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Physics monitor

Cover photograph : 'Elementary', in its Chinese form, drawn by H. Yukawa as the logo for the 19th International Conference on High Energy Physics held at Tokyo from 24 to 30 August. A report from the Conference is the lead article in this issue.

Tokyo Conference

In the opening address at the International Conference on High Energy Physics, held in Tokyo from 24-30 August, KEK Director T. Nishikawa pointed out that this — the 19th conference in the so-called 'Rochester' series — was the first time the traditional biennial international meeting had been held outside venues in Europe, the USA and the USSR.

The conference was truly an international affair, with some 1000 participants from nearly 50 countries. Despite its size and complexity, with the first three days being given over to parallel sessions, the mammoth meeting was managed with impressive efficiency and precision, thanks to the Organizing Committee led by G. Takeda. But then almost everything in the seething Japanese metropolis seems to run this way.

No single big discovery or new development emerged as the highlight of the conference. Nevertheless, there was much progress to report over a wide range of investigations and the general picture which emerged was of a firming-up of our understanding of particle interactions.

In particular, the techniques of quantum chromodynamics, which describe the interactions of constituents deep inside hadrons, appear to have progressed to a level where there is now widespread agreement with experiment. However, the effects due to these deep interactions of quarks and gluons are difficult to detect and even harder to measure, and Leon Lederman urged his fellow experimentalists to strive hard to pin down these delicate effects.

Quantum chromodynamics calculations can encounter problems and the theoreticians have to find ways of avoiding them. With calculations difficult to carry out and experimental effects hard to measure, the path towards a quantitative understanding of the inner workings of hadrons is a rocky one, but the mood at Tokyo was optimistic.

One particular new result was the observation of the second upsilon resonance near 10 GeV by two teams working at the DORIS electron-positron storage ring at DESY (see also page 298). Until this precision measurement on the upsilon prime, the Fermilab data was always a bit ambiguous, allowing the broad enhancement between 9.5 and 10.5 GeV to be fitted by either two or three resonances, so the number of upsilons remained open to question. However the accurate result from DESY has now ruled out a two resonance fit, showing that there are at least three upsilons and that this new particle family indeed consists of narrow resonances. This consolidates the picture of the upsilons as the bound states of a new type of quark and antiquark.

As the mass of the upsilon prime from the latest DESY experiments is slightly lower than first indicated from Fermilab, this increases the relative importance of the third and heaviest upsilon. Latest predictions for its mass give 10.38 GeV and the DORIS experimenters were urged to push to this mass region. DESY Director, Herwig Schopper, indicated however that the electricity bill during recent months with DORIS cranked up to its record energies has caused severe pain to the Laboratory's wallet. Maybe the third upsilon is for PETRA.

As well as the DESY results and accumulated data from Fermilab, upsilon sightings were also reported by three teams working at the CERN ISR — the CERN / Columbia / Oxford / Rockefeller, Athens / Brookhaven / CERN / Syracuse / Yale and CERN / DESY / Frascati / MIT / Naples / Pisa collaborations. These high energy results confirm the upsilon as a way of life and show how production levels increase with energy.

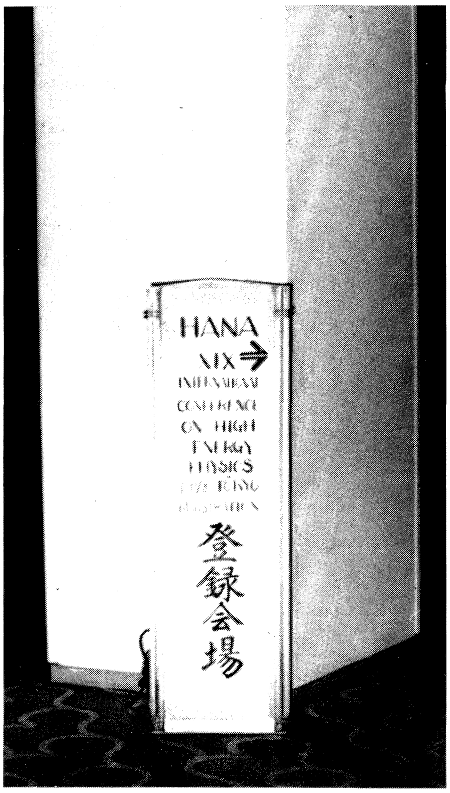
Experiments on dilepton production by hadrons now reach out as far as 19 GeV in the dilepton mass spectrum but no heavier states are evident. Lederman added wistfully that some sets of data seem to show small enhancements at the extreme end of their mass spectra, providing a tantalizing glimpse of things to come.

Inside the proton

It was perhaps indicative of the introspective mood of the Conference that as much attention was paid to the non-resonant background production of dileptons as to the new resonant states. This background provides a valuable window on the interactions of quarks/partons deep within the hadrons and provides a testing ground for quantum chromodynamics. Theory and experiment now agree in many respects and determinations of the distribution of virtual quarks in the 'sea' surrounding the nucleon, using data from dilepton production, now agree with other determinations, for example from the CERN / Dortmund / Heidelberg / Saclay neutrino experiment.

In another example of the use of very recent results to search for inner hadronic effects, Gideon Alexander of Tel-Aviv presented an analysis of upsilon decays measured in PLUTO before the detector was resited at PETRA. Theorists predict that decays of the heavy quarkonium state should show signs of the production of three gluons, in much the same way that positronium decays into three photons.

The observation of two jets in hadron production from electron-positron collisions at SLAC, now nearly ten years ago, was one of the first pieces of evidence for the existence of constituents within hadrons. The idea now is that, across a heavy resonance such as the upsilon, this two-jet behaviour should be replaced by a triple jet pattern. Such an effect would be a valuable proving ground for quantum chromodynamics predictions, which



Nearly there! For many travel-weary participants at the Tokyo Conference, this welcome sign showed that at last the end of their journey was in sight.

are otherwise largely restricted to small scaling violations and the like.

G. Flügge of DESY pointed out that jet behaviour does indeed seem to change across the upsilon region, although in some cases the deviations from a statistical 'phase space' decay are not very marked. Confirmation of this gluon effect could come from the first experiments at PETRA.

More evidence for the interactions of hadron constituents in hadron-hadron collisions was summarized by R. Sosnowski of Warsaw, using data from experiments at the ISR by the CERN / Columbia / Oxford / Rockefeller, British / French / Scandinavian, CERN / Collège de France / Heidelberg / Karlsruhe, CERN / Saclay and Brookhaven / CERN / Syracuse / Yale collaborations. These results show good indications of jet production, both on the trigger and away sides of the interaction and with the 'spectator' particles. This goes a long way towards substantiating the hypothesis that these phenomena are due to interactions between constituent particles inside the hadrons and are similar to the jets seen in electron-positron annihilation.

Additional evidence for jet production in hadron collisions was described in a parallel session by W. Selove of Pennsylvania, reporting results from a Fermilab / Lehigh / Pennsylvania / Wisconsin group which investigated high transverse momentum reactions in both proton-proton and pion-proton collisions. Jet-type signals are seen in both types of processes and allow the different quark behaviour in pions and protons to be compared. According to Selove, this work could go on to measure the angular distribution of constituent quark-quark scattering.

Charm searches

Results from charm searches came from a variety of directions in the parallel sessions — cosmic rays, neutrino beam dump experiments, high energy photoproduction studies, etc. In summarizing these attempts to pin down the production levels and lifetimes of free charmed particles, Bob Diebold of Argonne said that the present situation seemed 'confused' and hoped that it would resolve itself over the next few years.

