be able to define the structure of the correct theory very closely. He ended with a tantalising glimpse of how a superunified theory might look and how we may be able to see a shadow of its structure at accelerator energies.

Most other speakers concerned themselves with comparisons of the data with the expectations of various quark models and the corrections to be expected on the basis of QCD calculations. The basic agreement was impressive but a few problems remain — the pseudo-scalar states in charmonium, a theory to accommodate all results bearing on the structure of the

weak interactions, the compatibility of the various attempts to determine the running coupling constant in QCD, to say nothing of where to fit the tau lepton in!

The Conference closed with some looks into the future. Pief Panofsky and Herwig Schopper were concerned with the immediate future in the form of the PEP and PETRA storage rings respectively. The construction of PETRA is well up to schedule and colliding beams are expected before the end of 1978. Despite rumours to the contrary, even SLAC cannot build accelerators overnight and PEP is expected to be available for physics at the earliest in October 1979. John DeWire and Leon Van Hove then looked a little further into the future at the plans for CESR storage rings at Cornell and the ECFA recommended very high energy electron-positron facility for Europe.

The final talk was by J.D. Bjorken who took a bold leap into the dark and speculated about how things might look in ten or twenty years' time. He pointed out that there is ample evidence from cosmic ray physics in the multi-TeV region of interesting effects and events which cannot be explained by extrapolations from existing accelerator data (see page 289). Otherwise his dominant theme was the understanding of the weak interactions. Something interesting must happen in the region of 100 GeV where the weak and the electromagnetic interactions become equal in strength. In particular, if the  $Z^0$  exists and can be produced as a free state in electron-positron annihilations, it will provide an unrivalled source of information on all the interesting effects that one expects in gauge theories.



# Around the Laboratories

## BERKELEY TPC facility for PEP

A large, sophisticated detector based on the new technique known as the Time Projection Chamber (TPC) has been chosen as one of the first experimental facilities for the electron-positron machine, PEP. This detector, whose cost is 10 million dollars, is being built at Berkeley and will be ready for PEP in late 1979 or early 1980.

The central element is the TPC, developed at LBL by David Nygren and coworkers, which can provide excellent pattern recognition and charged particle identification of electrons, pions, kaons and protons over large solid angles, even in high multiplicity events. In addition, a multiplate liquid argon calorimeter measures the energy and direction of gamma rays, and muons are identified by their penetration of an iron hadron absorber. The detector will thus have exceptionally broad sensitivity in the search for new phenomena opened up by the higher energy of PEP.

The TPC is a large volume cylindrical drift chamber (2 m long, 2 m diameter) which provides three dimensional spatial data, by using proportional wires to read out the two coordinates orthogonal to the drift direction, and timing information to determine positions along the drift direction. It covers about 95% of  $4\pi$  steradians solid angle, sits in a 1.5T solenoidal magnetic field, and is filled with a mixture of 80% argon and 20% methane at a pressure of up to 10 atmospheres. An electric field of 15kV/m is generated in each half of the cylinder, parallel to the magnetic field. Charged particles which traverse the cylinder ionize the gas along their trajectories and the ionization electrons drift towards sense wires in the endcaps.

The drift time from the position

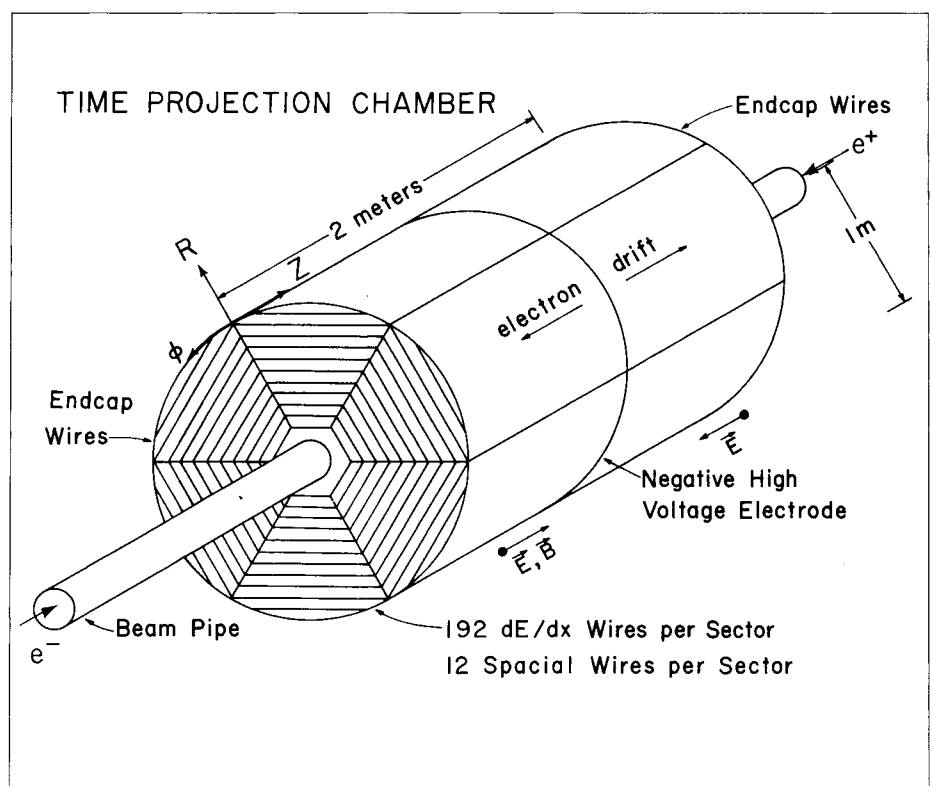
where the electrons are liberated to the wires is measured and, using the known drift velocity (about  $7\text{ cm}/\mu\text{s}$ ), the coordinates of up to 192 points on the trajectory (there are 192 sense wires) can be calculated, each with a resolution of 2 mm. This can be done for many densely spaced trajectories in the chamber, because the drift time to a sense wire is measured with a charge coupled device — an analogue shift register that can store the pulse height information from up to 455 hits on each wire, thus effectively dividing up the volume of the TPC into many small subvolumes. Since 192 good points are measured for most trajectories, it should be easy to sort out all the tracks in a complex jet-like multihadronic event, even with synchrotron radiation or beam induced background present.

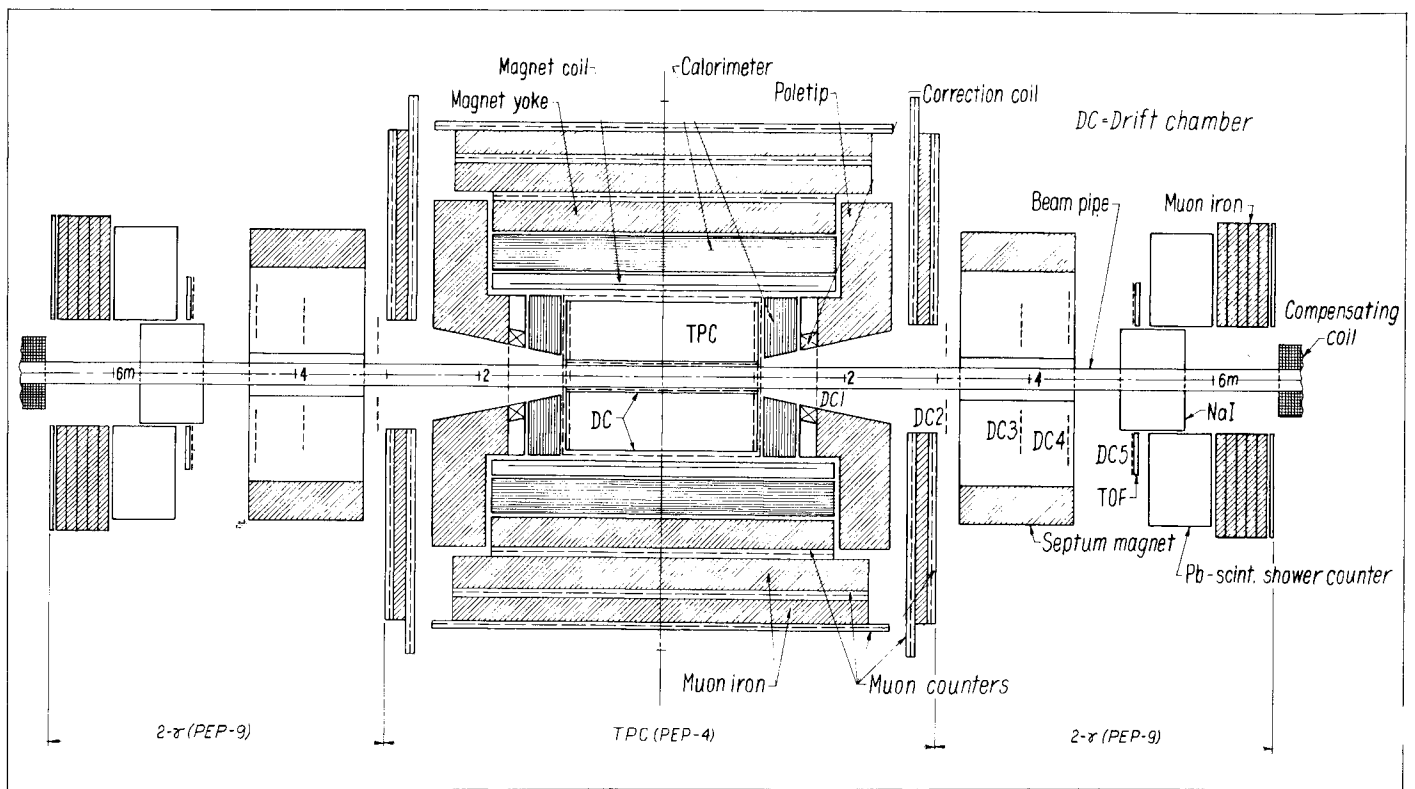
Twelve of the radially spaced sense wires in each endcap have the cathode plane locally segmented into square pads ( $8\text{ mm} \times 8\text{ mm}$ ) under each wire.

*A schematic representation of the Time Projection Chamber which is being developed at Berkeley for use on the PEP colliding beams. Electrons, liberated in the cylindrical drift chamber volume by the passage of charged particles, drift to end-cap wires and the signals which are picked up can be interpreted to give spatial and time coordinates and provide particle identification.*

The determination of the position of the induced pulses on these cathode pads, which are at a known radial distance, thus gives the radial and azimuthal coordinates of twelve points on each trajectory. Since the solenoidal field bends the tracks in a plane parallel to the endcaps, this information gives the momentum of the particles. The amplitude of the pulses induced on the cathode pads varies as the solid angle subtended from the point on the sense wire where the track segment has fallen. It has been verified experimentally that the centre of this distribution can be found with an accuracy of  $150\mu\text{m}$ . This results in a momentum resolution of about  $0.7\% \times P$  (GeV/c) at high momenta.

The field not only serves to bend the particles for momentum measurement, but also suppresses transverse diffusion of the electrons as they drift towards the endcaps. This helps to obtain a resolution competitive with drift





chambers even over a metre of drift.

The TPC thus provides three dimensional information — radial (from the pattern of wires hit), azimuthal (from the pulses on the cathode segments) and along the drift direction (from the time at which the information appears on the wires). It does not face the serious problem of unscrambling tracking ambiguities encountered in conventional systems of wire chambers.

The ionization electrons are also used to measure the energy loss ( $dE/dx$ ) of the particle in the gas. Since this loss depends on the particle velocity, the measurement can be used, together with the momentum measurement, to determine the mass and thus identify the particle.

The energy loss of a particle in a thin layer of material has enormous fluctuations — the so-called 'Landau tail' which results from the spectrum of delta rays produced in passing through the material. These fluctuations make a high resolution measurement of energy loss impossible with a single sample and the key to achieving high resolution is to take many independent samples. This is achieved in the TPC because each of the 192 wires in the endcaps is used to sample the electrons from each track; the gas is at 10 atmospheres to ensure that each sample has an adequate number of ionization electrons. The Landau tail can be eliminated by using, for exam-

ple, only the 50% of the smallest 192 energy loss samples. With this simple algorithm, it has been experimentally verified that a resolution in  $dE/dx$  of 2% or less can be obtained with the TPC geometry.

With such a good resolution individual electrons, pions, kaons and protons over a momentum range from 100 MeV/c to greater than 15 GeV/c can be identified. This can be done for all the particles in complex, multiparticle events using the pulse height information from each wire.

A system of drift chambers complements the TPC. Four concentric cylindrical drift chambers immediately outside the beam pipe, at the inner radius of the TPC, serve as the trigger element by defining a radially directed track. A cylindrical drift chamber outside the TPC forms a coincidence with the inner chamber signal to reduce the background rate.

The 1.5T field is generated by a superconducting solenoid, which has only 0.44 radiation lengths total of material (measured radially). It contains a low resistance aluminium bore tube, closely coupled inductively to the superconducting coil, which is used as an energy dump during a magnet quench. The coil has 2000 turns of superconducting wire (1.7 mm  $\times$  1.6 mm) which carries a current of about 2000A. Refrigeration is via a cooling tube wrapped around the coil, circulating liquid helium mixed with

gaseous helium. The uniformity of the field inside the TPC is very good — the radial component is less than 0.1% of the axial field and will be reduced to 0.01% with shimming and use of room temperature correction coils. The magnet yoke weighs about 220 tons and is used as part of the muon detector.

The energy and direction of gamma rays are measured in a liquid argon calorimeter which covers 95% of  $4\pi$  steradians while still being of moderate size (and thus reasonable cost), because of the compact size of the TPC. There are three calorimeters — two attached to the pole faces of the magnet and a cylindrical calorimeter situated just outside the superconducting coil. The cylindrical calorimeter has a diameter of about 2.5m and a length of 3.8m, and the planar units are rings having an inner diameter of 0.4m and an outer diameter of 1.8m. Each calorimeter has a total of 18.7 radiation lengths in 54 alternating layers of metal and liquid argon. To minimize ambiguities and maximize stereo information, the collector strips are deployed at three stereo angles,  $120^\circ$  apart, and alternate regularly. While most of the collector strips are 3.0cm wide, there is an inner layer of 1.5cm strips, so that about 98% of the photons are located before significant spreading of the cascades has taken place. Regardless of the materialization point, the posi-



Side view of the TPC configuration as it will be installed on PEP. It has the experiment number PEP-4 and will be integrated with an experiment, PEP-9, to measure two photon processes. The locations of the different elements of the TPC facility can be seen.

tion resolution ranges from 4.5 mm for low energy photons (about 100MeV) to 1.5 mm for energies over 1 GeV. The energy resolution is  $9\% (1/E)^{0.55}$ , with E in units of GeV.

Identification of low momentum muons is done using  $dE/dx$  in the TPC, while at higher momenta they are identified by their ability to penetrate a thick iron absorber which surrounds the TPC and the photon calorimeter. The iron (including the magnet yoke) is 1 m thick, resulting in a hadron 'punch through' probably of only 1%. Proportional chambers detect the muon after the iron with a spatial resolution of 1 cm.

The TPC Facility will be able to detect and study in detail many of the phenomena expected at PEP interaction energies. Members of the TPC collaboration are W.C. Carithers, O. Chamberlain, A.R. Clark, O. Dahl, P.H. Eberhard, D. Fancher, L. Galtieri, M. Garnjost, R.W. Kenney, S.C. Loken, L.T. Kerth, R.J. Madaras, P. Martin, D.R. Nygren (spokesman), P. Oddone, M. Pripstein, P. Robrish, M. Ronan, G. Shapiro, M.L. Stevenson, M. Strovink, M. Urban and W. Wenzel from Berkeley; C.D. Buchanan, J.M. Hauptman, W.E. Slater, D.H. Stork and H.K. Ticho from California-Los Angeles; J.N. Marx (deputy spokesman), P. Nemethy and M.E. Zeller from Yale; W. Gorn, A. Kernan, J. Layter and B. Shen from California-Riverside; and B.A. Barnett, C.-Y. Chien, L. Mandansky, J.A.J. Matthews and A. Pevsner from Johns-Hopkins.

## CERN Still greater accuracy from MWPCs

Further studies on the abilities of multiwire proportional chambers indicate that the localisation of ionizing radiation in space can be achieved with an accuracy of around 30  $\mu\text{m}$  (or

Diagram representing the method of extracting accurate two dimensional information from a multiwire proportional chamber. The avalanche initiated by the passage of a charged particle reaches the anode wire, a, giving a negative signal. Neighbouring wires, b and c, and the strips of the cathode planes, x and y, receive positive signals from the ions moving away from the anode wire. Measuring the signal heights makes it possible to calculate the 'centre of gravity' or point of origin of the avalanche with great accuracy.