According to Diebold, specific assumptions, such as the assumed atomic number dependence and the type and/or number of charmed particles being looked for, were often not made clear in individual papers, and this did not help in the comparison of data. Experimental results also did not tie in with theoretical predictions. In a parallel session, F. Halzen remarked that calculations of the production of heavy quarks should be straightforward and very reliable, adding that perhaps additional mechanisms could be introduced to provide the necessary corrections. Other theoreticians were openly sceptical about the value of the experimental results.

Wong-Yong Lee of Columbia presented evidence for the production of a charmed antibaryon by a team using the tagged photon beam at Fermilab. A peak is seen in the antilambda plus three pion mass spectrum at 2.27 GeV, close to the value reported at Fermilab a few years ago using a different set-up. The antibaryon, rather than baryon, signal seemed puzzling to some. There was also a report of a charmed baryon signal from an experiment at Serpukhov.

G. Flügge reported work at DESY which has consolidated the spectrum of the F mesons displaying both charm and strangeness. There appears to be as yet no reliable sighting of F mesons at SLAC, although the existence of the particles now cannot be doubted.

The charmonium spectrum now begins to look crowded, and results on psi prime decays from the new sodium iodide/lead glass detector at DORIS point to a new hidden charm state near 3.6 GeV. The exact quantum numbers of this state have yet to be fixed.

The other newcomer to the list of particles was covered when G. Feldman of SLAC drew a clear picture of the tau heavy lepton. Quantum chromodynamics calculations give good results for the decay of this particle into a muon (or an electron) plus two neutrinos but the description of the decay into a pion and a neutrino is not in such good shape. The mass of the tau's neutrino is consistent with zero.

Dibaryons and baryonium

A number of speakers covered the dibaryon discoveries at Argonne (see October 1977 issue, page 330). A. Yokosawa of Argonne said he had 'tons of data' on a string of dibaryon states above 2 GeV. Baryonium too got its share of attention at the Conference, although the narrow 2.95 GeV state reported last year by a team working at the Omega spectrometer at CERN has been submerged by new data. However, the existence of both broad and narrow mesonic states with strong coupling to the baryon-antibaryon channel now looks good.

According to some theoreticians, these new effects could be just the tip of a big iceberg of new hadron physics with multiquark states and there was talk of seeing this in electron-positron annihilation.

In one of the early parallel sessions at the Tokyo Conference, G. Alexander of Tel-Aviv described how the DORIS data on upsilon decays had been analysed to search for signs of triple gluon production. Quark/gluon interactions were one of the main talking points at Tokyo.

As well as the dibaryon results, the work with polarized protons at Argonne has also produced possible evidence for new effects, described as 'dramatic' by V. Tsarev of Lebedev in his rapporteur talk. Experiments using polarized beams and polarized targets were first covered in a parallel session by A. Krisch of Michigan who pointed out that the comparison of high momentum transfer results from collisions with similarly and oppositely polarized protons at 11.75 GeV seemed to point to some coherent effects between the proton constituents, possibly due to gluons. It seems bizarre that the Argonne ZGS, soon to cease operation, is still such a fruitful source of significant new results.

Neutrino experiments

In the neutrino area, there was little new to report, as charged current experiments, according to rapporteur K. Tittel of Heidelberg, seem to be in step with each other. Scaling violations agree with those seen in electron experiments and provide yet another example of agreement with quantum chromodynamics predictions. Determinations of the 'sea' content of virtual quarks inside nucleons from these experiments show 11-14 per cent level for non-strange quarks but a 2-4 per cent level for strange quarks, indicating that this virtual quark sea surrounding the three valence quarks is not SU(3) symmetric.

With everything behaving so nicely in neutrino experiments, physicists can afford to look at finer details of the reactions in their quest for new or unexpected results. Some effort has gone into looking for signs of gluon jets in the hadronic components but more work is required before any pronouncement can be made. Other studies have concentrated on like sign muon pairs and different experiments give the ratio of like to unlike sign muon pairs from zero to about 12 per cent. Again it seems too early to say anything definite.

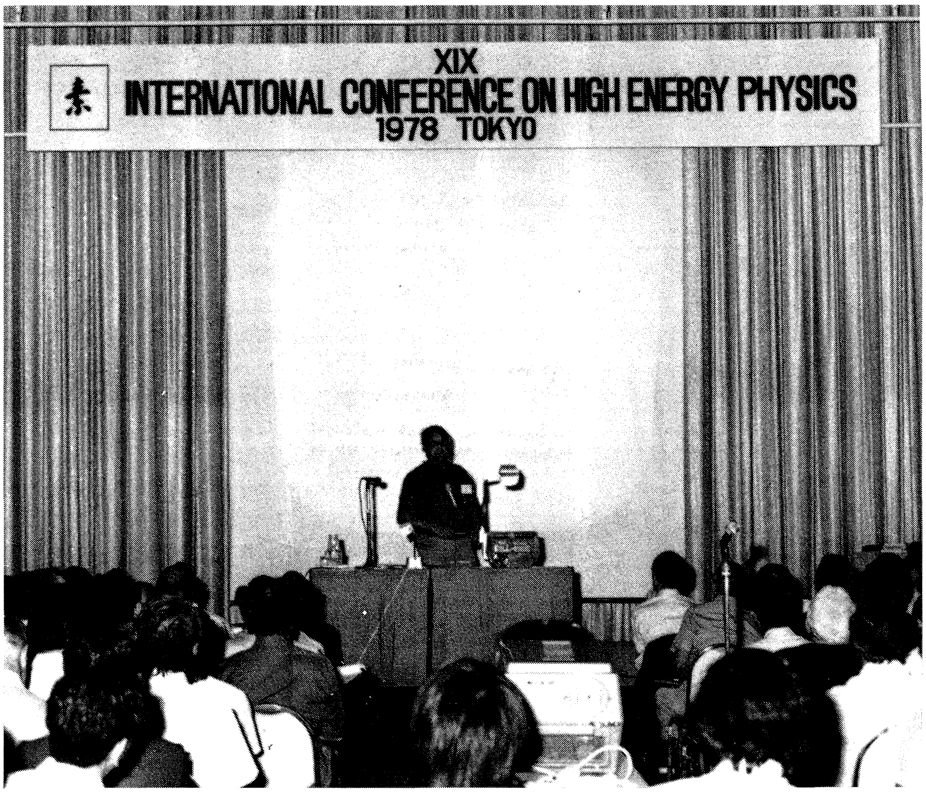
In the neutral current area, the Weinberg-Salam theory seems to reign supreme. With the storm of events initially observed for high energy neutrino-electron scattering in Gargamelle now subsiding, C. Baltay of Columbia indicated that the world average neutral current data for this type of reaction points to a value of the mixing angle, Θ, giving $\sin^2 \Theta = 0.23$.

In the parallel sessions, Dick Taylor from SLAC presented his epic result on polarized electron scattering (see August issue, page 245), which had firmly established the Weinberg-Salam model as the premier theory. Additional fuel for this theory came from L. Barkov who presented the Novosibirsk results on the behaviour of polarized light in bismuth vapour (see June issue, page 200).

However D. Boulware in a subsequent unscheduled parallel talk said that bismuth experiments at Seattle had still to detect any positive effect, despite using new apparatus. But last-minute news from the Oxford group indicated that a parity violating effect had at last been seen, though its magnitude was not in agreement with the standard theory. This lack of agreement between the different groups searching for parity violation in atomic physics did not seem to worry Steve Weinberg, who was convinced that everything would come out right in the end.

In theory

The last morning of the conference was given over to theory. Weinberg painted a rosy picture of the understanding of weak interactions, pointing out that the existence of six flavours and six leptons would provide a handy framework for describing CP violation. In his customary style, Weinberg was able to cover new theoretical ideas while at the same time dealing



with details of experiment and phenomenology.

With hadronic and electro-weak gauge theories in such good shape, it was natural for Weinberg to turn to unification schemes bringing together the different aspects of particle behaviour. One possible consequence is the existence of a new realm of 'hyperweak' interactions with only a minute fraction of the strength of conventional weak interactions. These forces would convert quarks to leptons and make the proton unstable.

This topic was taken up by Abdus Salam, who pointed out the range of group structures now on the market to describe unified colour and electroweak effects. Depending on the nature of this grand symmetry, new phenomena are conceivable from new particle accelerators in the not too distant future. On the other hand, the underlying unification scheme might be such that the energies required to see its effects will be unattainable. Another approach is via the lifetime of the proton and, from his lofty theoretical seat, Salam urged experimentalists to search for signs of proton decay.

While the conference had no major breakthroughs to report, it showed steady progress over a broad front in our understanding of particles. If this progress continues when new results come in from the next generation of machines, we could at last begin to glimpse the unified picture of Nature of which Kepler and Einstein could only dream.

Farewell to Nimrod

On Tuesday 6 June, the Rutherford Laboratory's proton synchrotron 'Nimrod' was switched off for the last time, bringing to a close an era of home-based facilities for high energy physics research in the United Kingdom. The increasing cost of particle physics research, coupled with widespread financial pressures over the past few years, has forced the UK to close its national facilities in favour of maintaining a full commitment to the research programmes at CERN and at PETRA. As a result, Daresbury's electron synchrotron, Nina, was closed on 1 April 1977 (see April 1977 issue, p. 101), and now Nimrod has been shut down.

The construction of a 7 GeV proton synchrotron was approved by the UK government early in 1957. The Rutherford High Energy Laboratory (as it was then called) was set up as the first research establishment of the UK National Institute for Research in Nuclear Science, to be responsible for the construction and operation of facilities and equipment for universities and institutions carrying out research in the nuclear field. Dr. T.G. Pickavance was appointed as the Laboratory's first Director. The Laboratory became a part of the UK Science Research Council in April 1965.

With the approval of Nimrod, the UK university scientists were provided with a powerful proton accelerator having the second highest energy in Europe (or fifth in the world) and amongst the leaders in beam intensity (aiming for 10^{12} protons per pulse and 22 pulses per minute). The variety of particle beams available from Nimrod offered a broad range of possibilities for research into the properties of known particles and to search for new phenomena. Appropriately, the accelerator was named 'Nimrod' - 'the mighty hunter' according to the Book of Genesis.

The construction of Nimrod was completed in 1963 and on the 27 August protons were accelerated to the design energy of 7 GeV. The research programme officially started in February 1964 and by September 1964 the design intensity of 10^{12} protons per pulse was reached. This figure has since been exceeded by a factor of four.

Nimrod was officially inaugurat on the 24 April 1964 by the Rt. Hon. Quintin Hogg, then the UK Secretary of State for Education and Science, who described the project as '...essentially an act of faith in the value to a nation of knowledge acquired for its own sake, of brains engaged in free speculation about the ultimate nature of the Universe and the structure of matter'.

The machine has been successfully operated throughout fifteen years of high energy research providing about 60000 hours of beam time (or 2×10^{20} accelerated protons). About 20 universities have made use of the research facility and completed about 80 major experiments. There has been a great variety in the research programme which has been supported by the skilful development of ne detection techniques and the provision of large-scale and complex sets of apparatus. Extensive computing facilities have been provided for the analysis of the experimental results.

The outstanding feature of the Nimrod experimental programme has been the systematic high-accuracy study of the resonance region below 2.5 GeV. The pion-proton elastic channel has been studied with all combinations of pion charge, with and without polarized targets, including the very difficult measurements of the charge exchange polarization. The statistical accuracy and momentum coverage has overwhelmed earlier data.

In addition, the first systematic measurements of the inelastic final states lambda-kaon and sigma-kaon using electronic techniques have been carried out, including a measurement of the spin rotation parameters in the lambda-kaon reaction using a longitudinally polarized target. In recent years some of the attention has shifted to the kaon-nucleon system with high accuracy measurements of the kaon-proton elastic differential cross-section and polarization, and measurements of the polarization in the reactions $K^+n \rightarrow K^+n$ and $K^+n \rightarrow K^0p$ using a polarized deuteron target.

The analysis of all these data has produced the well-known superabundance of resonance states which prompted theoreticians to search for underlying symmetries and structure to explain the seeming chaos, producing first of all SU(3) and then SU(6) as classification schemes, and introducing quarks as the fundamental constituents of matter.

The quark model rests on two pillars : the first is the deep inelastic scattering of electrons, muons and neutrinos which shows that pointlike objects exist within nucleons and the second is the resonance spectrum, in particular that of the baryons, where an incredibly rich spectrum of states and their decay rates can be semi-quantitatively explained in terms of a very simple model of three quarks connected by harmonic oscillator forces.

The crowning glory of the quark model is, of course, the discovery of the psi and charmed particles, but it should not be forgotten that, without the earlier detailed work, to which Nimrod made a very significant contribution, and which first produced the quark model, there would have been no theoretical framework for these subsequent discoveries.

Nimrod has also been active in many other areas. Several experiments to check violations of fundamental symmetries have been performed, including one of the early investigations on the CP-violating decays of the long-lived kaon, a test of the $\Delta S = \Delta Q$ rule, and two experiments testing the charge symmetry invariance of the electromagnetic decays of the eta meson. An experiment which only recently completed taking data is testing the speculation that the CP symmetry broken in $K^0_L \rightarrow \pi^+\pi^-$ decays could be restored in a sufficiently high magnetic field. Pulsed fields of 30 T were obtained and it should soon be known whether or not the decay rate into two pions is reduced.

Hadronic experiments other than those directly concerned with resonance formation have tended to share the same features of high resolution and high statistical accuracy. A good example is the refined missing-mass technique used to measure directly the width of the omega (780), the eta prime (960) and the cusp in pion-proton elastic scattering near the eta threshold by making measurements at 1 MeV/c incident momentum steps near the thresholds for these resonances.

In the bubble chamber field Nimrod has also been very active. As well as heavy liquid and helium bubble chambers, two hydrogen chambers have taken over 11 million pictures, mostly on low energy formation or meson production studies. Two major innovative projects have been undertaken. The Rutherford Laboratory collaborated with CERN and DESY to produce the first operational track sensitive target in which the beam interacts in a volume of liquid hydrogen surrounded by a denser mixture of liquid neon and hydrogen. This technique combines the simplicity of interactions in the pure hydrogen chamber with the high gamma ray and electron detection efficiency of the heavy liquid chamber.

The second innovation was the construction of a rapid-cycling bubble chamber as the target for a specially-designed electronic detector system. Problems in the operation of the chamber and the early closure of

Sir John Cockcroft breaks new ground for the Rutherford Laboratory in 1957.

The Laboratory's first Director, Gerry Pickavance, and the Secretary of State for Education and Science, Quintin Hogg, at the inauguration of Nimrod in 1964.

(Photos Rutherford)

Stanford: Lots of PEP

In the wake of the news from DESY that PETRA is starting up, there is even more determination to bring the Berkeley/Stanford 18 GeV electron-positron storage ring PEP into action on the scheduled date of 1 October 1979. An additional injection of about $6 million in the next fiscal year will be needed to make this possible but there is confidence that this extra money will be found.*

Tunnel construction around the 2.2 km circumference is reasonably well advanced with about three-quarters of the 'cut-and-fill' sections completed and with the northern section remaining to be tunnelled. Intersection halls are being built. The injection links with the SLAC linac will be completed at the end of the year; the south injection tunnel (for electrons) has been concreted and the north injection tunnel (for positrons) will follow by April next year. The complex magnets which will make it possible to guide the electron and positron beams from the linac into the two tunnels towards PEP or to allow the electron beam through for linac experiments and for the smaller SPEAR storage ring, have been built by Berkeley and are awaiting installation.