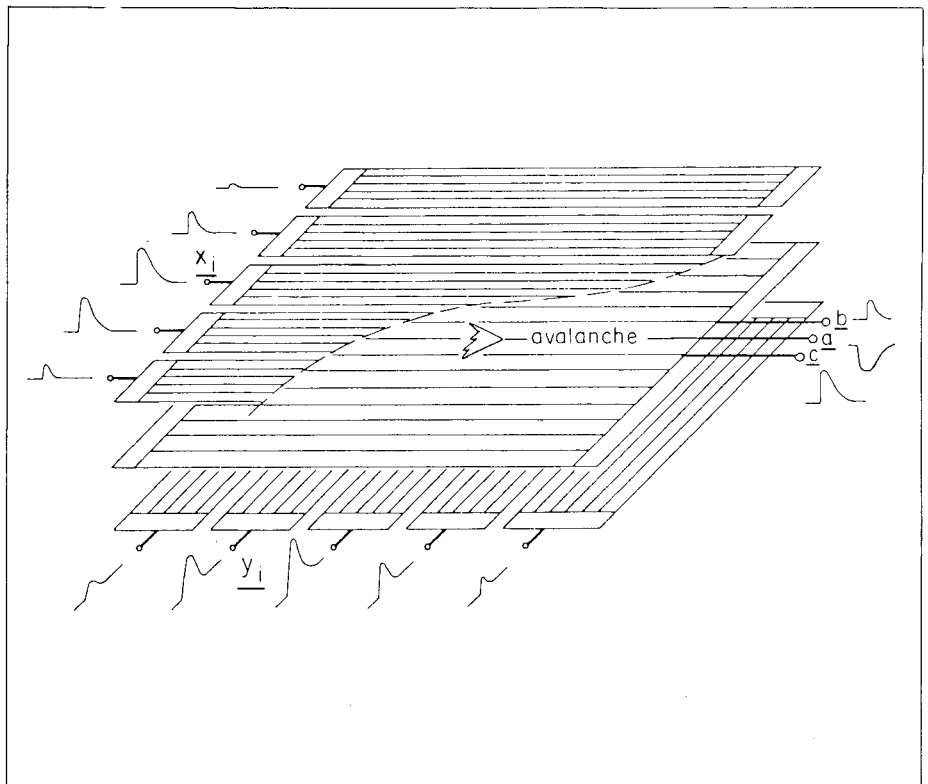
better for heavily ionising particles). These results came from a simple system and it is possible to use a single sense wire plane, together with signals from cathode wires, in the collection of two dimensional information with a time resolution of 30 ns.

Since the initial development of multiwire proportional chambers by the group of Georges Charpak at CERN in 1968, they have come into very widespread use in high energy and

Letters 1.5 mm high and 50  $\mu\text{m}$  wide were cut in a copper mask and irradiated with 1.5 keV X-rays while centred over an anode wire of a multiwire proportional chamber. This image was obtained via the signals generated from the avalanches, which were all produced around this single wire, using the 'centre of gravity' technique on the signals detected on the cathode wires and the neighbouring anode wires. Conventional techniques would have recorded a single line corresponding to the anode wire position. The 'centre of gravity' technique gives a continuous image despite the fact that the letter height is less than the spacing of the anode wires.

nuclear physics. They are also beginning to have interesting applications in solid state physics and biomedical research. They offer the possibilities of good spatial resolution, almost continuous sensitivity, multiparticle detection and (in special systems) two dimensional read-out and the detection of neutral particles.

In most of the existing chambers the accuracy with which the particle position can be located is dictated by the



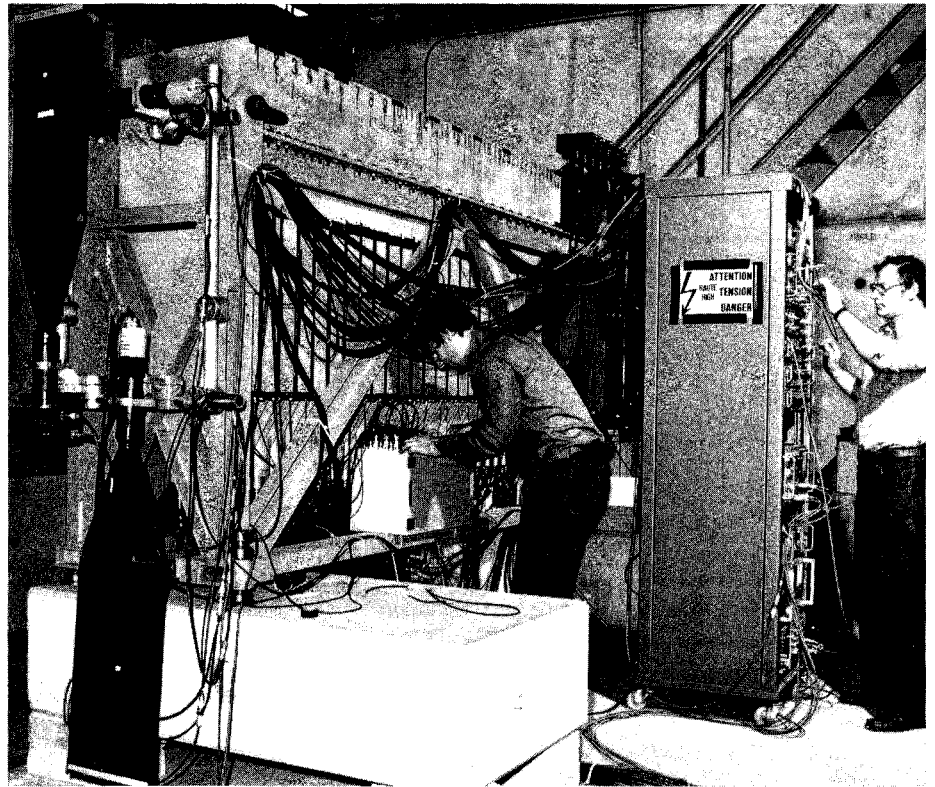
*A heavy target, nicknamed STAC, will be used in the large spectrometer for the study of muon-nucleon scattering in the North Area of the SPS by the European Muon Collaboration. It has been built and successfully tested in an electron beam at DESY and is now being tested in an SPS hadron beam in the West Hall. It consists of 26 iron/scintillator sandwich elements to measure the energy which the 280 GeV primary muon loses during its interaction in the target.*

*(Photo CERN 358.6.77)*

spacing of the wires in the anode plane which receive the electron avalanche initiated by the particle in the gas filling the chamber. For practical reasons associated with stringing thin wires over large chambers, this accuracy is usually of the order of a few millimetres. The drift chamber, which is a variant of the MWPC conceived by the same group in their early work, can improve this accuracy in one dimension to some tens of microns by measuring the time taken for a signal to reach the anode sense wire.

Several Laboratories, particularly Berkeley and Oak Ridge, have worked on the possibility of achieving two dimensional information from a MWPC. One technique is the clever use of signals from the cathode plane which eventually receives the pulse induced by the positive ions generated around the anode wire receiving the electron avalanche. The ions move away from the anode plane and distribute pulses on the wires or strips of the cathode plane. By measuring the 'centre of gravity' of the distribution it is possible to estimate where the avalanche originated. Crossed cathode strips on the two sides allow a two dimensional detection ability that is particularly useful for neutral radiation (neutrons, X-rays and gammas), since they produce electrons which may not have enough energy to traverse several chambers. Such MWPCs are beginning to find applications in medicine and biology.

The latest work at CERN has attempted to push the technique of 'centre of gravity' measurement to its limits. Using modestly priced amplifiers it was found that a 'gate' of 30 ns was sufficient to provide enough information to give excellent two-dimensional accuracy. This sets the time resolution of 30 ns. Gases were chosen to give moderate amplification (argon or xenon, with isobutane and methylal, with and without freon). This avoids loss of precision which can



result from saturation due to space charge when using the 'magic gas'.

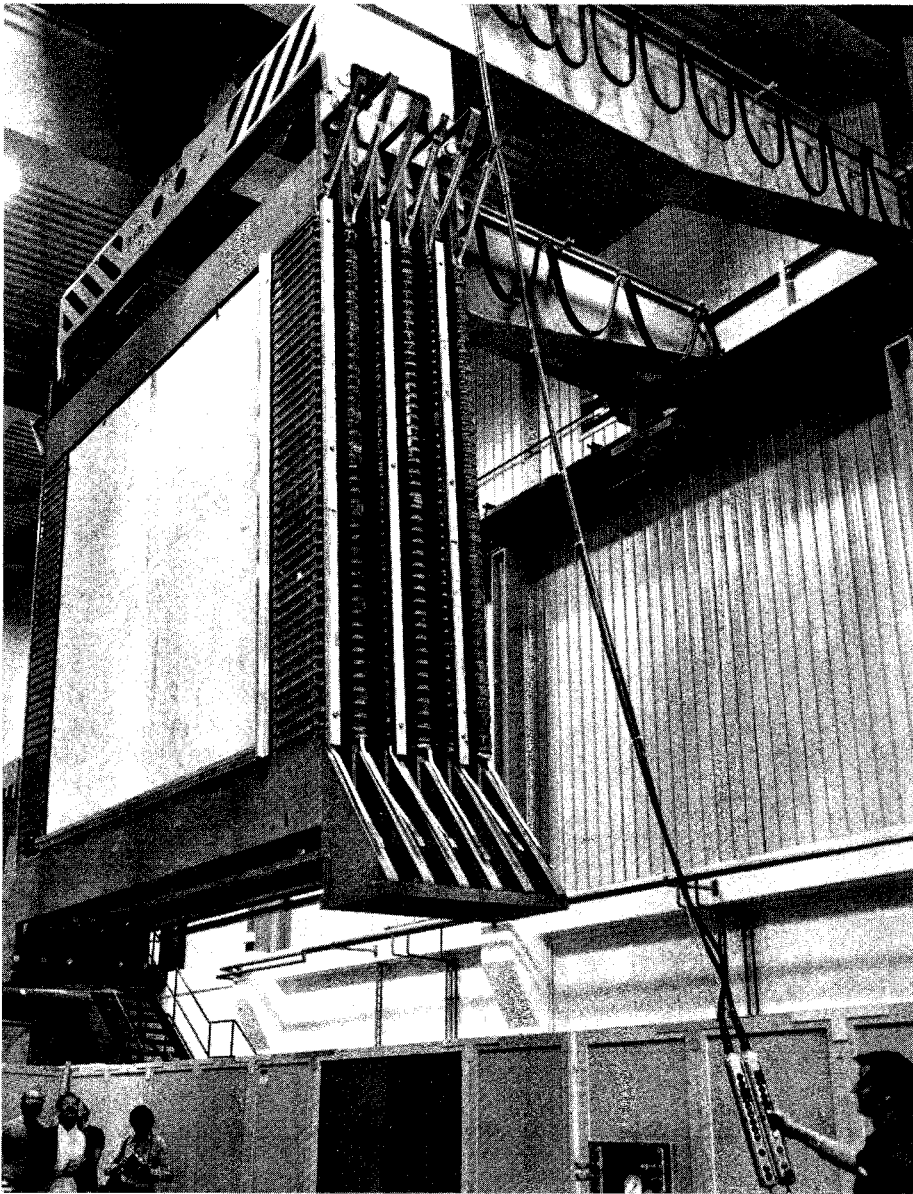
The achieved spatial precisions are about 30  $\mu\text{m}$  for soft X-rays (1.5 keV) and this limit is set by features of the physical phenomena which are happening in the chamber (such as the path lengths of photoelectrons). Work is in progress to measure the accuracy obtainable for minimum ionizing particles. For heavily ionizing particles, the situation should be even better and precisions of a few microns may be feasible depending more on the associated electronics.

Multiwire proportional chambers with parameters pushed to these levels of accuracy will have important applications in high energy physics, since they provide resolutions equivalent to drift chambers (with a resolution time better by an order of magnitude), and in X-ray imaging. Some chambers built at CERN are being used at the synchrotron radiation

facility, LURE, on the electron-positron storage ring DCI at Orsay (see October 76, page 350). They plan to study proteins and viruses with exposure times a factor of a thousand down on conventional detectors (reducing the risk of damage to molecular structures) while giving better quality images.

## Channelling our energies

Channelling — the effect of direction on the propagation of particle beams through crystals — is usually studied only at low energies (typically around 1 MeV). An experiment on channelling in the GeV energy range at the CERN 28 GeV proton synchrotron, therefore, needed a special collaboration of physicists (from Aarhus, CERN and Strasbourg) to provide the necessary expertise in both high energy and channelling techniques. The skills and



*The first of thirteen modules of a marble plate calorimeter en route for installation in the SPS neutrino beam for an investigation of neutral currents — experiment WA 18 by the CHARM collaboration (CERN / Hamburg / Amsterdam / Rome / Moscow). The use of marble (in 3 × 3 m slabs surrounded by magnetized iron) gives the best conditions for measurements on particle showers emerging from the neutral current interactions. The calorimeter will also be able to look at the polarization of muons coming from the WA1 detection system which immediately precedes it in neutrino beam.*

(Photo CERN 37.8.77)

reflected by the plane, again because of the cumulative effect of many soft collisions with atoms in the plane.

Below the critical angle, the particles are transmitted with an angular distribution which is much different from the distribution obtained for incidence above the critical angle (where a scattering pattern is similar to that seen using targets of amorphous material). Furthermore, since channelled particles spend much of their time far from the atoms, they experience less energy loss than a particle moving in a random direction.

At GeV energies, the channelling effects were found to be very strong. Even for incidence up to about ten times the critical angle (2 mrad) on a 4 mm germanium crystal, the emerging beam is still distorted because of channelling effects. This is presumed to be because the beam is multiply scattered through the crystal so that part of the beam reaches angles to the atomic strings of the order of the critical angle.

Negative charged particles are also influenced by the channelling effects. Actually, negative well channelled particles have a tendency to stay rather close to the atomic strings and were therefore expected to suffer increased energy loss compared to randomly scattered particles. In fact, experiment clearly demonstrated, for the first time, the increased energy loss of well channelled negative pions.

A simple way of demonstrating channelling for positive particles is to look for the yield of some nuclear reaction as a function of the incidence angle to the strings. A dramatic decrease in the yield by a factor of about a hundred is found in low energy channelling when the angle is below the critical angle. The collaboration found a simple way to demonstrate this effect at high energies by using the germanium crystal as an intrinsic energy loss detector. In a nuclear reaction at GeV energies, several particles emerge from the reaction, and this

knowledge of particle and solid state physicists complemented each other excellently in a first investigation at high energies. Some promising spin-off applications have become apparent and the experiment is continuing.

When a low energy (MeV) beam of positively charged particles is shone on a crystal, the incident particles, in general, pick their way round the atoms in the target in a more or less random way. However, if the beam comes in at a glancing angle to one of the principal axes of the crystal, an incident particle effectively sees strings of connected atoms. Interaction with this string gives many small momentum transfers from a large number of atoms to the particle and it is thereby gently steered away. The particle emerges with essentially an unaltered angle to the string although its azimuthal angle may be changed.

A common misunderstanding in channelling is that particles may be

trapped in a tube, for example, between four strings in a cubic lattice. This has led some people to hope that channelling could be exploited to bend high energy beams by transmission through a bent crystal. Actually, channelled particles are free to move nearly everywhere, with the exception of the small forbidden areas around the strings.

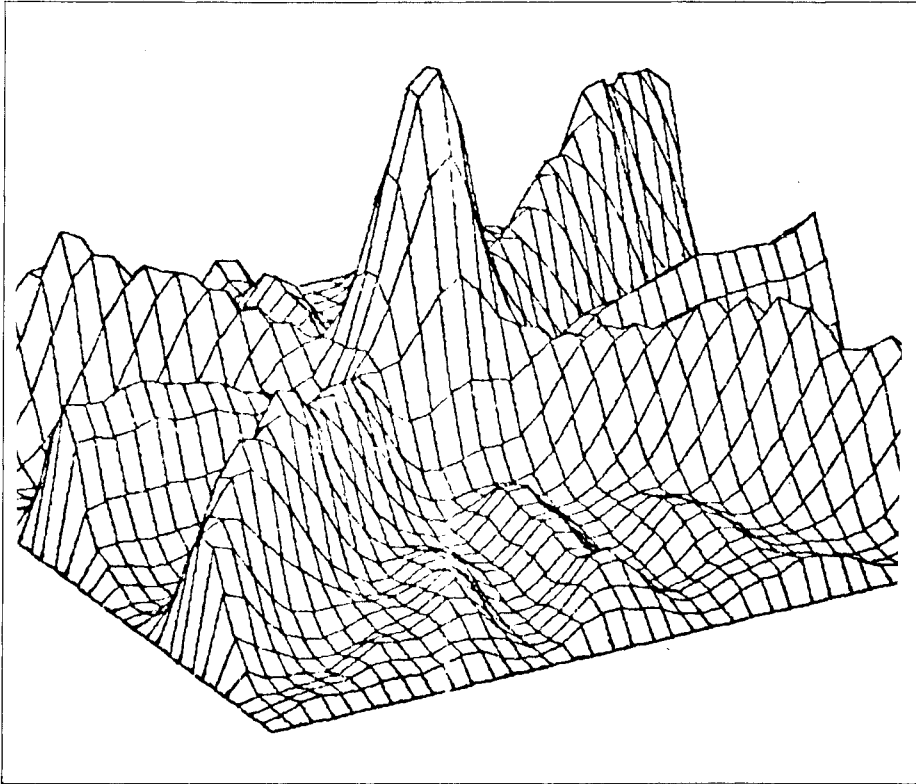
Channelling sets in when the incident angle to the atomic strings is below a critical angle which depends on both crystal type and energy. Typically the critical angle is of the order of a degree for low energy channelling but only a fraction of a milliradian for GeV particles.