The 'magnet factory' on the Stanford site began full-scale production in August to turn out the 192 dipoles (0.5 T field and 5.4 m long) at a rate of one per day. Several such magnets have been built and showed that this production rate can be achieved. The bending magnet laminations are stacked at the Laboratory, and the coils inserted in the assembled cores, which are then welded. Quadrupoles arrive already stacked and require only the coils to be put in place. Most of the sextupoles are being built by industry and the special large aperture quadrupoles for the intersection regions are being built at Berkeley. The installation of the magnets in the tunnel will begin in intersection region 8 (where electrons are injected and where the control room is located) and proceed anticlockwise around the ring.

The vacuum chambers, to give pressures of 10^{-8} torr in the ring, are being produced comfortably on schedule. Some minor troubles have been encountered in the plumbing of the r.f. power systems and they need tidying up before installation in the machine. This work is a little behind schedule but not worryingly so. Test cavities have been powered to levels in excess of the design value (6 MW at 350 MHz in 50 m of cavity).

Three detection systems are expected to be ready for the start-up of the machine - Mark II (the successor to the psi-finding Mark I magnetic detector), which has been in operation for physics on SPEAR since March, MAC and the 'free quark search'. Mark II has greater acceptance than Mark I and an improved time-of-flight system. Trigger biasses are much reduced and it has better photon detection and better pion and electron identification. It will have about another year at low energies before moving to PEP and will concentrate on the charmed mesons, the heavy lepton and jets.

The High Resolution Spectrometer (using the magnet of the Argonne 12 foot bubble chamber) and the ambitious Time Projection Chamber (being built at Berkeley) will probably follow in April 1980. It will also be decided this Autumn whether to bring the DELCO detector, suitably modified, to PEP. DELCO was moved from the SPEAR ring in July to make way for the 'Crystal Ball' spectrometer and it has been decided to build a Mark III to follow Mark II on SPEAR rather than to reintroduce an improved DELCO.

Mark III is being optimized for SPEAR energies (which the Mark II is not) and great attention is being given to minimizing multiple scattering. The Mark I magnet will be used and shower counters will be positioned inside the coil to spot low momentum photons. The detector will mop up the physics in the lower energy region where there is likely to be a lot of detailed work left after the departure of Mark II.

Thoughts are already turning to the post-PEP operation years. One option for the further development of the storage ring has already been tabled — an increase in the peak energy from 18 to 24 GeV by the addition of more r.f. cavities. This is, however, very expensive in power.

Another option is the addition of a proton storage ring in the same tunnel, an idea which was in the very first PEP proposal many years ago. It is strongly believed that any implementation of this option would come at a time when new technology would be imperative in the machine construction. The use of both high field superconducting magnets and superconducting r.f. cavities is envisaged in a colliding beam system involving 25 GeV electrons on 350 GeV protons.

When PEP comes on, the face of physics at SLAC will be considerably changed. It is anticipated that PEP will be operated for as many hours per year as money makes possible, that SPEAR will operate for 50% of the time as a high energy physics machine and the other 50% to provide beams into the Stanford Synchrotron Radiation Laboratory (SSRL), and that the physics programme using direct beams from the linac will absorb the remaining resources.

The linac programme is already beginning to thin out a little but it is still obviously very lively, as evidenced by the recent beautiful polarization experiment (see July/August issue, page 245). The streamer chamber is being phased out, the fast cycling 40 inch bubble chamber may be moved to the photon beam and a photon beam may also be fed to LASS (the Large Aperture Superconducting Spectrometer).

The photon beam and much else in the present and projected programme will take advantage of the higher energies which are becoming progressively available as the SLED project is

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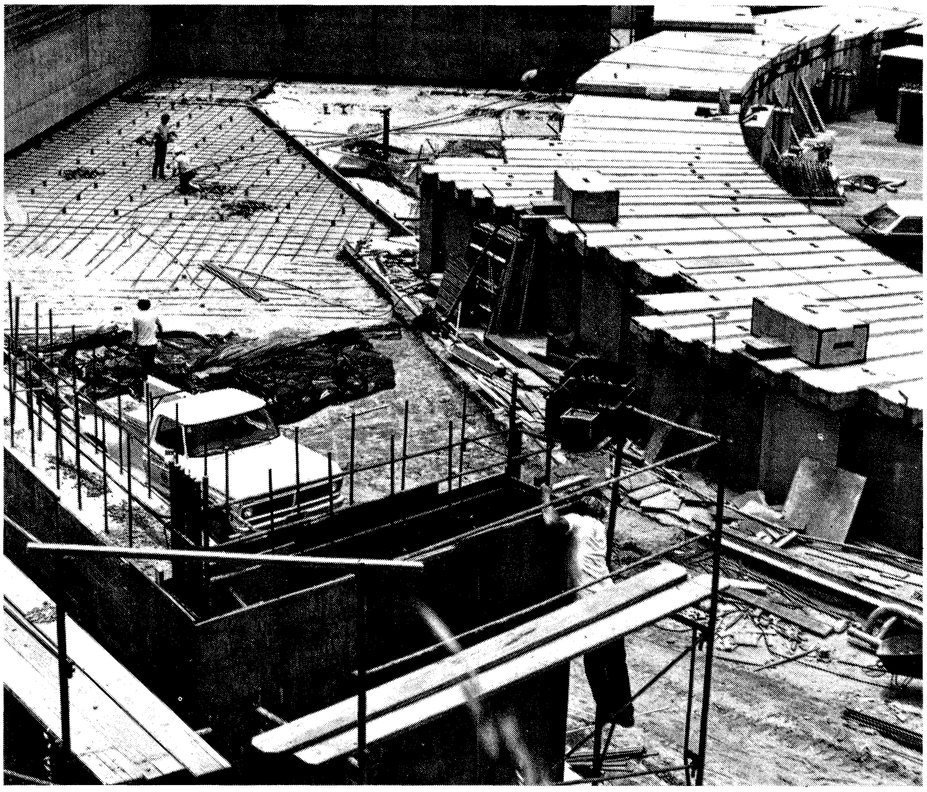
* *Late news: It has been.*



Work in progress in July on the building at the south arc of the SPEAR storage ring at Stanford to house extensions of the synchrotron radiation research facilities. The concrete tunnel of SPEAR can be seen curving around top right and three stubs already protrude from it where the radiation beam times will be located.

(Photo Stanford)

implemented. All the SLED units to double the linac output energy (with shorter pulse lengths) are completed but it may be 1980 before they can be installed (the rhythm being dictated by money).

The SSRL is busy with Phase 1 of its extension of the synchrotron radiation research possibilities at SPEAR. The present research uses eleven experimental stations drawn from three radiation ports and it has excelled in Extended X-ray Absorption Fine Structure (EXAFS) and photoemission work.

It has, however, suffered from the high energy physics concentration at SPEAR on the 4 GeV centre-of-mass region which has caused an 'X-ray drought'. This makes the radiation workers the only people in the world unhappy with the psi particles.

The present three-year development programme, funded to the extent of $ 6.7 million, will see the addition of new beamlines on the South Arc of SPEAR. Five beamlines feeding fourteen new stations will be housed in the building now under construction. A 'wiggler' will be installed to extend the X-ray range to the equivalent of 4 to 5 GeV electron beam energies. (A wiggler will be tried for the first time ever in SPEAR later this year.) The synchrotron radiation work on SPEAR, as elsewhere, is growing almost exponentially. There are at present some 250 active proposals for experiments, involving some 400 scientists.