To complete the picture it should be noted that atomic planes as well as strings can affect the motion of the beam through a crystal. If the incident angle to an atomic plane is below a critical angle (which is a little less than critical angles for strings) the beam is

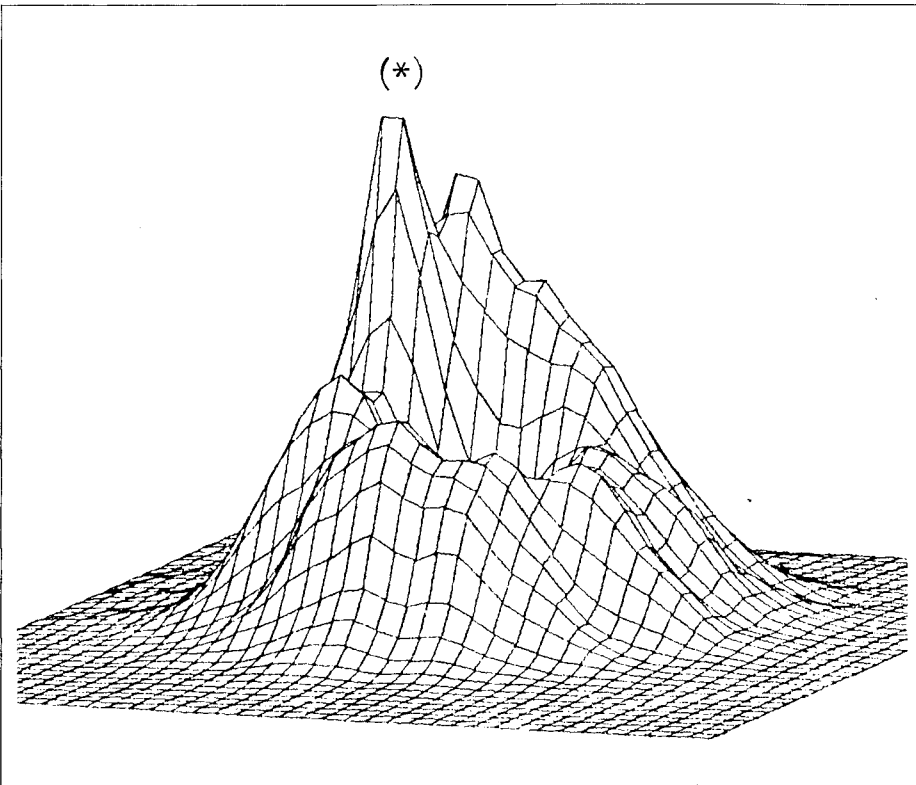
'Channelling' of charged particles through a crystal was seen for the first time at high energies in an experiment at the CERN PS. 1. The emerging beam intensity distribution when 6 GeV/c positive pions are shone on a 0.3 mm crystal of germanium. It shows a strong peak at the centre in the direction of the atomic 'string' within the crystal (the channelling direction) with well pronounced crests at

angles to it corresponding to channelling planes.

2. The emerging beam intensity distribution when 15 GeV/c protons are shone on a 0.74 mm crystal of germanium. The asterisk marks the direction of the incident beam and the three dimensional plot has a hole along the main crystal direction, where no particles are transmitted.



1.



2.

means that an exceptionally large energy loss is recorded by the crystal. This suggests the possibility of using solid state detectors to measure charged particle production cross sections.

In low energy physics, applications of channelling are well known, covering, for example, measurements on lattice locations, radiation damage effects and nuclear lifetimes. As a result of the pioneer work by the Aarhus / CERN / Strasbourg collaboration, potential applications can now be seen in high energy physics and could include measurements of particle lifetimes and triggering in production experiments.

The effect can also be used as a very effective and fast slit system for a divergent high energy beam. For example, low energy loss particles can cover an angle as low as 0.2 milliradians. If about 10 per cent of incident particles suffered little energy loss, the emergent intensity could be around  $10^6$  particles per second.

## Omega at the SPS

The large superconducting 'Omega' spectrometer was originally built for the experimental programme at the CERN PS and was used by a number of teams from 1973 to 1975. The spectrometer was then substantially upgraded to provide improved performance for physics with the higher energy beams from the SPS.

The existing optical spark chambers were interspersed with 0.5 and 1.0 mm pitch multiwire proportional chambers, two four-plane drift chamber modules of  $3.2 \times 1.6$  m<sup>2</sup> were placed at the exit of the magnet and a large photon detector was added downstream of an improved gas-filled threshold Cherenkov counter. Special trigger counters were provided by user groups for specific experiments based on the incident 40 GeV/c hadron or 80



*A downstream view of the Omega spectrometer in the West Area at CERN, showing just some of the additional equipment installed for the SPS physics programme. New hodoscopes, drift chambers and shower detectors abound, but dominating the picture (centre) is the large photon detector, consisting of a 700 element hodoscope array, followed by 340 lead glass counters. The spectrometer magnet itself is almost invisible under its 'igloo' (top centre).*

*(Photo CERN 181.7.77)*

GeV/c electron beams. A more powerful on-line computer system was also provided. Besides enhancing the capabilities of the spectrometer, one result of installing all this equipment has been largely to hide the original Omega magnet from view!

When the SPS beam arrived in November 1976 there was still much of this equipment to be commissioned, and, not surprisingly, the first experiment to get under way was one not requiring the full Omega set-up. Early this year, a 'beam dump' experiment sent 40 GeV/c unseparated hadrons into a copper target inside the magnet. A Birmingham / CERN / Ecole Polytechnique / Munich / Neuchâtel collaboration measured the cross-sections for psi production for all types of incident beam particles by detecting their decay into muon pairs, finding that while the psi is produced equally well by pions, kaons and antiprotons, it is much harder to produce by protons (see May issue, page 150). Collaborations involving Aachen / Bari / Bonn / CERN / Glasgow / Liverpool and Milan are now resuming studies of the intriguing heavy narrow resonances recently discovered at Omega and elsewhere.

An experiment now taking data which exploits the full Omega configuration is a study of the photoproduction of charm states by the WA4 (Bonn / CERN / Ecole Polytechnique / Glasgow / Lancaster / Manchester / Orsay / Paris / Rutherford / Sheffield) collaboration. An 80 GeV/c electron beam is scattered by a thin lead radiator, sending photons onto a liquid hydrogen target inside Omega.

The energy of each photon is 'tagged' by measuring the energy difference between the initial and scattered electron and a special photon tagging system has been built to cover incident photons over the energy range 20 to 70 GeV/c. Since large numbers of neutral pions are produced in this experiment, a 9 m<sup>2</sup> detector has been

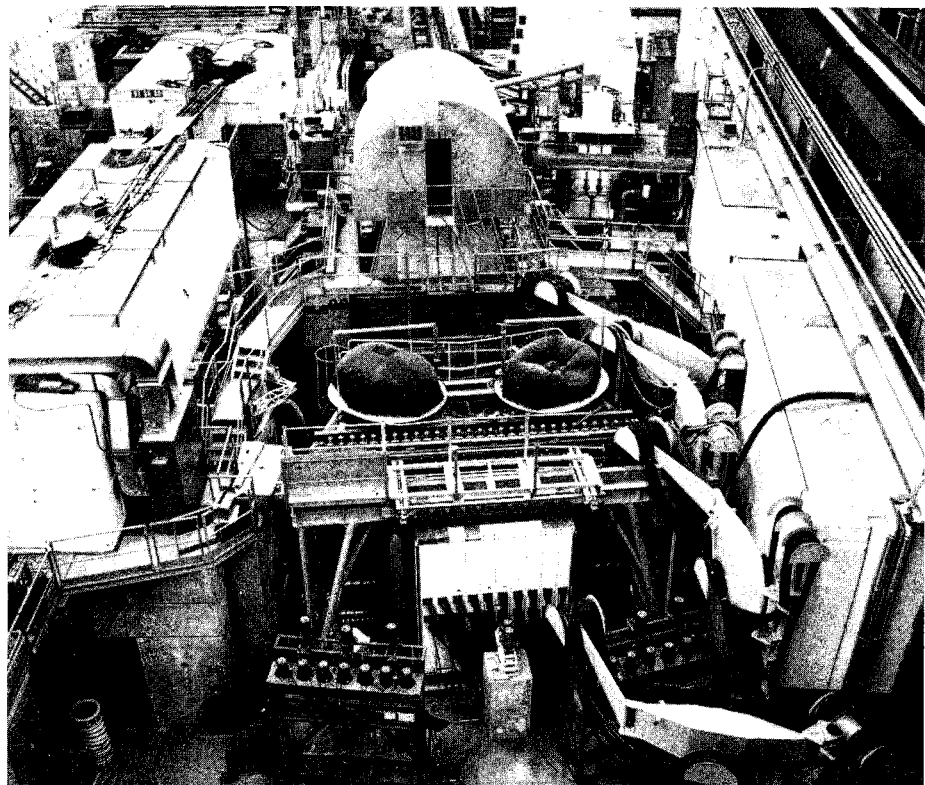
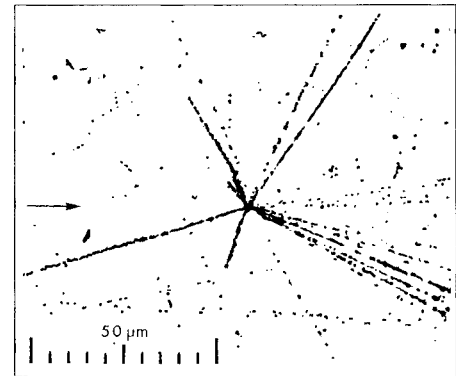
built to measure the position and energy of secondary photons using an active converter of 40 lead glass bars, each 1.5 m long, followed by a 700 element scintillation counter hodoscope and a wall of 340 lead glass counters. This assembly enables the experimenters to identify and measure photons, electrons and neutral pions.

Photoproduction experiments encounter a large background due to the electromagnetic production of electron-positron pairs at a rate several hundred times that attributable to hadronic production. However, a photoproduced charm event would be characterised by high multiplicity, with five or more charged tracks being produced, and this suppresses the electromagnetic background contribution by a factor of several hundred. By intercepting those final states in which a charged kaon is produced, selection is improved still further and the experiment can be run at high intensities —

*An enlarged view of an interaction in an emulsion plate exposed to the Omega tagged photon beam. Over 600 such plates have been exposed, and are being scanned and analysed in detail in a search for decays of charmed states. The emulsion plate is exposed to the beam in place of the liquid hydrogen target.*

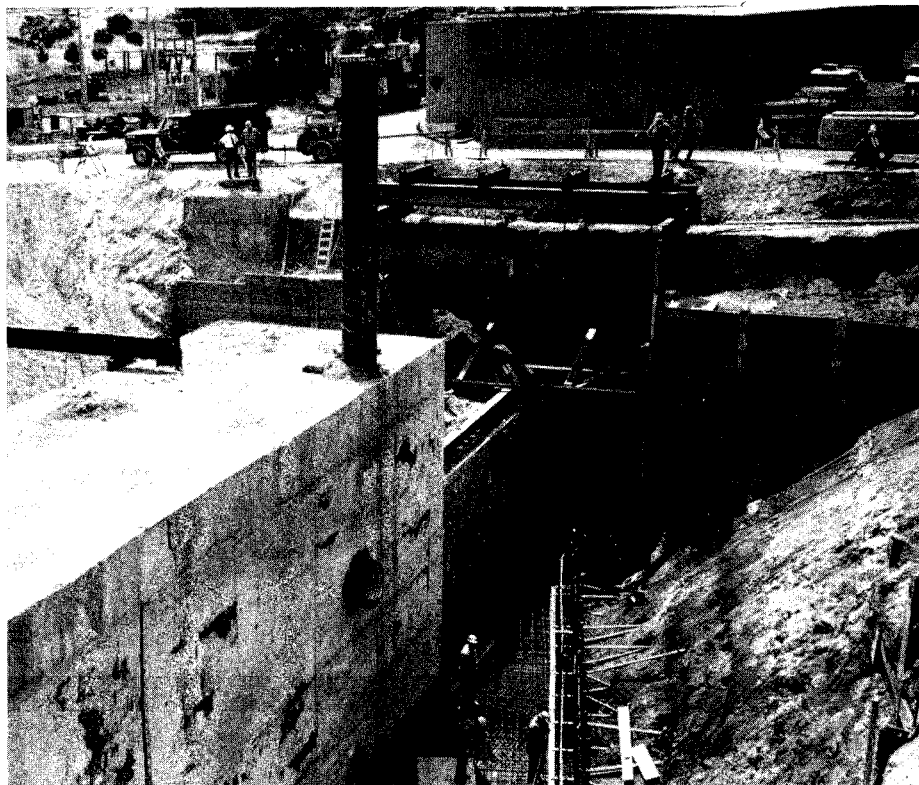
$3 \times 10^{12}$  protons per pulse. After several early test runs, a 20-day run in July and August succeeded in recording over one million hadronic events onto magnetic tape and these are now being avidly scanned for signs of charm production.

The lifetime of photoproduced charm decays is being investigated using emulsion techniques by a Bologna / CERN / Florence / Genoa / Paris / Santander / Valencia collaboration supported



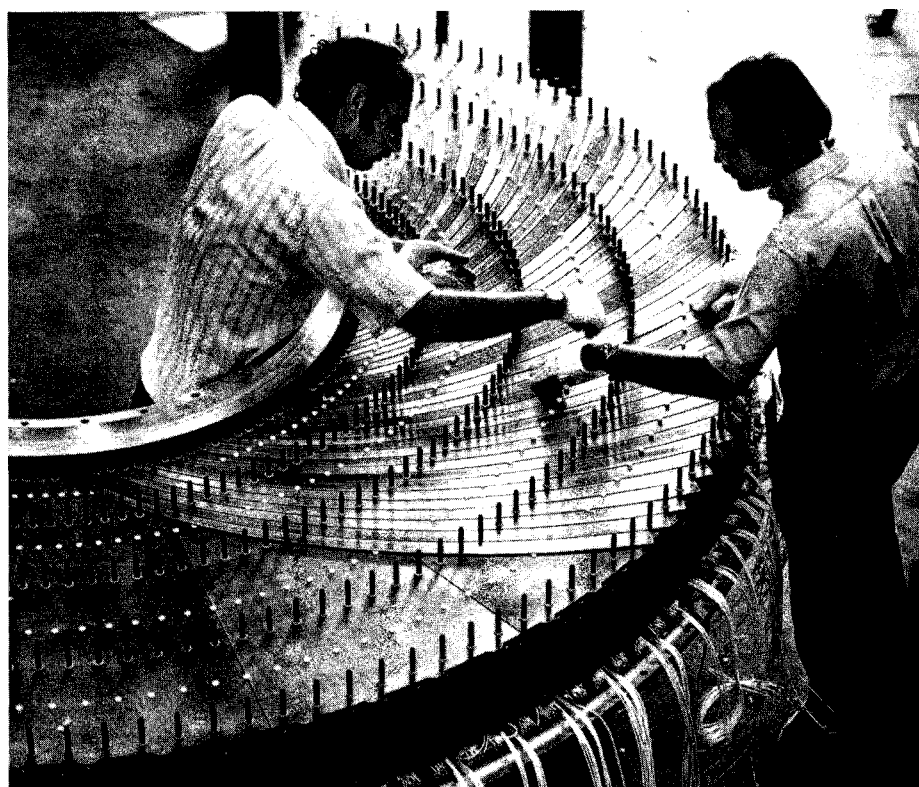
Excavation and construction work for PEP is now well under way while the linear accelerator is switched off. The two storey beam switchyard housing is seen in the foreground and the klystron gallery in the background. The steelwork in the foreground will reinforce the floor of the PEP injection tunnel. Since this photo was taken, the linear accelerator housing has been pierced at this point to provide access from the injection tunnel.

(Photo Stanford)



The Mark II detector is now being made ready for installation in SPEAR to replace the famous Mark I detector which found the *psis*, etc. The photo shows the mounting of lead strips nearing completion for the liquid argon shower chamber end caps.

(Photo Joe Faust)



by the WA4 group (not the Birmingham / CERN / Ecole Polytechnique / Munich / Neuchâtel collaboration as reported in May). In this experiment, information from the Omega electronic detector is used to pinpoint the vertex of a charm decay in a thin emulsion plate. Some 600 plates have been exposed to the tagged photon beam and thousands of photo-hadronic events have been stored in the emulsions.

As part of a plan to provide a 40 GeV/c r.f. separated beam for Omega, two accelerating sections, each consisting of five welded cavities, have been constructed at the Nuclear Research Institute at Karlsruhe. These sections now produce reliable fields of 1.4 MV/m and will be installed in the Omega beam-line before the end of the year. This will provide enriched beams of kaons and antiprotons greatly extending the scope for hadronic experiments at the SPS. Further plans for Omega include the replacement of the existing optical spark chambers by multiwire proportional chambers, allowing experiments to be run with lower deadtime losses and enabling smaller cross-sections to be measured.