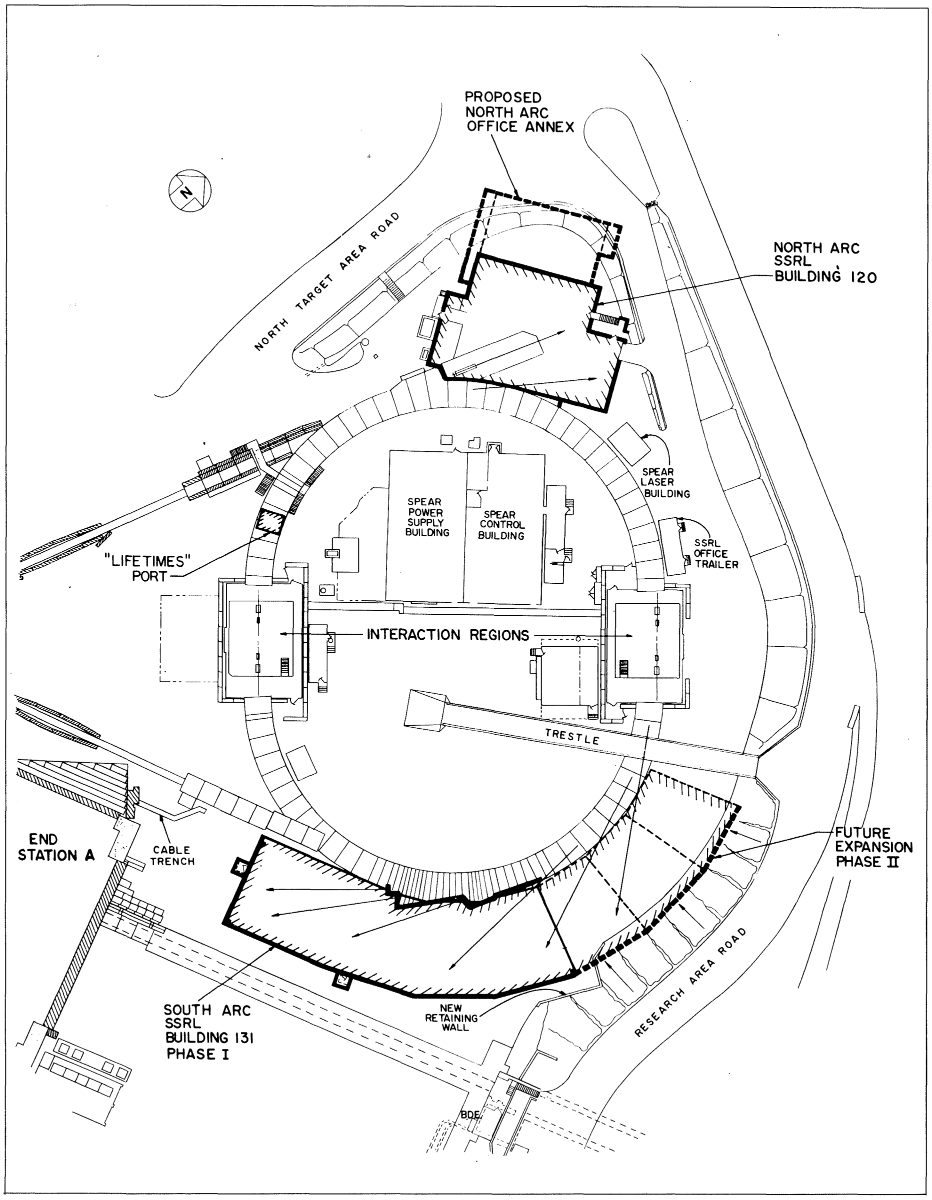


Diagram of the SPEAR storage ring with the synchrotron radiation areas picked out by heavy lines. On the north arc is the existing facility; on the south arc to the left is phase I of the extension now under construction where new beams will be installed.

Proton-antiproton project at CERN

We have referred several times before to the proposal to collide proton and antiproton beams in the CERN SPS ring. Now almost all the details of the project are fixed and it was presented to the CERN Council at its June meetings. While the orders for the hardware to make the project real are being prepared, some crucial tests took place at the end of July with the storage, for the first time ever, of a beam of antiprotons.

The proton-antiproton project is seen as the major extension of the research facilities at CERN in the immediate future. With collision energies of up to 270 GeV per beam (the maximum energy at which beams can be stored with the SPS magnets run d.c.) it will certainly open up a new region of physics where several phenomena, underlying the presently very successful theoretical ideas, are expected.

The most dramatic of these new phenomena could be the appearance of the charged Ws and neutral Z — the heavy vector bosons which are the intermediate particles carrying the weak force in analogy to the photon carrying the electromagnetic force. The best estimate at present puts their masses at around 80 GeV and demonstration of their existence would be a great triumph of modern physics.

The same scheme which predicts the Ws and Z requires other particles, known as Higgs particles, to complete the unified picture of weak and electromagnetic phenomena. The Higgs particles are at the origin of 'spontaneous symmetry breaking' (see September 1977 issue, page 272) and could also appear in the newly accessible energy range. In addition, access to higher energies could reveal heavier particles of the J/psi and upsilon type — the products of still heavier constituent quarks.

Regardless of the particle searches, the ability to collide hadrons at hundreds of GeV energies should yield more information on the quarks and gluons of which they are assumed to be made and hence tell quantum chromodynamics (the theory which attempts to explain their behaviour) where to go.

These are some of the physics attractions which are luring both CERN and Fermilab to a proton-antiproton project. The difficulty in its realization is to achieve a sufficient antiproton beam intensity to make the physics accessible. At CERN this will require an intricate sequence of manoeuvres which we now summarize.

Providing the antiprotons

The heart of the scheme is an antiproton accumulator (AA) where stochastic cooling will be applied to give intense beams of the required quality. The accumulator will be built 7 m below ground on a site roughly midway between the 28 GeV proton synchrotron and the Intersecting Storage Rings. Its circumference will be one-quarter of that of the PS, and equal to that of the 800 MeV Booster.

The ring will have a very large radial aperture, up to 70 cm, to have maximum acceptance for the antiprotons and to help particle mixing which is important for stochastic cooling. The ring will be maintained at an ultra-high vacuum of about 10^{-10} torr. Twelve large high field bending magnets and twenty-four quadrupoles will leave more than half the circumference free for the stochastic cooling units, injection and ejection systems, diagnostic devices and a r.f. cavity. The antiprotons will be produced when 26 GeV protons from the PS are deflected out of the ISR transfer tunnel, TT 2, and strike a primary target. To concentrate these antiprotons in the accumulator, a method has to be used which crowds as many protons as possible into a quarter of the PS circumference.