With the first experimental results from the SPS already to their credit, the Omega teams are eagerly awaiting further exciting results.

## STANFORD Construction work starts for PEP

While the ground-breaking ceremony for PEP (pictured on the cover of the June issue) took place on 2 June, construction work began in earnest when the electron linac beam was turned off on 27 June. The immediate task was to add the PEP North and South injection tunnels to the existing linear accelerator housing before the beam is turned on again at the end of October. During this period, workers must ex-

The layout of the superconducting pion channel which is to be built for therapy with pion beams at the SIN cyclotron.

cavate down nearly 15 m, cut into the linac walls, build two injection tunnels, seal off the ends (to keep the radiation in and the dirt out) and backfill.

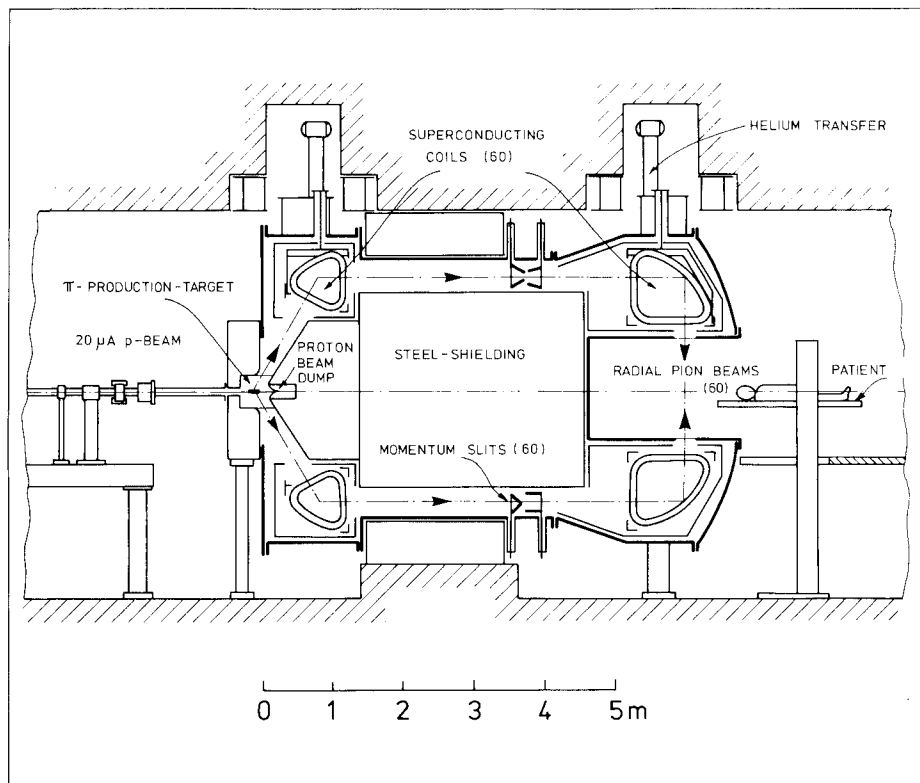
Normally this would not be too great a construction job, but a maze of existing utilities such as duct banks, water pipes and service buildings have provided an interesting obstacle course. Because the excavations use the 'cut-and-fill' method, all these obstacles have to be suspended in mid-air across the excavated pit with the help of an increasing number of beams, tie-rods and suspension cables. As the diggers work their way down to the linac housing, timber walls are used to hold back the surrounding earth until enough of the linac housing is exposed to begin concrete forming for the two injection tunnels.

Meanwhile at SPEAR, the Mark I detector which discovered the psi particles has been removed and Mark II is now taking shape. This new detector encloses a cylindrical system of drift chambers, while the two ends are capped with more detectors to provide almost complete  $4\pi$  solid angle coverage of the interaction region. It will later be moved to PEP.

## SIN Pion Therapy Facility

The development of radiotherapy using pion beams, which is one of the few practical applications of high energy physics knowledge at present, has received a great deal of attention at SIN from the very beginning. The first stage to use pions for medical purposes started in 1975 with the commissioning of the biomedical pion channel  $\pi E3$ , in which a considerable amount of dosimetry and radiobiological experience has been gained.

The logical extension of this preparatory work to actual medical applications, including pion radiotherapy itself, requires a more intense beam.



Because of demands for increasing dose from the radiotherapists and because of delays in acquiring a new higher intensity injector cyclotron, the  $\pi E3$  beam has proved inadequate for such purposes.

Various designs for a new pion beam were examined during the Autumn of 1975. These included a conventional channel incorporating giant quadrupole lenses, a forward-extracted double dipole beam with an electrostatic separator, and finally a superconducting toroidal pion channel producing sixty independently controlled confocal pion beams. A decision was made in favour of the latter design, which had previously been conceived and realized at the Stanford High Energy Physics Laboratory in collaboration with the Stanford Medical Centre.

The advantages of such a system compared with equally intense conventional beams, include a better ratio of peak to entrance dose deposition (multi-port effect) and greater ease in providing variable three dimensional dose distribution. Major modifications made to the original Stanford design have been the use of a proton beam for meson production, instead of the less efficient electrons, and the choice of a pion production angle of  $60^\circ$  rather than  $150^\circ$ . This latter decision followed measurements of pion production cross sections at SIN during the Summer of 1976.

In addition, field boundary rotations of typically  $1.5^\circ$  were introduced to compensate for effects on axial focusing by the extension of the fringe field, a modification which allowed a 30% increase in the calculated available pion intensities. The design of the pion therapy facility including the superconducting channel is now finalized and is expected to be realized towards the end of 1978.

The proton beam for the new biomedical facility will be separated off from the main beam after extraction from the ring cyclotron. The primary beam splitter will be an electrostatic septum with a field on both sides of the septum foil to double the separation angle. This has the advantage over pulsed splitters that it does not alter the time structure of the beam and allows a continuously variable splitting ratio. The estimated beam losses (0.1% or less) on the septum are no real problem. The separation angle of 5 mrad from the primary splitter is increased to 100 mrad by a septum magnet which allows complete separation of the beam to the facility.

The beam will be directed onto a separate target station immediately in front of the superconducting pion channel. The target will be gas cooled (in contrast to the other external targets at SIN which have radiation cooled rotating wheels). A gas cooled system facilitates the exchange of targets of different materials and

Two major excavation / construction projects have taken place around the main ring at Fermilab during a four week August-September shutdown. The use of precast construction techniques permitted them to be completed comfortably within the scheduled time.

1. To the southeast of the Central Laboratory building, the transfer hall has been lengthened to help in maintenance and to reduce personnel exposure to residual activity (particularly important at the higher intensities at which the accelerator is now running). It will also make extraction at 1 TeV feasible. The main ring lies exposed on the left and a precast tunnel section is being lowered into position in the transfer hall.

geometry should they be needed.

Typical targets will be 3.5 cm of copper or molybdenum. The expected pion intensities which can be directed into the patient are typically  $2.10^9$  per s, giving a dose rate of 50 rads/min in a cylindrical volume of 1 litre. A therapy fraction may thus be delivered in a few minutes.

Work is now proceeding on the constructional details, on the very demanding therapy planning schemes necessary to realize the required doses in all cases, and on the numerous administrative activities with international and Swiss medical personnel, concerned with the coordination and realization of therapy in the course of 1979.

## FERMILAB Preparing for colliding beams

A three week Study on colliding beams was held in Aspen, Colorado, from June 27 to July 15 concentrating on proton-proton and antiproton-proton collisions using the Fermilab Main Ring and Energy Doubler / Saver. A year ago, the decision was taken to exploit the possibility of colliding the proton beams in the two accelerators and a new Department, the Colliding Beams Department headed by Jim Cronin, was established in the Research Division. The study was organized by this Department to aid its work in the coming months. It involved about fifty physicists from 15 institutions and laboratories in the USA (including ERDA and NSF) and guests from CERN and Saclay.

The two principal objectives are to achieve proton-proton collisions at energies up to 1 TeV against 250 GeV with a luminosity of  $10^{30}$  per cm per s or more and antiproton-proton collisions in the Doubler / Saver providing up to 2 TeV in the centre-of-mass with



1.

a luminosity of  $10^{29}$  or more.

As a step towards the first objective, experiments on beam storage have been under way in the Main Ring to investigate its suitability as a storage ring. The results of these experiments (reported below) were one of the major topics of discussion, led by Alvin Tollestrup, at the Study. As a step towards the second objective, the Accelerator Division under Russ Huson has started construction of a small ring beside the Booster to test electron cooling of a proton beam; work on this topic at the study was led by Peter McIntyre of Harvard/Fermilab.

The test ring for the electron-cooling was given considerable attention and some aspects of the interaction of the solenoidal magnetic field at the cooling region with the beam were clarified together with corresponding necessary modifications of the lattice. Other subjects were a detailed comparison of the electron beam design with that planned in the equivalent cooling project at CERN, a review of antiproton production cross-sections, target system, beam transport and acceptance by the Booster. Two solutions were obtained to the problem of correct phasing of the r.f. system for simultaneous acceleration of both antiprotons and protons in the one ring. Utilization of the intense antiproton beams available at up to 1 TeV for fixed target physics was also considered and preliminary discussions were held on a

more ambitious antiproton cooling project that would yield higher luminosity.

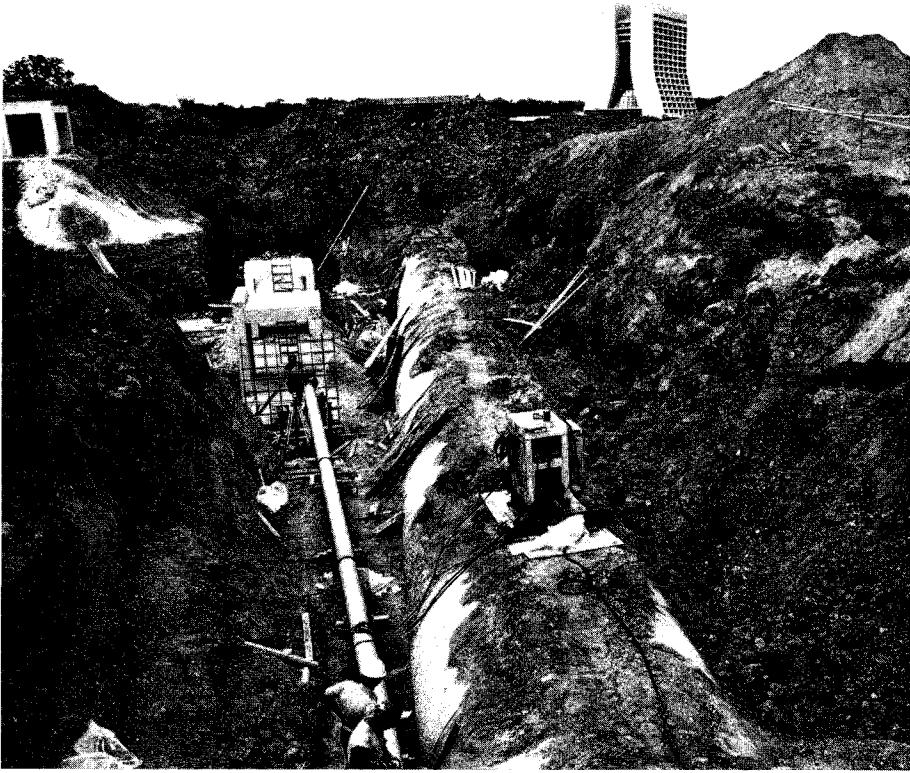
There were three other headings for the discussions — beam manipulation at intersection regions (led by Bob Diebold of Argonne), detectors (led by Dave Hitlin of SLAC) and other topics (led by David Ayres of Argonne).

Two basic arrangements for bringing about Main Ring / Doubler collisions were studied — a transposed geometry in which the beams cross and a 'kissing' geometry in which the two beams are brought to touch while moving in opposite directions.

In general, the transposed geometry has more flexibility and was found to be better suited to experiments. For example, a full 50 m can be left free for experiments with a fixed interaction point at the centre and the luminosity can be increased by adding special magnets to make the beams cross at a small angle and still leave approximately 10 m for a detector. The special magnets are considerably more straightforward in the transposed scheme. The principal drawback is that at least one sixth of the Main Ring must be lowered and the Energy Doubler built as a non planar machine.

The detector group considered detection systems emphasizing the physics of particle production at large angles and studied optimum systems for the two cases of asymmetric proton-proton collisions of 1000 and





2.

250 GeV and symmetric 1000 and 1000 GeV antiproton-proton collisions.

Four magnetic detectors received attention — solenoid, dipole, toroid, and magnetized iron configurations. The solenoid design was chosen as the best for the central detector. A thin superconducting coil with a radius of about 1.25 m and a length of 6 m producing 1 to 1.5 T served as the basis and various track chamber packages for inside the coil were examined. Liquid argon with lead plates located just outside the coil was regarded as a suitable photon and electron detector. Iron for the return flux was integrated into a hadron calorimeter utilizing proportional tubes and located behind the argon detector. Finally, 0.5 m or so of iron constituted an outer shell and acted as an external muon identifier. End-cap detectors were envisaged to increase the angular coverage.

The major item for the General Topics group was the design of colliding beam areas. Various designs that could accommodate a variety of experiments were examined and recommendations were made to perform some radiation measurements to help the design. These measurements and final area design will be a major activity in the next year.

Consideration was given to the future development of a bypass to the Main Ring providing up to a 300 m

long straight section for studying colliding beam interactions under optimum conditions at up to 2 TeV. Finally, the possibility of a 15 GeV electron beam in the Main Ring colliding with 1 TeV protons in the Energy Doubler was considered; a luminosity of  $10^{32}$  per  $\text{cm}^2$  per s appeared feasible.

#### The storage ring tests

The characteristics of the Main Ring at Fermilab as a storage ring have been explored in several recent accelerator study periods, in preparation for its use as part of the colliding beam facility. The time dependence of the beam intensity along with transverse and longitudinal beam distributions were measured as functions of vacuum pressure, horizontal and vertical machine tune, beam energy and other operating conditions.

Most stores were initiated at intensities from  $1.5$  to  $2 \times 10^{13}$  protons and the energy varied from 75 GeV to 200 GeV. The pressure averaged around the ring was  $10^{-7}$  torr or less. Backgrounds at a long straight section were measured and significant effort went into the control techniques so as to simplify the storage procedure and to record the data of interest.

Scattering from residual gas is one cause of deterioration of beam quality and reduction of intensity, setting a limit to how long a useful beam can be stored. There are two ways that a

2. The second venture in contemporary archeology occurred between the r.f. station and the transfer gallery where the reverse injection / antiproton extraction stub was installed to be linked on to a stub installed earlier at the booster. Completion of the reverse injection line tunnel now requires trenching and tunnel installation only between the two stubs.

proton can interact with a nucleus of the residual gas — the catastrophic nuclear interaction and the gentler, but much more frequent, Coulomb scattering. A proton undergoing a nuclear interaction is immediately lost and this mechanism alone should lead to an exponential decline in intensity without altering beam size. With a pressure of  $10^{-7}$  torr the predicted lifetime is 12000 s roughly independent of energy. Lifetimes, measured from the initial rate of change of intensity during a store, have been as long as 25000 s (about 7 hours), corresponding to an average pressure of about  $5 \times 10^{-8}$  torr.

Coulomb scattering, on the other hand is a diffusion process leading to gradual growth in beam size. Initially, when the size is well within limiting apertures, very little beam is lost but as the size grows protons can pass beyond the boundary. After a long time, the beam asymptotically approaches a size determined by the limiting aperture and the intensity then decays exponentially with a lifetime that depends quadratically on the energy. At  $10^{-7}$  torr, the expected lifetime for this process is 2800 s at 100 GeV and 11200 s at 200 GeV.

As in normal acceleration, the horizontal and vertical tunes of the machine (number of betatron oscillations per revolution) are extremely important variables when storing a beam. For example, setting the tune at the fifth-order resonances at 19.4 causes rapid beam growth and intensity loss and, conversely, at the empirically-determined best tunes, the intensity dependence approaches the gas scattering limits.

As understanding of the intensity dependence grew, more attention turned to the transverse and longitudinal beam distributions. The luminosity for head-on collisions is directly proportional to the product of the two beam intensities and inversely proportional to the beam size. The

# Physics monitor

longitudinal distribution of a bunch affects the length of the interaction region and hence the size of the detectors.

Transversely, the beam growth rate settles down to the predicted gas scattering value after an initial period of about a minute of somewhat faster growth which can be prevented by starting with longer bunches. The bunch length grows from about 2 to 5 ns in a similar period and then stabilizes. The early evolution of these beam distributions is receiving much experimental and theoretical attention.

The backgrounds in the straight section were large and the variations with angle and distance from the beam pipe were measured under various conditions. Integrating the early measurements gave an estimated total flux of 230 MHz through a hypothetical detector of 1 m radius for  $10^{13}$  protons in the ring; later measurements, with somewhat better average pressure, correspond to a flux of 84 MHz.

There are indications that the backgrounds are due to high multiplicity events affecting a small fraction of the bunches. The background rate is approximately proportional to intensity (rather than to proton loss rate) and to local vacuum pressure, suggesting an origin in local beam-gas interactions. A bakable vacuum pipe has been installed in the straight section to reduce local pressure and further background reduction will be accomplished by means of vacuum improvements throughout the ring, by shielding, and by beam scrapers.

## Building particles from new quarks

The observation at Fermilab of high mass enhancements in muon pairs is evidence, though not yet conclusive, for the existence of a new heavy quark (see August issue, page 223).

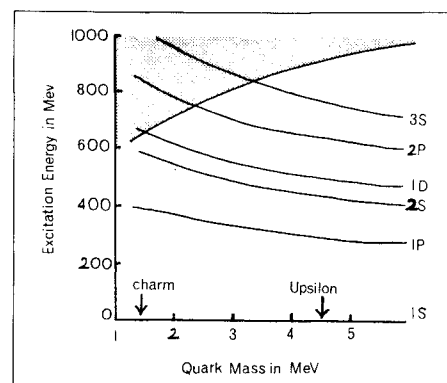
The study of the spectroscopy of the now abundant charmed mesons has enabled physicists to parameterise the interaction between heavy quark-antiquark pairs and months before the sighting of the Upsilon enhancements by the Columbia / Fermilab / Stony Brook collaboration, E. Eichten and K. Gottfried from Cornell had pointed out that heavier quarks, if they existed, would have an even richer spectroscopy. The structure which already seems to be seen in the Upsilon enhancements could bear this out.

By analogy with the well known positronium bound states of an electron and a positron, these quark-antiquark bound states are often referred to by an '-onium' suffix, so that the bound states of a charmed quark and a charmed antiquark (the J/psi family) are examples of 'charmonium'.

For the lightest quarks (u and d — the constituents of the nucleons), the quark-antiquark binding is not powerful enough to form proper '-onium' states but only resonances which decay strongly. For the strange quark (s), the situation is marginal. The phi meson, for example, is only just above the threshold energy for strong decay into  $K\bar{K}$ . If the  $s\bar{s}$  binding were a little more powerful, then a 'strangeonium' bound state would be seen.

For charmed quarks (c), the masses and binding energies are such that the lowest lying  $c\bar{c}$  bound states cannot decay into a channel which displays 'naked' charm. The lightest of the naked charm mesons, the D, has a mass of 1864 MeV, and a charmonium state has to be heavier than 3728 MeV ( $2 \times 1864$  MeV) before strong decays

*The predicted variation in the pattern of quark-antiquark '-onium' bound states, neglecting spin. The shaded area shows where strong decays into mesons having 'naked' flavours are possible. On the left, one sees the spectrum of charmonium with 1s (the psi), 2s (psi prime) and 1p (chi) states all below this threshold. The higher the quark mass, the greater the number of stable (narrow width) states.*



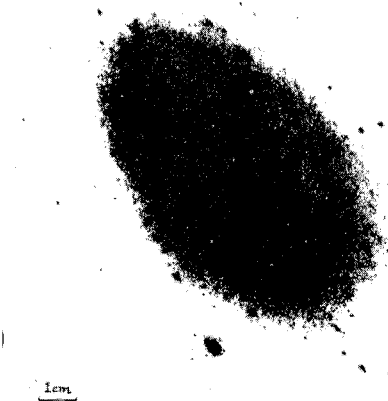
into D mesons become possible. Lighter charmonium states, like the J/psi at 3095 MeV, therefore have very high stability (narrow widths) compared with their heavier counterparts and this was the feature which made the J/psi discovery so dramatic.

Since the discovery in 1974 of the first charmonium states, at 3095 and 3684 MeV respectively, the spectroscopy of charmonium has been unfolded by an impressive series of experiments at SPEAR and DORIS.

The new states correspond to higher excitations of the  $q\bar{q}$  interaction, to states where the  $q\bar{q}$  has rotational angular momentum as well as intrinsic spin, and to states where the  $q\bar{q}$  spins line up antiparallel. Quarks with spin  $1/2$  can bind together as  $q\bar{q}$  states either with their spins parallel (total spin 1), or antiparallel (total spin 0). These latter charmonium states are particularly difficult to observe as their symmetry properties preclude them from coupling directly to a photon and they are therefore seen only indirectly in the decays of the spin 1 states formed in colliding beam experiments.

The interaction between a quark and an antiquark can be simulated by a static attractive potential that is independent of quark mass. Neglecting spin effects, the expected spectrum of bound states can then be calculated using the Schrödinger equation, where the quark mass comes in through a kinetic energy term. The calculated

*The famous 'Andromeda' cosmic-ray event seen by a Brazil/Japan collaboration. The picture shows just the central region of a cluster of over 300 particles detected over an area of  $40 \times 50 \text{ cm}^2$  in a detector of area  $48 \text{ m}^2$ .*



variation of level spacings relative to the ground state is shown in the diagram.

The shaded region indicates where the 'onium' states can decay strongly into pairs of particles having the appropriate 'naked' new flavour. On the left one sees the spectrum of charmonium with  $1s$  (the  $\psi$ ),  $2s$  (the  $\psi'$ ) and  $1p$  (the  $\chi$ ) states bound, but incapable of decaying strongly into charmed mesons. The  $1d$  state corresponds to the newly-discovered  $\psi(3772)$  state just above threshold for production of charmed mesons (see August issue, page 225).

On the right, a quark mass of about  $5 \text{ GeV}$  shows the pattern of states expected for Upsilon and there are roughly twice as many narrow-width bound states allowed. According to this picture, physics at the new CESR, PEP and PETRA colliding beam machines could contain a richness that will challenge the ingenuity of the best experimenters!

## Cosmic events

Even assuming that all the eagerly-awaited particles such as intermediate vector bosons, Higgs particles and quarks are discovered with the next generation of particle accelerators, this

will probably not mean that hadron physics becomes a closed book. Cosmic ray experiments have already hinted that startling new phenomena occur at the prodigious energies reached by the primary cosmic radiation particles.

Since the early 1960s, cosmic ray physicists have been probing the interactions seen in the earth's upper atmosphere with primary particles of energies of hundreds of TeV ( $1 \text{ TeV} = 1000 \text{ GeV}$ ). They think that at about  $100 \text{ TeV}$ , a bunch of new phenomena could start to appear, in a totally unexpected, and still unaccountable, way.

In contrast with the sophisticated computer controlled experiments mounted in high energy physics laboratories, the investigations of cosmic ray physicists are crude. This is no reflection on the physicists, but simply a result of the nature of cosmic radiation. The incoming particles are randomly distributed in energy, direction and type, and cause primary reactions high up in the earth's atmosphere, producing complicated showers of secondaries. By taking their apparatus to a high enough altitude, on a mountain or in a balloon, the experimenters hope to get as close as possible to the initial primary interactions. Only by collecting the products of these interactions can the nature of the incoming cosmic ray particle be inferred, and even then only approximately.

The detectors used in these cosmic ray experiments are frequently of the 'emulsion chamber' type, in which a specially-designed sandwich of X-ray films and lead plates, extending in some cases over an area of some  $40$  square metres, is exposed on a suitable mountain site for about a year. The lead plates produce a multiplication of gamma-rays produced initially from the decay of a neutral particle like a pion, and by examining the gamma-ray cascade, the production of neutral pions can be inferred.

Other measurements on the exposed stack enable estimates to be made of the height of the primary interaction above the stack and the total energy in the primary interaction. Because the nature of the incoming primary particle is unknown, this energy is usually given as an equivalent gamma-ray energy — the energy of an incoming gamma ray which would have produced comparable effects.

For interactions whose equivalent gamma ray energies are greater than  $100 \text{ TeV}$ , the multiplicity of secondaries is found to be much greater than would be expected by extrapolating the behaviour seen at lower energies. At  $100 \text{ TeV}$ , the highest expected multiplicity on the basis of lower energy behaviour is about  $30$ , while in some cases the observed level is nearer  $100$ .

The number of observed neutral pions on the other hand is remarkably low. One famous example of this is the famous 'Centauro' event seen in the emulsion chamber experiment mounted on Mount Chacaltaya in Brazil by a Brazil/Japan collaboration, in which ninety hadrons are produced with no neutral pions!

The event got its name because the clusters of event seen at the bottom of the detector apparently had the shape of a Centaur — a mythical creature, half horse and half human. Other famous high energy cosmic ray interactions include Andromeda and the Texas Lone Star, both huge lumps of hadronic matter produced by primary cosmic ray interactions in which extremely large numbers of secondary particles are seen.

Whatever the new generation of accelerators will be able to tell us, it begins to look as if hadronic physics could keep on providing surprises as the energy is increased. With unexpected phenomena seen at  $100 \text{ TeV}$  energies, talk of asymptotic behaviour at laboratory energies seems premature.

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## Instantons

Many particle physicists are convinced that applications of gauge theory hold the key to further understanding. In the still short history of the subject, however, many people have been preoccupied with goldmining for new physics and have not spared much thought for the extra pure mathematics which might be needed to produce a workable theory. General relativity is one example of an area of physics where the use of new mathematical techniques has paid considerable dividends.

Whatever gauge theories might tell us about the behaviour of particles, it is already clear that there are deficiencies in our present methods of handling them. These methods usually turn to perturbation theory, where one hopes that a mathematical series can be found which gives, term by term, a closer and closer approximation to the correct result.

Although fine for electromagnetic and weak interactions, this approach does not work for strong interactions because of the large coupling constant involved. While gauge theory games continue with the limited mathematical techniques at our disposal, some theoreticians are standing aside from the mainstream activity to see if other mathematical ideas could be used instead. Although there has been no major breakthrough, some general deficiencies of the usual picture of gauge theory applications have been discovered.

By ignoring the conventional perturbation theory approach, A. Polyakov and collaborators and G. 't Hooft have shown that the existence of peculiar new entities cannot be ruled out, and it was quickly realised that these new entities, called 'instantons', could, if they exist, play havoc with conventional ideas of quantum number conservation and selection rules. In addition,

a number of mathematical specialists have tried to put the ideas of Yang-Mills gauge theories into a more general mathematical framework, so that these 'instantons' and other peculiarities can be described in a natural way.

The idea of a Yang-Mills gauge theory is to produce a mathematical picture which describes the required symmetry of particle properties and comes out naturally with the right conserved quantum numbers. Just as the theory of quantum electrodynamics exploited the symmetry of its interactions in four dimensional space-time, subsequent work has concentrated on finding the additional 'internal' symmetries of interactions which might have to be superimposed on our familiar space-time world.

In this picture, each point in space-time is supplemented by an internal space which describes the microscopic behaviour of a particle at that point. When we go from one space-time point to another by two different paths, we do not necessarily land up at the same point in the two corresponding internal spaces. The difference between these two internal points is not observable and this freedom, or arbitrariness, is exploited in the gauge theory approach to produce the required picture of the interaction.

But the mathematics of gauge theory can become clumsy and difficult to handle. Just as a Fourier transform which takes ordinary space into momentum space can sometimes greatly simplify a mathematical problem, so it has been suggested by M. Atiyah at Oxford that some of the difficulties of handling Yang-Mills theories could be overcome by transforming the problem into some other space.

The approach is analogous to the well known technique of representing two-dimensional rotations by a system of one-dimensional complex numbers. As well as reducing the number of

dimensions of the problem, the technique means that the nature of the interaction becomes implicit in the algebraic geometry of the new space.

The different types of physical behaviour are then characterised by integer numbers (like quantum numbers) which describe the topology of the mathematics in the new space. One 'simple' type of behaviour corresponds to lines in the new space but to points (i.e. events) in space-time and these are the 'instantons' discovered mathematically by Polyakov and whose relevance for physics has been elaborated by 't Hooft.

These considerations show that there can be more than one vacuum for each gauge theory picture. What does this mean? Naively, one empty space is much like another, but if there are invisible internal symmetries at work, then there might be residual internal directional effects still around when everything else is taken away. These directional effects could distinguish one vacuum from another.

A normal Yang-Mills gauge transformation should take one of these vacua into another. One mathematical result of this is that there should be something intermediate between the two vacua, which is itself gauge invariant, and therefore observable. These mysterious intermediate phenomena, which spend their time burrowing from one vacuum state to another, are the 'instantons'. Although they are events rather than particles, this burrowing is analogous to the well known quantum mechanical tunnelling effect where particles can statistically seep through an obstacle even though they do not have enough energy to get over it.

The existence of instantons could give rise to all sorts of anomalous effects, and certainly the exponentially-decaying profile of a burrowing instanton is something which cannot be described by ordinary perturbation theory. The most interesting pos-



# People and things

sibilities emerge if the instantons could get out of their trap between neighbouring vacuum states and become free. This would require a tremendous amount of energy and could have been possible in the 'big bang' which created the universe. There, the instantons could have wiped out our conventional rules of baryon number conservation.

Whatever the future may hold for instantons, the increasing collaboration between pure mathematicians and theoretical physicists should pay dividends.

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## *Ken Green*

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*Ken Green, Brookhaven scientist for the past 30 years, one of the leaders in the construction of the 33 GeV AGS and world authority on accelerator design and construction, died in August at the age of 66. After studying at Berkeley with the group headed by Ernest Lawrence, Ken Green arrived at Brookhaven after the war years to become deputy to Stan Livingston, who was then organising Brookhaven's first accelerator project, the Cosmotron. He went on to head the building of the AGS synchrotron which was completed in 1960. He headed the Accelerator Department for many years, participated in the design of the Isabelle storage rings and his last work was in connection with the electron storage ring for the USA National Synchrotron Light Source. Ken was one of the pioneers of accelerator building who contributed considerably*

*to establishing accelerator technology as such a thoroughly understood discipline. He was absorbed by his work and projected his enthusiasms with great gusto. His colleague for many years, John Blewett, writes, 'We have lost a man of extraordinary talent... Ken was skilled as a physicist, both experimental and theoretical, as an electronic engineer, as a power engineer, as a mechanical engineer and as a civil engineer. Withal he was a man with whom it was a delight to associate. Brookhaven will not be the same without him.'*

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## *Energy Department*

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*A Department of Energy has been created in the USA and is beginning operation under James Schlesinger. It takes over some 20000 staff and an annual budget of \$ 10600 million. Prominent among its component parts is the large Energy Research and*



*Ken Green speaking at the Dedication ceremony of the Brookhaven AGS in 1961.*

*(Photo Brookhaven)*

*Development Administration (ERDA) which is responsible for funding the high energy physics research programme in the USA.*

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#### *Exhibiting themselves*

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*The second exhibition under the title 'Italy: Science and Technology' (see also August issue 1976) took place in Bucharest (Rumania) from 11-17 June. The sector devoted to Nuclear and Elementary Particle Physics, co-ordinated by INFN, has been enriched and updated — in particular, the CERN SPS and the Italian participation in its experimental programme were presented. A multiscreen show with the title 'Man and Science', presenting the history of the impact of Science and Technology on Society, was realized with scientific advice from our INFN correspondent, A. Pascolini. The exhibition was opened by the Italian Under-Secretary for Scientific and Technological Research, G. Postal, who signed on that occasion the renewal of the agreement for scientific and technical co-operation between Italy and Rumania. A series of seminars and meetings on various themes completed the exhibition.*

*The Rutherford Laboratory is participating in the Systems 77 Exhibition at Munich from 17-21 October. They are presenting sophisticated computer aided design techniques (two of them as live demonstrations using visual display terminals linked to a GEC 4080 computer): 'THESEUS' uses 3-D interactive graphics to help engineers solve design problems using finite element analysis. 'GFUN' is a program which calculates the field produced by conductors and magnetic materials in three dimensions. 'Aspect Display System' is a powerful interactive graphics hardware system with real time zooming and 3-D coordinate transformation capability. The*

*Rutherford exhibit is in collaboration with NRDC and Compeda Ltd who are involved in commercial exploitation of the systems.*

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#### *SSRP to SSRL*

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*From 1 September the expanding research programme of the Stanford Synchrotron Radiation Project (SSRP), which uses the light emerging from the SPEAR storage ring at SLAC, has been recognized by a change of status. It is now named the Stanford Synchrotron Radiation Laboratory (SSRL) and will report as an independent research laboratory to the Vice-Provost at Stanford University.*

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#### *STELLA in orbit*

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*The Council of Ministers of the European Economic Community (the Common Market) has authorized 1.2 million Swiss Francs for a small satellite earth station and associated computer equipment for use by CERN in an exciting experiment on high speed data communications by satellite. The experiment will involve the Rutherford Laboratory in the UK, DESY in Germany and Saclay in France as well as CERN and will be carried out together with the respective European PTT (posts and telecommunications) organisations.*

*Called STELLA (Satellite Transmission Experiment Linking Laboratories), the project should be fully operational by 1979, when data from high energy physics experiments will be transmitted between the Laboratories using the Orbital Test Satellite (OTS), the prototype communications satellite built by the European Space Agency (ESA) which will be launched from Cape Kennedy.*