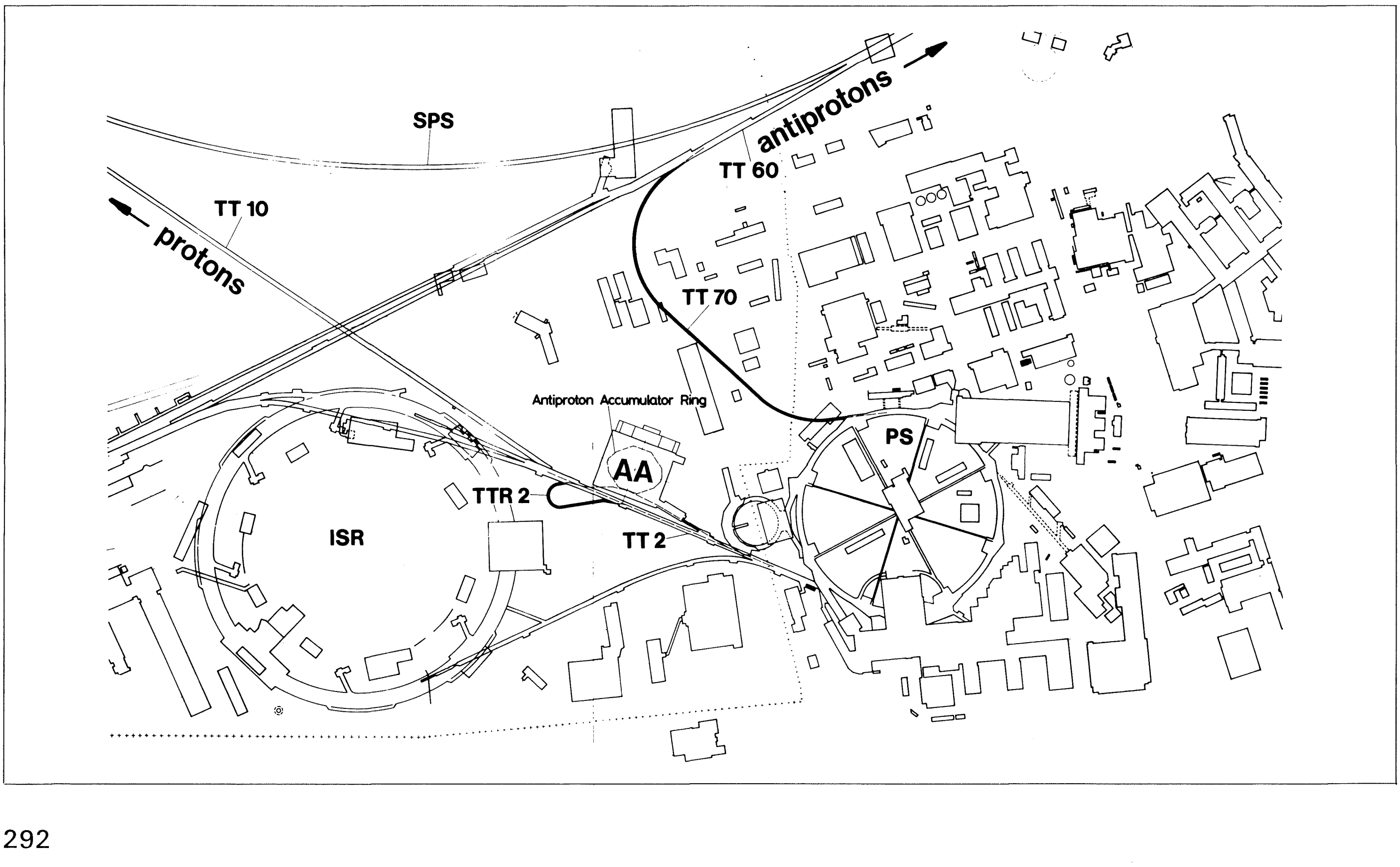
The PS Booster produces five bunches of protons in each of its four rings. In normal sequential operation, these bunches are fed into the PS one after another. However the particles can also be combined into two lots of five double bunches. These will be injected into the PS at slightly different energies, so that one lot overtakes the other. At this moment, the r.f. system will capture them both, giving five bunches of protons, each with four times the normal intensity. It is this concentrated proton beam which will produce the antiprotons with a production maximum near 3.5 GeV/c.

Once in the accumulator, each newly-injected pulse of antiprotons will first undergo a rapid precooling to reduce the momentum spread from ± 7.5 to ± 1 part per thousand after which it will be taken by the r.f. system across the vacuum chamber to be stacked with previous batches. This has to be accomplished before the next burst of antiprotons appears.

The stack, which will be shielded from the effects of the injection and precooling kicker magnets by movable shutters, will be cooled continuously both longitudinally and transversely, so that particles migrate to the bottom of the stack, eventually forming a beam of sufficient density. 24 hours of stacking is expected to give 6×10^{11} antiprotons.

Because of limitations in available straight section space in the accumulator, the injection and ejection of antiprotons will take place in the same section of the ring. This means that the extracted particles will be travelling away from the PS and have to be brought back through a loop tunnel.

In the original design study, it was proposed that the 3.5 GeV antiprotons would be transferred directly to the SPS for subsequent acceleration up to 270 GeV. However, this low injection energy posed a number of problems in the SPS. Instead, it was decided to take the antiprotons to the PS for acceleration to 26 GeV, which is above the potentially troublesome SPS transition region near 22 GeV.



The proton-antiproton scheme for CERN. Protons from the PS produce antiprotons which are cooled and stored in an accumulator ring, AA. They then loop back to the PS, and are accelerated to 26 GeV before being sent to the SPS. There they are accelerated with protons to 270 GeV and collided in long straight section 5.

To do this, however, affects the SPS proton injection system also since protons and antiprotons must be accelerated from the same energy together. The TT10 transfer tunnel must be upgraded to handle protons at 26 GeV for the new project, while retaining the capability to handle 10 GeV particles during normal SPS operations as at present.

Once in the PS, r.f. manipulations will reduce each antiproton bunch length to less than 1.5 m so that it can be injected straight into one 200 MHz bucket of the SPS, where it will be stored while similar operations are carried out on subsequent bunches of antiprotons. Twelve bunches will thus be equally spaced around the SPS perimeter.

In the SPS

To transfer these antiprotons from the PS to the SPS, where they will circulate anticlockwise, a new transfer tunnel TT 70 will be built. The antiprotons will be extracted from the PS in straight section 58 with equipment previously used for extraction into the East Hall. The particles will join TT 60, now used to extract protons from the SPS for the West Area, and be injected through the existing SPS extraction system.

Before the twelve antiproton bunches are passed to the SPS, twelve companion bunches of protons will have been injected, circulating of course in the opposite direction. The protons and antiprotons will then be accelerated to 270 GeV.

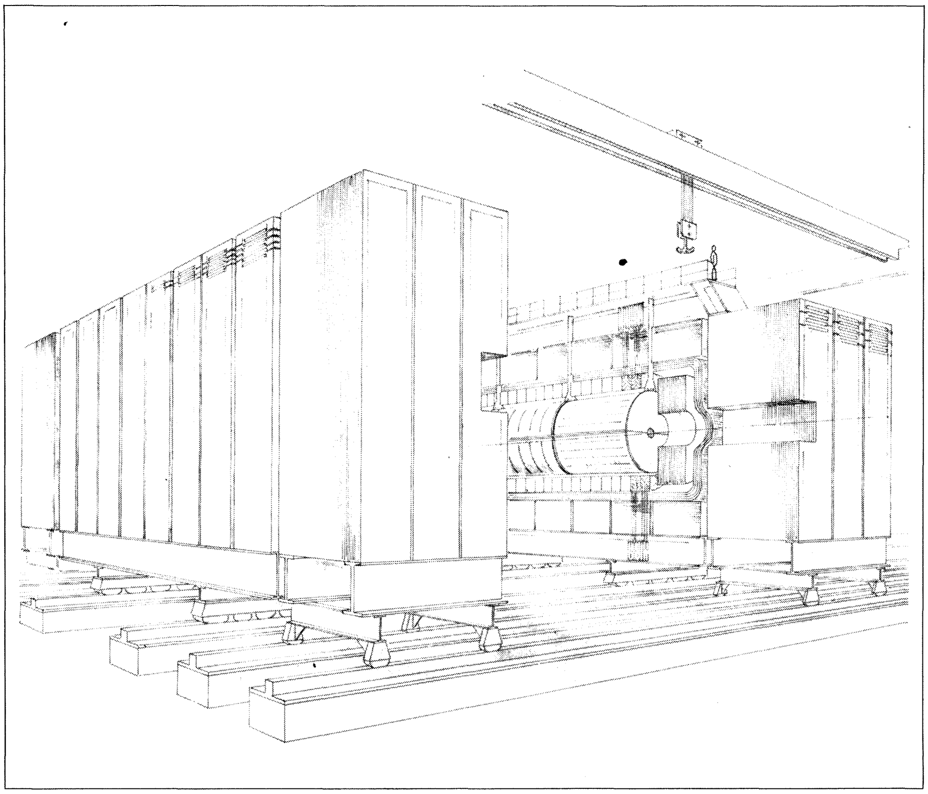
To accomplish this, the SPS will have four travelling wave r.f. cavities, two of them fitted with reversal switches. In this way two cavities can be used to accelerate protons, while the other pair deal with antiprotons. To achieve the required luminosity of 10^{30} per cm^2 per s, some r.f. gymnastics will combine the bunches of protons and antiprotons into six pairs.