*The aim is to demonstrate the possibility of sending data between computers at speeds comparable to the data processing speeds of the computers themselves, and at extremely*

*low error rates. Experience from STELLA could be valuable for industry and the PTTs by testing the behaviour of such communications links in practice. At the same time, high energy physicists will obtain valuable practical experience in the use of such links to improve communications between Laboratories collaborating in physics experiments.*

*Already there has been considerable investment in satellite communications in the USA and a system potentially involving hundreds of small ground stations for high-speed digital transmissions has recently been approved. STELLA is the first European venture in this direction. We hope to carry a full account of the project in a future issue.*

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#### *CERN School*

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*The 1978 CERN School of Computing, organized in collaboration with the Institute for Nuclear Research Warsaw, will be held at Jadwisin, Poland from 28 May to 10 June. It is intended for post graduate students and young research workers in physics or computer science from CERN Member States or collaborating Laboratories in Western Europe. The theme will be large scale data collection and processing in high energy physics. Further information from Mrs. Ingrid Barnett, Scientific Conference Secretariat, CERN, CH-1211 Geneva 23, Switzerland.*

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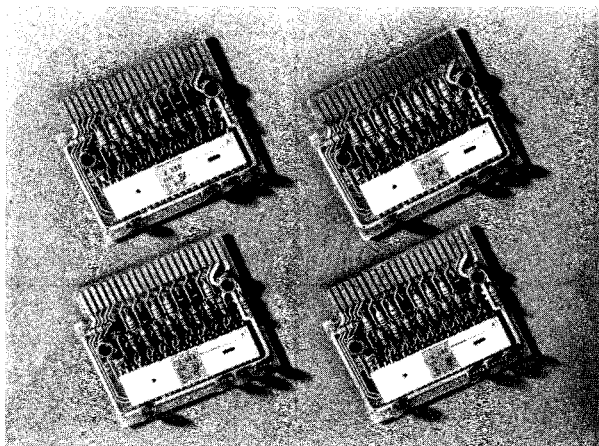
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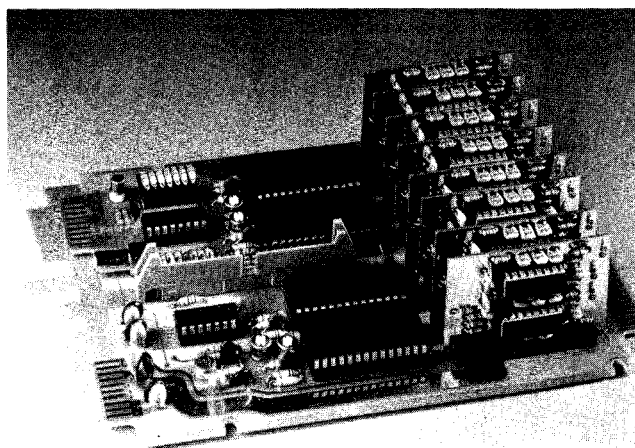
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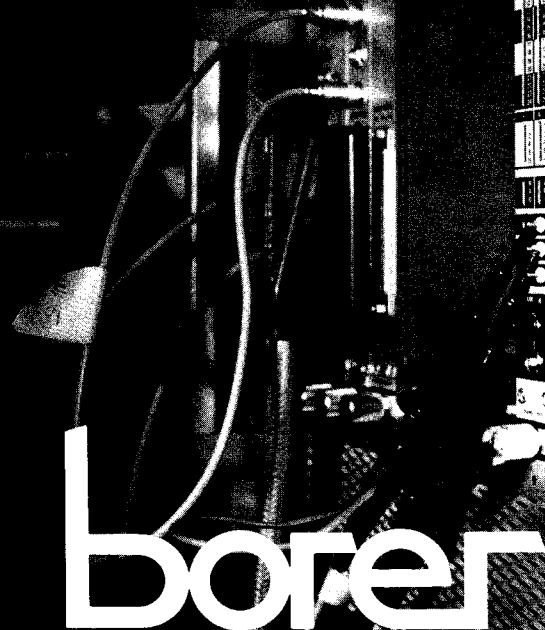




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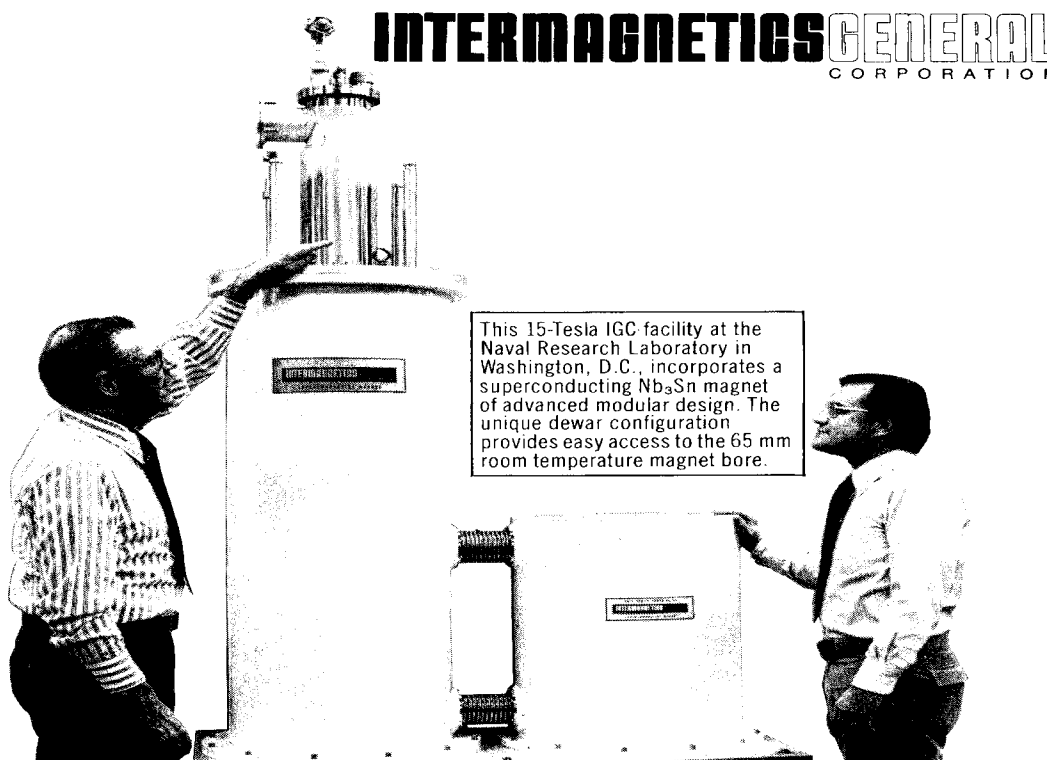
The "record" magnet, commissioned by the Japanese National Research Institute for Metals, uses a combination of Nb<sub>3</sub>Sn tape (manufactured exclusively by IGC) and V<sub>3</sub>Ga tape (manufactured by Vacuum Metallurgical Co. Ltd. of Tokyo). By extending this approach, IGC believes that the goal of producing 20 Tesla in a superconducting magnet is now technically attainable.

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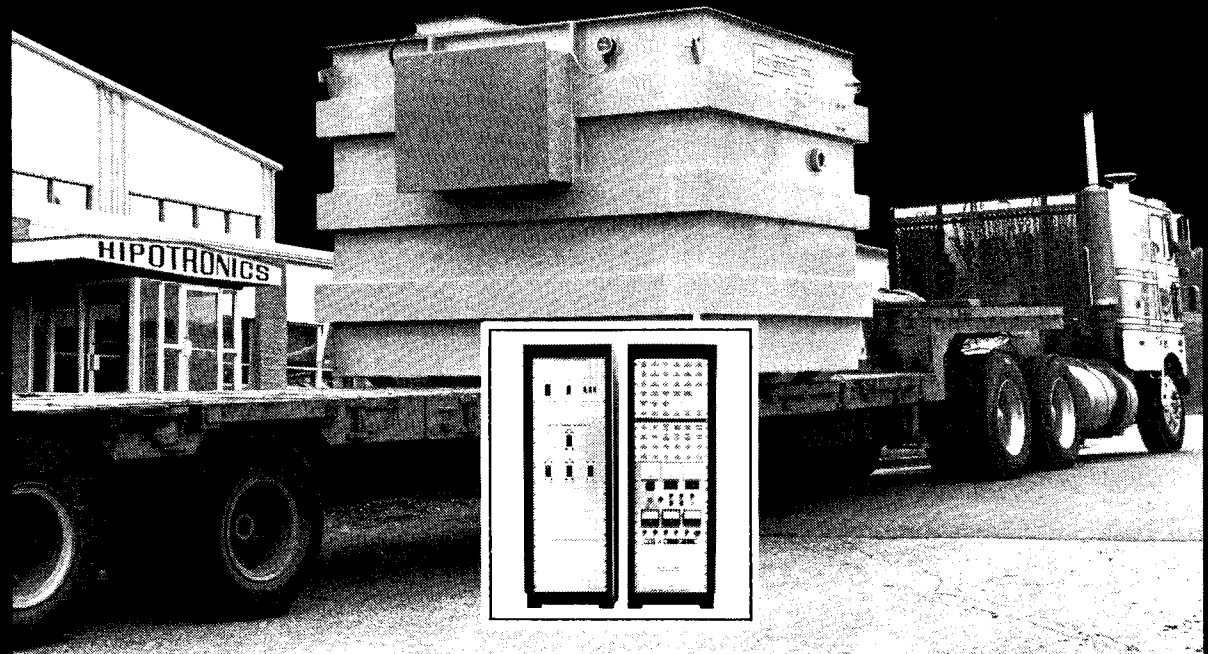
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Institute	Field Strength (Tesla)	Cold Bore (mm)	Homogeneity in 1 cm sphere
National Research Institute for Metals Tsukuba, Japan	17.5	30	10 <sup>-3</sup>
	and 13.5	160	10 <sup>-3</sup>
Lebedev Institute Moscow, U.S.S.R.	16.6	40	10 <sup>-4</sup>
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Naval Research Laboratory Washington, D.C.	15.0	86.4	10 <sup>-4</sup>
University of Campinas Brazil	15.0	54	10 <sup>-3</sup>



This 15-Tesla IGC facility at the Naval Research Laboratory in Washington, D.C., incorporates a superconducting Nb<sub>3</sub>Sn magnet of advanced modular design. The unique dewar configuration provides easy access to the 65 mm room temperature magnet bore.

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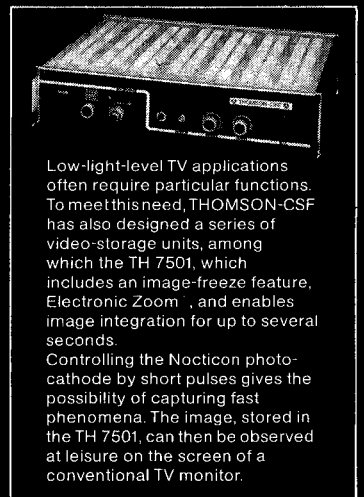
The Nocticon has an S 20 -type photocathode and a silicon-diode-array target, scanned by an electron beam from a gun similar to that of a regular Vidicon.

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- low dark current
- low lag

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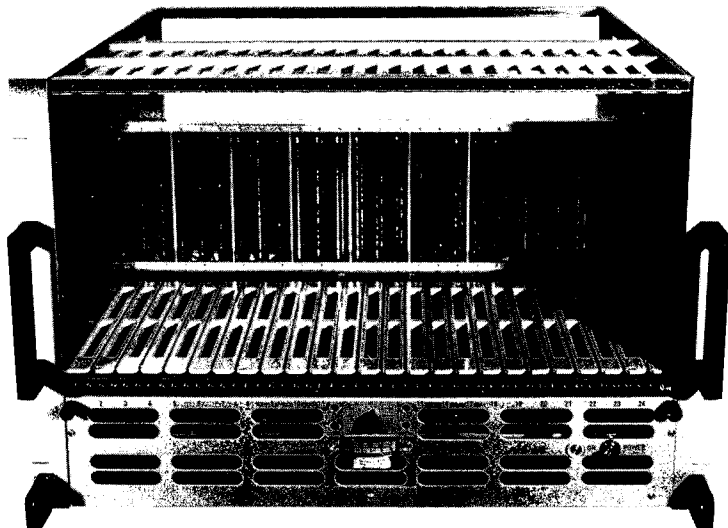


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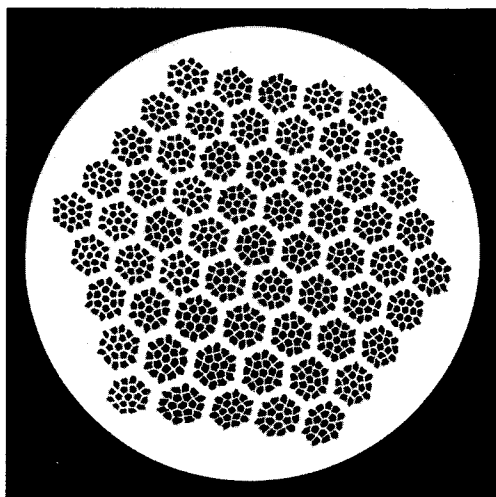
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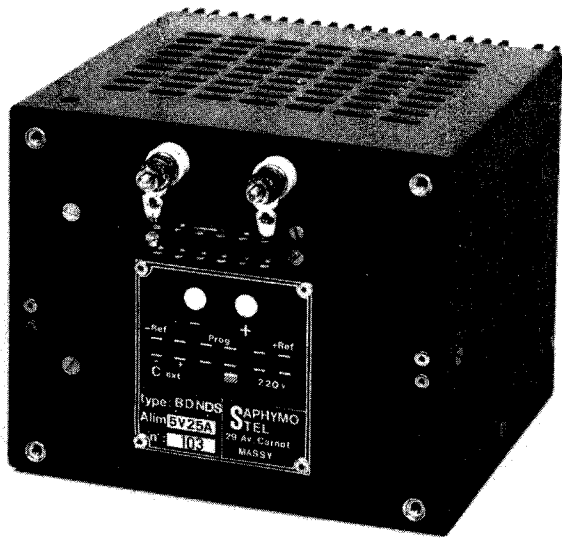
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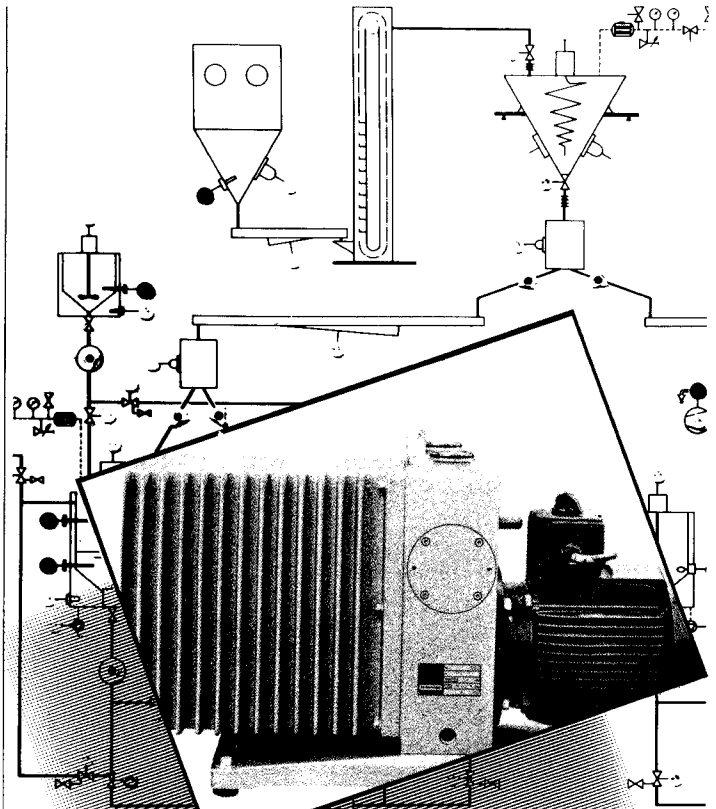