The vacuum in the SPS ring must be improved to protect the valuable antiprotons from excessive scattering by residual gas molecules. A level of at least 10^{-9} torr is required to retain good luminosity over 24 hours while the next antiproton beam is built up. The number of sputter ion pumps in the SPS will be doubled, and an additional sublimation pump will be installed on each pumping port.

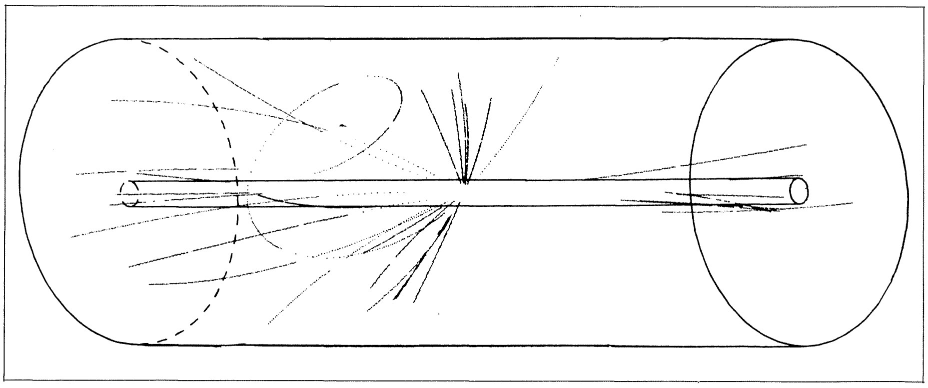
Finally, the beams will be compressed by low-beta quadrupoles either side of the collision point in Long Straight Section 5, which soon will be the scene of construction work for a large underground experimental area.

The detection system

The detector for the new underground experimental area will be built by a collaboration of physicists from Aachen /



An artist's view of the large detector which will be built for the proton-antiproton project shows how the sides can be rolled back to give access to the central volume.



Computer simulation of a proton-antiproton interaction in the detector planned for the SPS. The Monte-Carlo generation uses a simple quark model extrapolated to beam energies of 270 GeV and the event corresponds to two high transverse momentum jets emitted at large angle plus the remaining two forward jets. Out of the 42 charged tracks of this event, some remain undetected in the beam tube and additional forward chambers will help. The picture corresponds to the information which should be recorded on tape (geometrical acceptance of the detector, chamber read-out capabilities are included).

Annecy / Birmingham / CERN / London / Paris / Riverside / Rome / Rutherford / Saclay / Vienna. The total weight of the 10 m long by 5 m wide apparatus will be well over 1000 tons and this precludes raising and lowering the equipment. It is planned to have the underground hall large enough so that the apparatus can be rolled back into a 'garage' when it is not in use and a shielding wall will allow development work on the detector during normal SPS operation.

The detector is designed to cope with many particles, collecting unbiassed information over as wide a solid angle as possible, taking energy measurements by both magnetic curvatures and calorimetry and allowing simultaneous detection of electrons, muons and neutrinos with large transverse momentum (the neutrinos being detected by missing energy measurements).

A large conventional dipole will supply the main magnetic field of 0.7 T over a volume of 85 m^3, using thin aluminium coils. Inside the magnet surrounding the beam tube will be an array of drift chambers with image read-out, covering a cylindrical volume about 6 m long and 1.11 m radius. The central chambers will have their wire planes arranged vertically, while forward chambers will have them arranged horizontally. Wire spacing will be 5 mm and the drift distance of 18 cm arranged so that signals from one bunch of electrons can be collected before the subsequent batch arrives. It is hoped to achieve a spatial resolution of 250 μm on each wire.

Around the track sensitive chambers will be the photon and electron detector, consisting of 48 crescent-shaped modules of lead-scintillator sandwich with end cap shower counters. To gauge energy flow where the particle densities become too great for analysis by magnetic means and to allow for possible new highly-penetrating hadron components, an outer hadron calorimeter will be used. This will consist of slabs of scintillator fitted between the C-shaped plates of the return yoke of the magnet (80 cm of iron) together with end caps to close the effective volume. Muons transversing all the modules will be detected by drift tubes (300 m^2 in six planes).

Additional forward calorimeters will be installed to analyse particles produced in the narrow forward cone.

The total cost of the project is estimated at 130 million Swiss francs including almost 40 MSF for the detector and construction of the experimental area. The modifications to the existing accelerators, the accumulator ring (about 50 MSF) and the new beam transfer lines account for the rest of the money. The construction time is expected to extend to the end of 1980 (including a six month SPS shutdown) so that experiments start in 1981.

As it now stands, the approved project involves colliding high energy protons and antiprotons at only one point, Long Straight Section 5, in the SPS ring. The project could be enlarged if more money were available by adding an additional collision area in the SPS. Also antiprotons could be injected in the ISR to give proton-antiproton collisions in a different energy range. There is also interest in doing physics with very low energy particles, so as for example to create 'exotic atoms' with orbital antiprotons.

Long live the antiprotons

Before the project could get under way in earnest, there was one big question which had to be cleared up. Antiprotons had only been seen as transient secondary particles and no proper lifetime measurements had been possible. If the antiproton were not stable, it would be impossible to store the particles and the whole proton-antiproton project would have to be abandoned.

According to the CPT (charge, parity and time reversal invariance) theorem, which is a cornerstone of our present understanding of elementary particles, the antiproton should be as stable as the proton, living for at least 10^{28} years. If the antiproton were not stable, the whole foundation of modern field theory would be undermined and theorists would have to go back to the drawing board.

However, such an instability could account for the apparent asymmetry between particles and antiparticles in our Universe, where particle behaviour dominates and antiparticles are a curiosity. We could say that particles and antiparticles existed in equal numbers at the beginning of the Universe but the antiparticles have decayed away.

Earlier this year, the small storage ring known as ICE (Initial Cooling Experiment) was used to demonstrate that the stochastic cooling technique can be used to improve the quality of a beam of protons. On 29 July, experimenters at ICE held their breath as antiprotons were injected into the ring.

Of the 240 or so antiprotons injected, about 80 survived more than three days later. The loss is consistent with antiproton scattering on residual gas molecules in the ring vacuum. The antiprotons, like protons, seem to be long-lived. The tests improved the experimental limit on the known lifetime of the antiproton by nine orders of magnitude and show that beams of antiprotons can be stored for long periods. The proton-antiproton project, therefore, stays alive also.

Shedding light already

To complete recent news on protons and antiprotons at CERN, we report another entertaining first observation which took place on 31 August. Synchrotron radiation was observed from the proton beam in the SPS.

Hardly a month goes by without some story in CERN COURIER concerning synchrotron radiation from electron beams. It is an expensive pain to the constructors of high energy electron-positron storage rings; it is a very fruitful source of physics and of medical and industrial applications to many others. The mass of the proton, however, takes its low intensity radiation spectrum into the far infra-red even from the highest energy Fermilab and CERN machines. It has never been studied or used.

A paper by R. Coïsson from Parma University a year ago discussed radiation from particles passing through a field discontinuity, such as the edge of a magnet, and maintained that the spectrum from these positions could be shifted much higher than the critical frequency.