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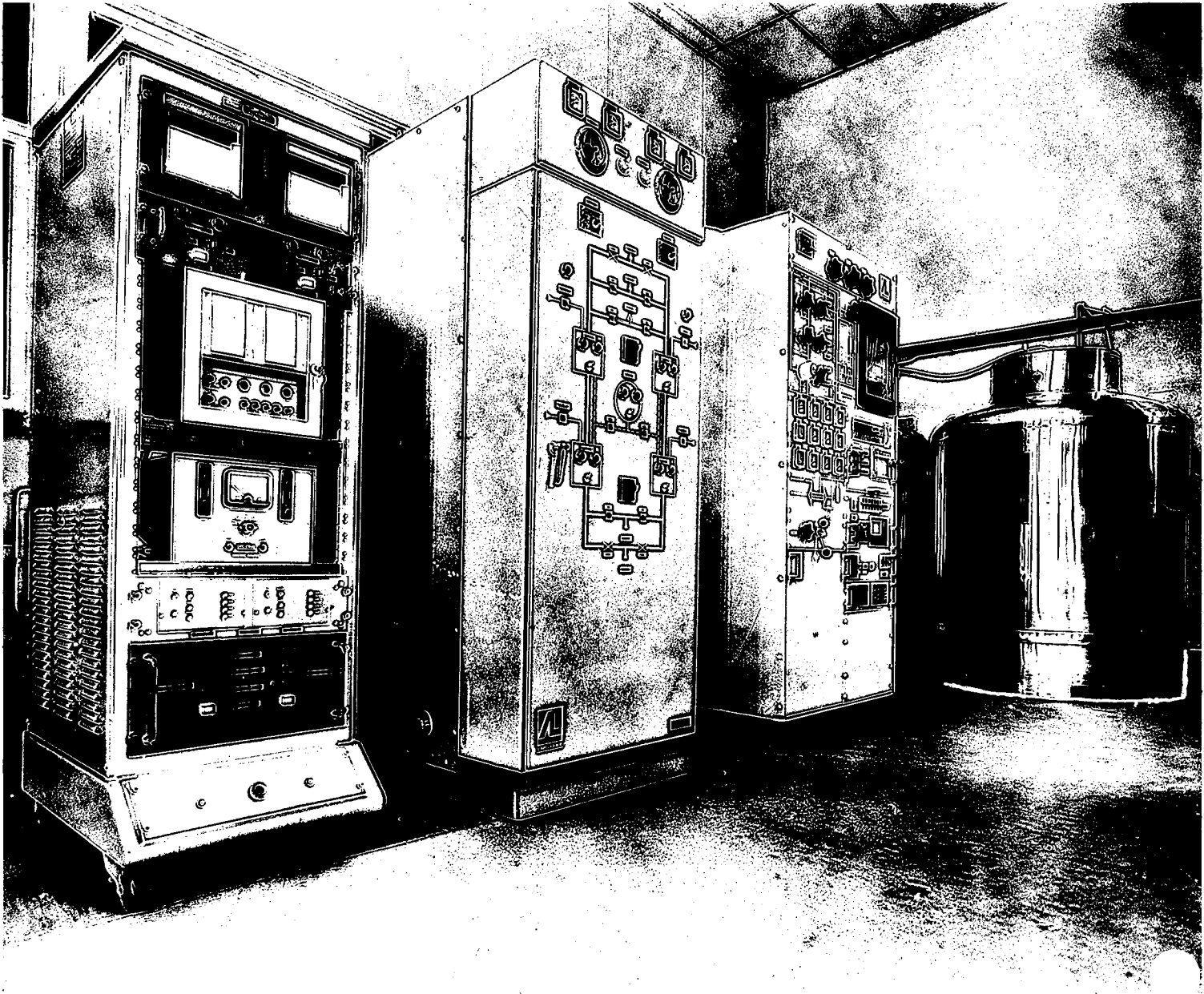
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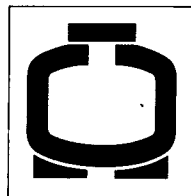
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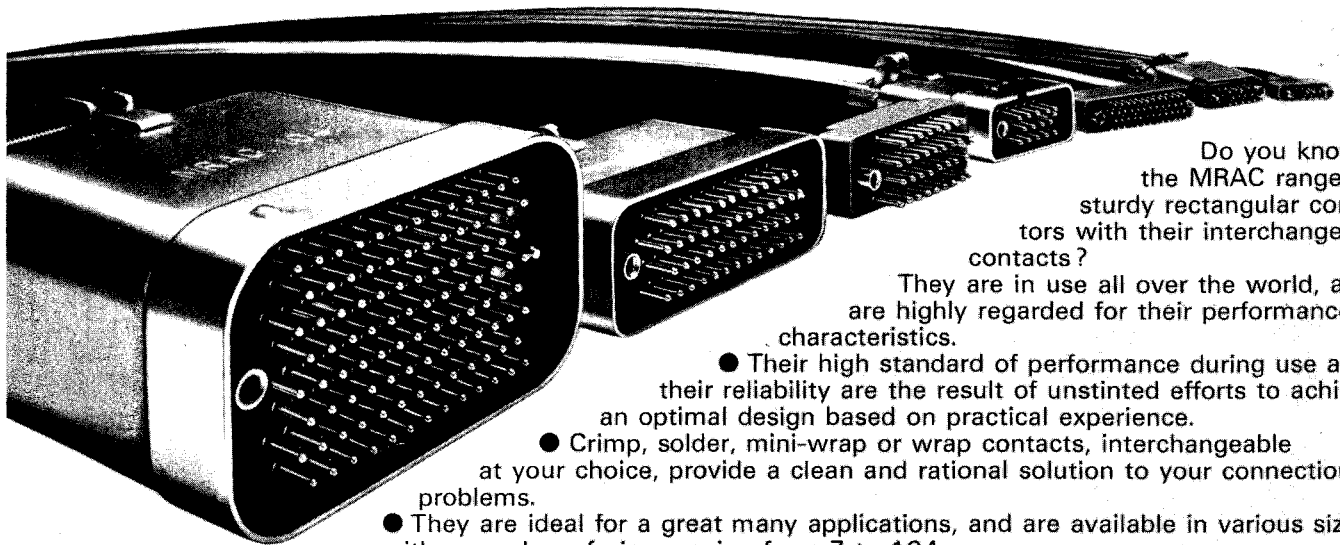


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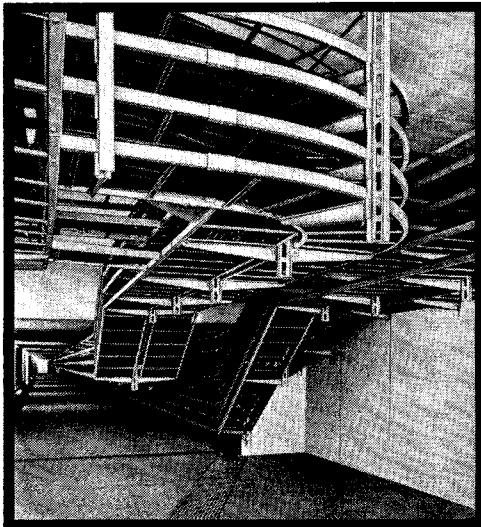
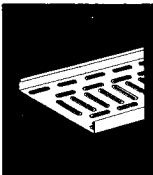
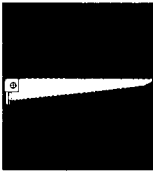
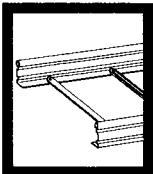


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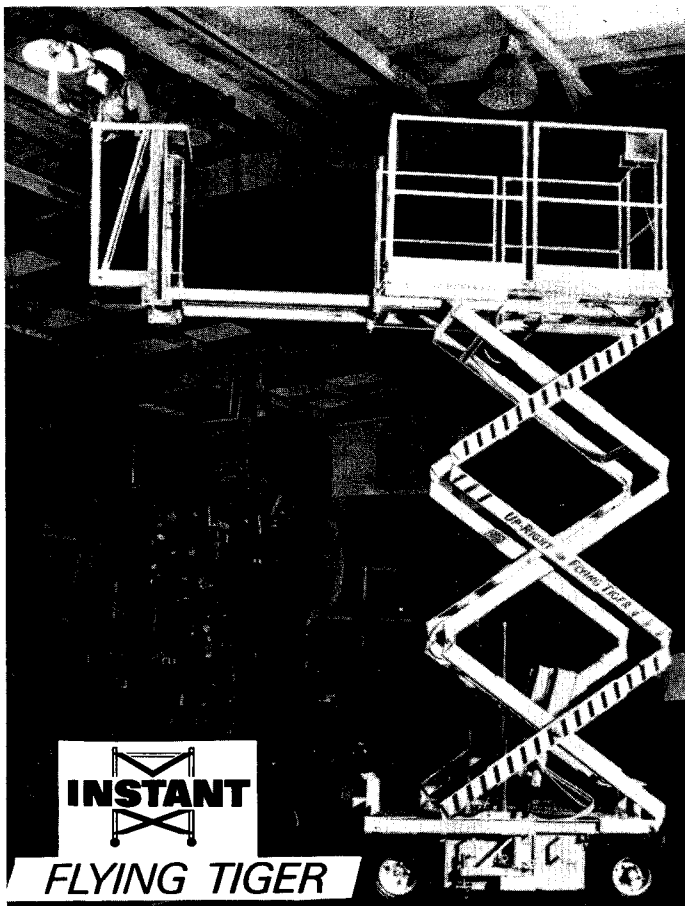
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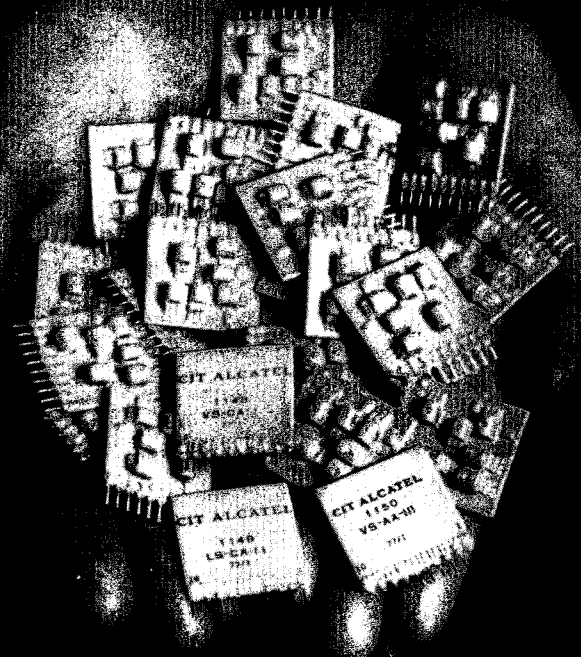
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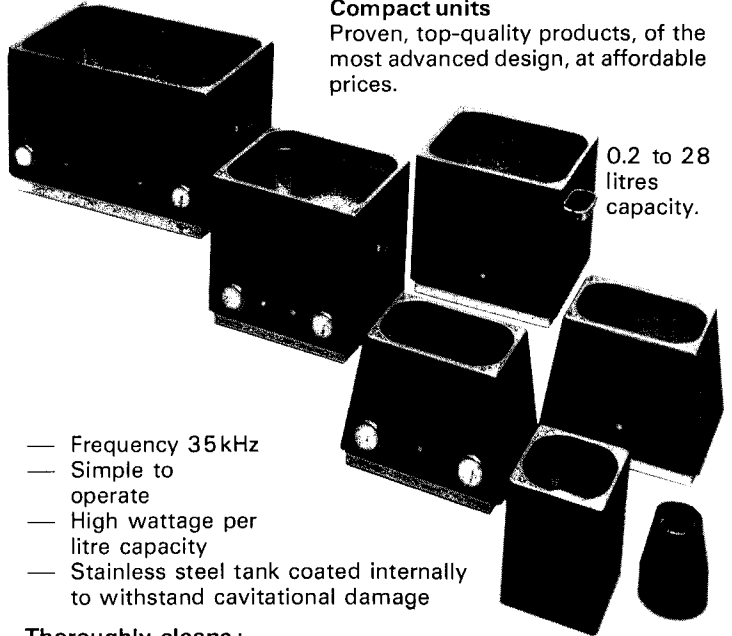
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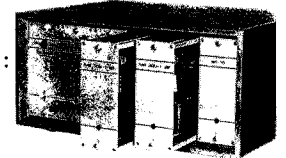
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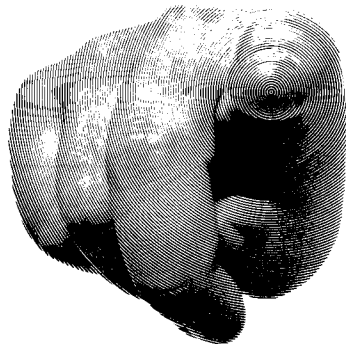
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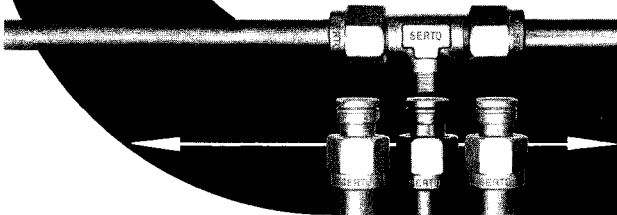
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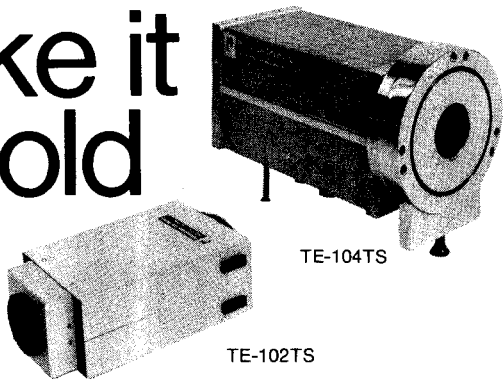
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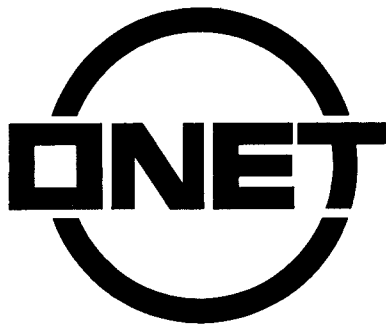
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Lubriflon-PTFE, Ertalon, Ertacetal, Eltflon pour applications électroniques

### ● POLYPLATE PROCESSING

Condensateurs, cônes d'antennes, substrates

### ● TUYAUX FLEXIBLES

pour basse, moyenne et haute pression, types spéciaux avec capacité de résistance aux radiations — fluide eau déminéralisée

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standard ou sur plans en tous matériaux

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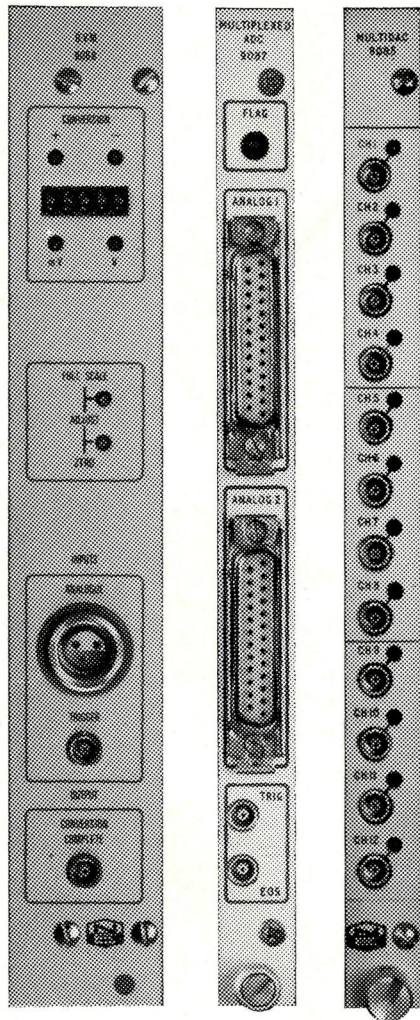
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# CAMAC

## Analogue Input-Output Modules



### 9068 Digital Voltmeter

- \* 4½ digit BCD display
- \* Conversion uses dual ramp technique
- \* Six programmed ranges
- \* Choice of scan speed, 20ms or 2ms

### 9087 16 Channel Multiplexed ADC

- \* Sample and hold
- \* Conversion by successive approximation
- \* Mask register and channel labelling
- \* 32 Word Buffer
- \* 20 microseconds conversion
- \* 12 Bit Resolution

### 9085 12 Channel DAC

- \* Control register to hold output at zero until overwritten
- \* Response time 500 microseconds
- \* 12 Bit Resolution
- \* Output sampled and held

Write for full details and request new CAMAC Catalogue No.108



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# Top-level performances for VIP\* from LABEN amplifiers

\* very important physicists

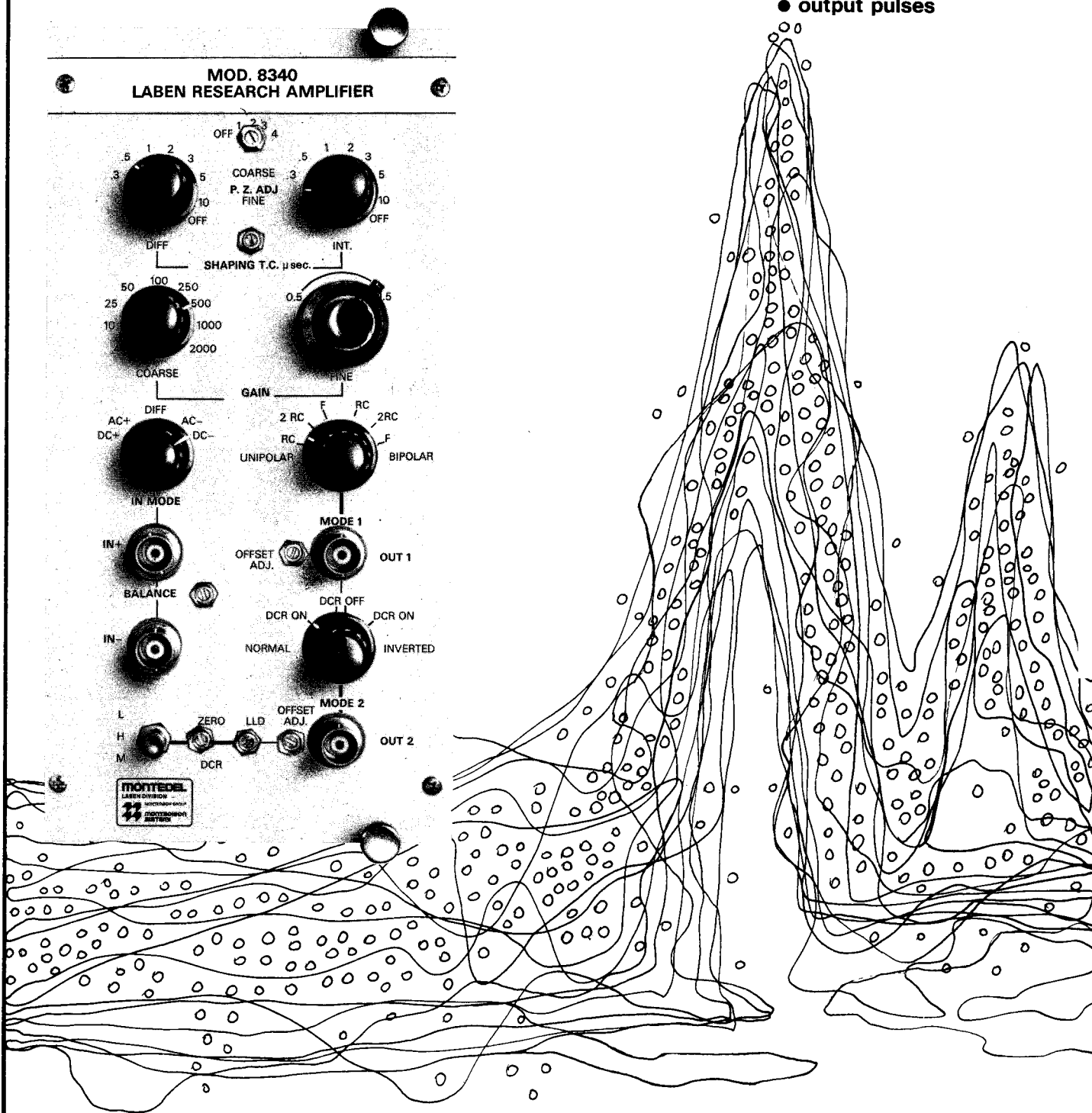
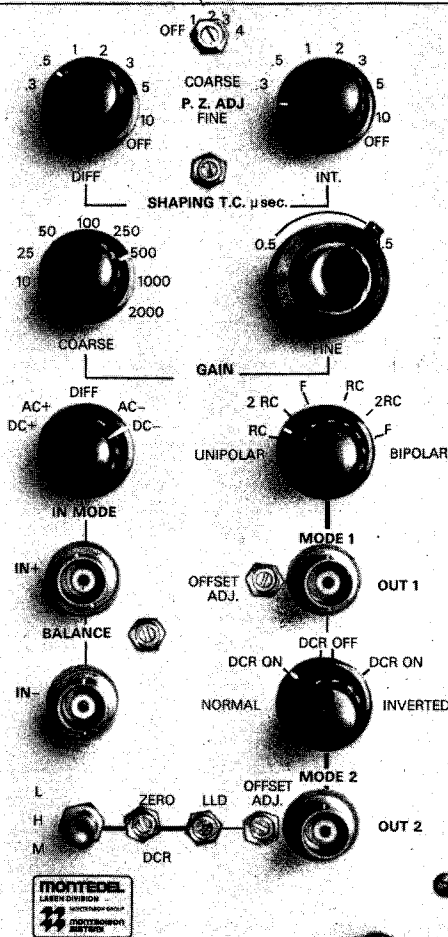
LABEN RESEARCH AMPLIFIER MOD. 8340

look through Mod. 8340 while operating: a very new concept in shaping allows true DC coupling between input and output, thus reducing DC restorer defects at very high counting rate; also available single or double integrated output pulse for normalization measurements, pile-up rejection and live-time correction

a wide choice of:

- independent time constants for pulse shaping
- gain range
- output pulses

MOD. 8340  
LABEN RESEARCH AMPLIFIER



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Telephone: 2365551  
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SISTEMI

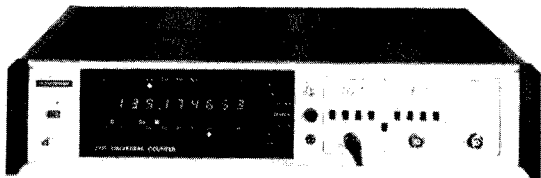
# Nouveautés Schlumberger

Progrès-  
grâce à des recherches et développements intensifs

## Fréquencemètres universels série 2710/11 pilotés par microprocesseurs

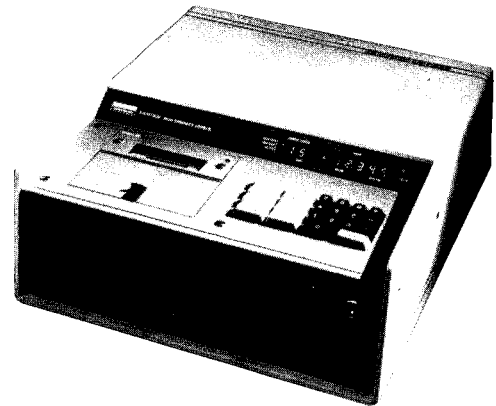
Nouvelle génération de fréquencemètres à la fois performants et simples d'emploi.

Plages de fréquence 120 et 520 MHz ● mesures effectuées par la méthode réciproque ● périodemètre et chronomètre avec résolution 10 ns ● mesure de phase de 0,5 Hz à 1 MHz avec résolution 0,1° ● trois oscillateurs de référence ● interface système (IEC) pour programmation et traitement des informations



## Système d'acquisition de données 3430 alimenté par réseau ou batterie

Compact et facilement portable ● 30 entrées analogiques / 20 entrées digitales ● linéarisation pour 7 types de thermocouples ● détection de limites et enregistrement des canaux en alarme ● périphérique incorporé ou extérieur ● prix imbattable

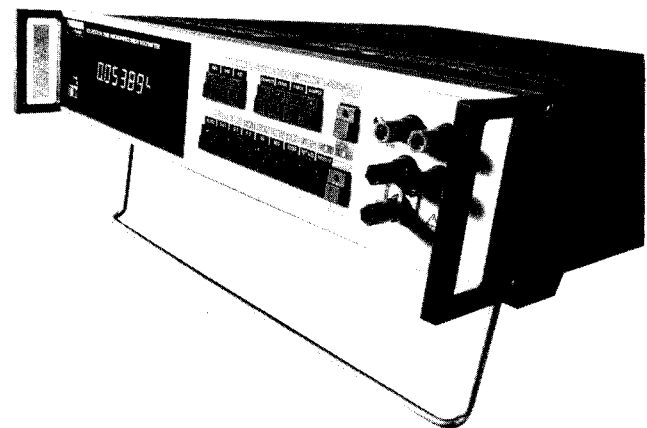


## Deux voltmètres inhabituels avec traitement «on line» des valeurs mesurées

De nouveaux horizons s'ouvrent grâce aux nouveaux voltmètres à microprocesseur modèles 7055 et 7065. Outre les fonctions voltmètres-ohmmètres, précises et rapides, ces appareils permettent le traitement «on line» de 8 programmes et 16 présentations des résultats

- 3 fonctions de mesure DC, AC, Ohm
- longueur d'échelle à choix (3 x 9 à 6 x 9)
- haute précision et linéarité
- 43 mesures/sec avec affichage 5 x 9
- 4 interfaces: binaire, BCD, RS 232, IEC
- et en plus, un choix incomparable de traitements de l'information tels que:
  - multiplication/division ● % de déviation offset ●
  - quotient ● maxima/minima ● limites ● statistiques
  - températures ● horloge numérique, etc.

Pour en connaître davantage sur ces appareils européens, demandez-nous une démonstration ou l'envoi d'une documentation détaillée.



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Schlumberger Messgeräte AG

# ENTRY- CONTROL

## Electro-magnetic Lock + PARTNER Keys



## A New Security Concept

2 different solutions by DOM safety technology for entry control, which are capable of being combined with one another:

1) **Electro-magnetic Switch and Bolt Lock**  
mechanical locking of doors and containers, at the same time remote control of alarm and surveillance systems with regard to their being functionally intact, .ie. in operation as well as remote control of such security installations.

### 2) **PARTNER Keys**

DOM cylinder locks in the DOM-ix turn key system with 10 pin tumblers, which are prepared for these keys, they can only be operated simultaneously by means of both halves of the key, Partner key 1 + 2, so that only two persons with the right of entry can enter together.

Further detailed information and advice (no obligation - on a postcard please); Key-word: "ENTRY CONTROL" from:

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**DOM AG-Sicherheitstechnik**  
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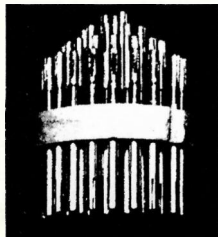
**Connectors with CERAMIC insulating material resistant to radiation and to high temperatures**



S + D 1051  
19 PINS

Connectors with ceramic insulating material are existing now in following versions:

- coaxial
- coaxial for high voltage
- biaxial
- multiple: 2, 3, 4, 5, 10, 19 and 48 pins



CONTACT BLOCK  
48 PINS

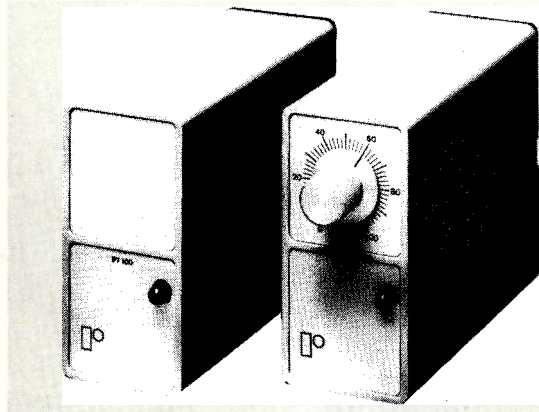


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Commutation différentielle réglable entre 0,5 et 5°C  
Modèles livrables pour diverses plages courantes  
Potentiomètre de valeur de consigne et indicateur de valeur effective montables séparément  
Nombreuses possibilités de combinaison des éléments

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**NEW  
in  
CAMAC**

**high-  
resolution  
fast-clearing  
octal TDC**



LeCroy's Model 2228A establishes the new state-of-the-art in multiple-input nanosecond time measurement. The densely packaged 2228A offers 8 independent 11-bit TDC's operating over full-scale ranges selectable from 100 nsec to 5  $\mu\text{sec}$ . This permits per count resolution as low as 50 psec, suitable both for precise Time-of-Flight and Drift Chamber applications. In addition, conversion may be quickly aborted, permitting immediate readiness to accept a subsequent event.

For applications where fast data readout is necessary, a switch-selectable readout mode allows the 2228A to be used with a special crate controller to read out only the channels containing valid data. Also, both conversion slope and the full-scale time are side-panel adjustable, permitting fine calibration and user-selection of conversion time.

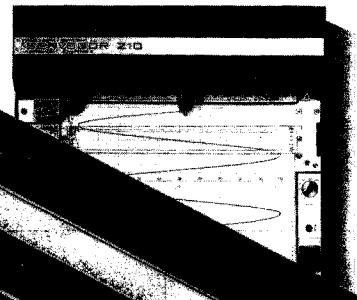
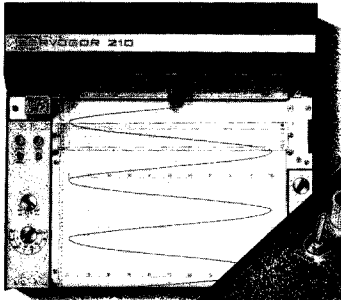
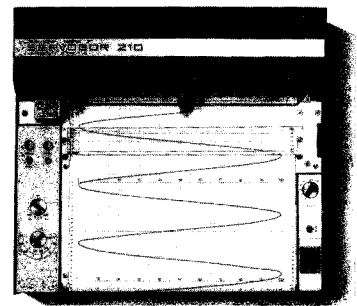
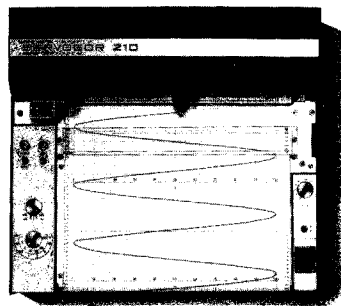
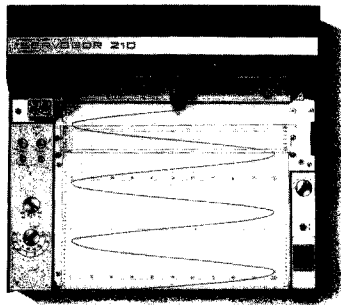
**ADDITIONAL FEATURES:**

- 11 bits over time ranges from 100 nsec to 5  $\mu\text{sec}$ .
- 50 psec resolution.
- 300 nsec fast reset.
- Uncompromising differential and integral linearity.
- Adjustable conversion time.
- Low power dissipation.
- Socketed IC's and hybrids.
- Surprisingly low cost.

For complete technical data and pricing information, call or write your local LeCroy Sales Office or circle the number below on the Reader's Service Card.

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# Save time, money and anxiety with EIMAC's 100 kV, long pulse switch tube.



EIMAC's new X-2062J ceramic-metal tetrode switch tube is admirably suited to the tough service involved in high voltage, high current, long pulse operation.

Look over these outstanding features:

1. High holdoff voltages—in excess of 100 kV.
2. High pulse current—85 amperes at a pulse duration up to one second.
3. Low internal tube drop at maximum current—about 2 kV. An ideal modulator.
4. Pulse rise and fall time easily adjusted. No deionization time to frustrate you.
5. Minimum sensitivity to load changes. Short or open circuit? High reactance? The X-2062J accepts these burdens in stride.
6. Fully responsive to load arcs. Rapid turn off time.
7. Fully effective as a combination modulator and regulator where high plate voltage is required.

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# SEN is back with

## THE RED LINE

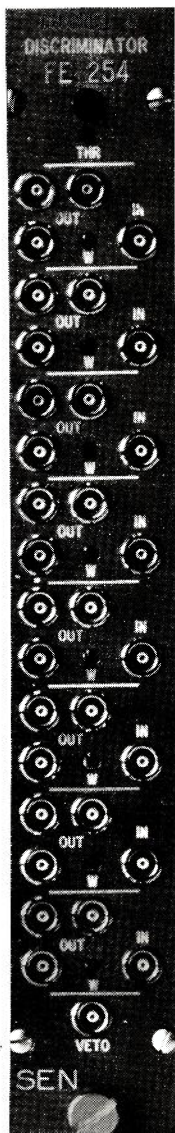
FE-NIM modules

This month, we introduce the heart of the range:

# FAST DISCRIMINATORS

FD 254

8 channel Updating

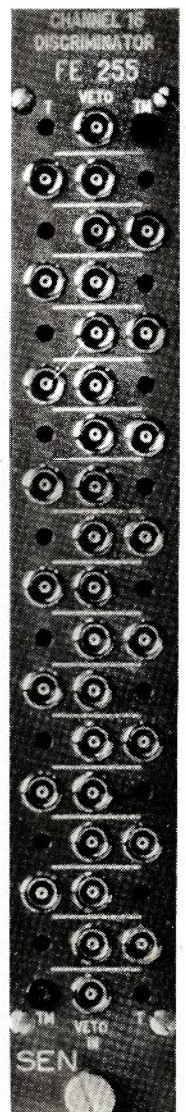


- 100 MHz updating operations
- zero dead-time 200 MHz fast veto
- improved temperature stability
- designed for ease of maintenance uses standard components
- excellent sharpness, even at < 30mV threshold

input	:	1 per channel
threshold	:	from $\leq 30\text{mV}$ to - 1V common for 8 channels screwdriver adjustable
threshold monitor	:	10 x threshold, accuracy $\pm 1\%$
output	:	3 per channel (FD 254) 1 per channel, driving one or two outputs using the LEMO FY/00-250 new adapter. (FD 255)
width	:	from $\leq 5\text{ns}$ to $> 40\text{ns}$ screwdriver adjustable rise time : < 2ns fall time : < 2ns (2 outputs loaded)
fast veto	:	1 per 8 channel zero dead-time
double pulse resolution	:	< 10ns
max. freq.	:	100 MHz (200MHz input)
I/O delay	:	$\leq 15\text{ns}$
time slewing	:	< 1ns for 10% to 100% overdrive

FD 255

16 channel Updating



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