A make-shift system was put together at the SPS looking at the edge of a magnet near the injection straight. A light beam was observed emerging from the machine (above 300 GeV and with at least 5 × 10^{12} protons) rising in intensity as the proton energy increased and disappearing on ejection. More precise measurements will be made in October.

Quite apart from being a nice bit of physics in itself, this discovery might have direct relevance to the proton-antiproton project since, if the phenomenon is big enough and its detection can be refined, it could prove an excellent non-destructive beam observation technique.

Los Alamos: Mesons on the mesa

The 800 MeV proton linear accelerator LAMPF at Los Alamos is keeping its nose ahead of the rival meson factories — SIN in Switzerland and TRIUMF in Canada (plus a facility now being built in the Soviet Union near Moscow) — in terms of accelerated beam intensity. The machine is now regularly operated at 360 µA and the steady advance to the design intensity of 1 mA is expected to be completed as predicted in 1980.

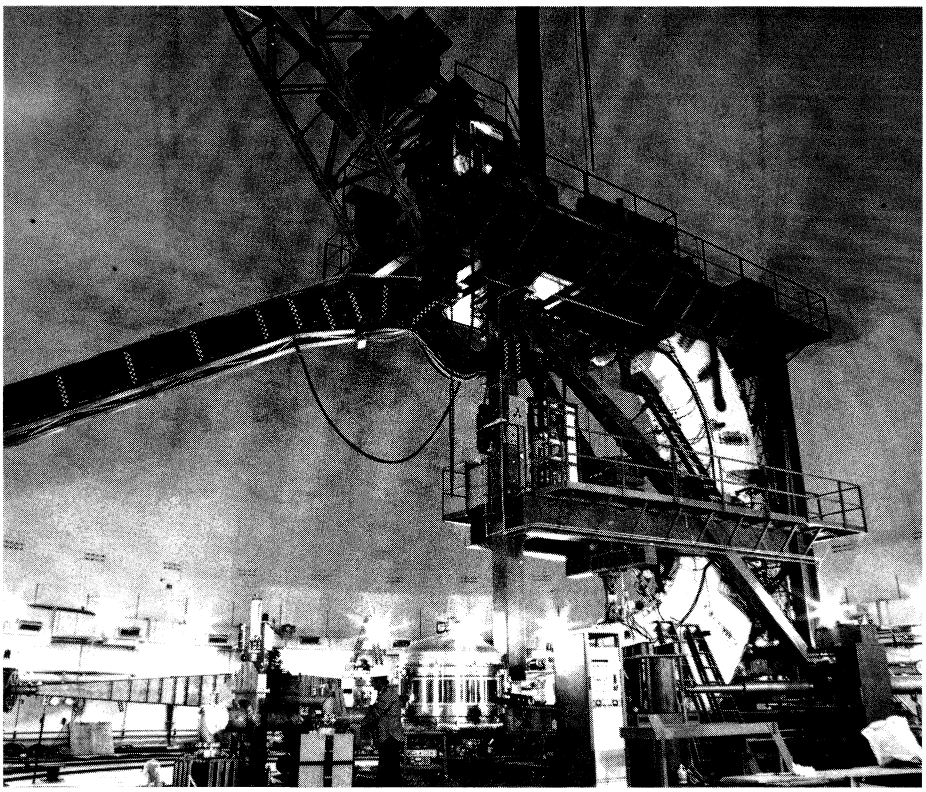
In the present fiscal year, the machine operated for some 4000 hours at full power with a reliability of about 83%. An average of some ten experiments were going on at any one time and, in general, they were receiving more particles than they could readily cope with. The same number of running hours were anticipated for the next fiscal year but some $2 million may be added to the LAMPF budget following an unprecedented initiative in Washington to increase the funding for the use of the machine. It could result in the number of research hours going up by about 20%. This initiative was prompted particularly by the outstanding success of the practical applications programme at the accelerator — a programme which has always been strongly promoted by LAMPF Director, Louis Rosen, as a very worthwhile supplement to the basic programme of nuclear research.

The physics experiments are gradually mapping out the details of the nucleon-nucleon and pion-nucleon interactions in great detail. A polarized proton beam and polarized target are giving additional information and two large spectrometer systems — the High Resolution Spectrometer (HRS) and the Energetic PIon Channel and Spectrometer (EPICS) — are achieving very precise energy resolution (100 keV in the case of the HRS).

There are experiments crossing the boundary between nuclear and particle physics. For example, the decay of the neutral pion into three gammas, in violation of charge conjugation symmetry is being looked for. Muon and electron number conservation is being tested using the unique beam of electron-type neutrinos, from the decays of positive muons, directed into heavy water where the electron neutrinos can convert a neutron into a proton and electron. The interaction is used to calibrate the experiment. If the separate lepton number conservation is violated, electron antineutrinos could be present giving detectable positrons on interaction with a proton.

An experiment is beginning on LAMPF to search for asymmetry in proton-proton scattering in violation of parity. It will push to higher sensitivity a null result previously obtained on the Laboratory's Van de Graaf in contradiction with the result of V.M. Lobashov et al. Direct leptons have been looked for to establish whether there is a threshold energy for their

View of the 800 MeV proton linear accelerator, LAMPF, stretching out along one of the mesas in the spectacular scenery of New Mexico. (Photo Los Alamos)



Left: The High Resolution Spectrometer, HRS, which is one of the major facilities at LAMPF for high precision measurements on nuclear forces. *(Photo Los Alamos)*

Right: A PIon Generator for Medical Irradiation, PIGMI, one of the projects in the newly formed Accelerator Technology Division at Los Alamos.

production. Proton energies of 256 and 800 MeV were selected since they are either side of the pion production threshold. There was no evidence for direct leptons at either energy.

Unlike the high energy physics world, advances in energy are not the key to unlocking new doors in nuclear physics. The 800 MeV from LAMPF is an ideal energy for this research. The key is more intensity and this is being pursued. The limitations are tied-in to the problems of handling accelerator and detector components, which 'see' the extremely high fluxes of particles, rather than the ability of the machine itself to accelerate higher currents. There are already pressures at LAMPF for a higher duty factor (which possibly could be pushed to 9%) and for variable energies (a run cycle of 10 weeks per year may be assigned to running at 700, 650, ...MeV).

Future developments at LAMPF are reviewed by the User Community and the Laboratory itself. A nucleon-nucleon meeting will be held later this year and, next year, a two-week Workshop is planned to outline the most fruitful directions in which to improve the facility during the next ten years.

Practical applications

Among the practical applications at LAMPF, the biomedical facility, which is used for pion cancer therapy, has received most publicity. The pion bea is now rather fully catalogued in terms of what settings are needed to produce particular characteristics of size and stopping distribution. The beam is used about a third of the time for the treatment of patients and the rest of the time for radiobiology and the physics associated with clinical work.

About sixty patients with about a hundred tumours (head, neck, lung, bladder, pancreas...) have been treated and doctors are very encouraged by the results. It seems as if total regression has been achieved in about 50% of the tumours treated though the 'follow-up' times have so far been comparatively short.

Further work will be done to improve the beam, to investigate the effectiveness of combinations of pion treatment with conventional X-radiation and neutron treatment, to develop techniques of dynamic irradiations (the patient moving in the pion flux) and to improve the visualization of the pion stopping distribution (perhaps using positron cameras).

The isotope production facility in the beam stop area is in operation full time during machine operation producing isotopes for use particularly in medicine — bromine-77 to label estrone, selenium-72 for brain tumour localization, copper-77 to label gleomyacin, xenon-127 for pulmonary studies and many others. On the pure research side new isotopes far from stability have been produced and studied in a Nuclear Chemistry Facility.

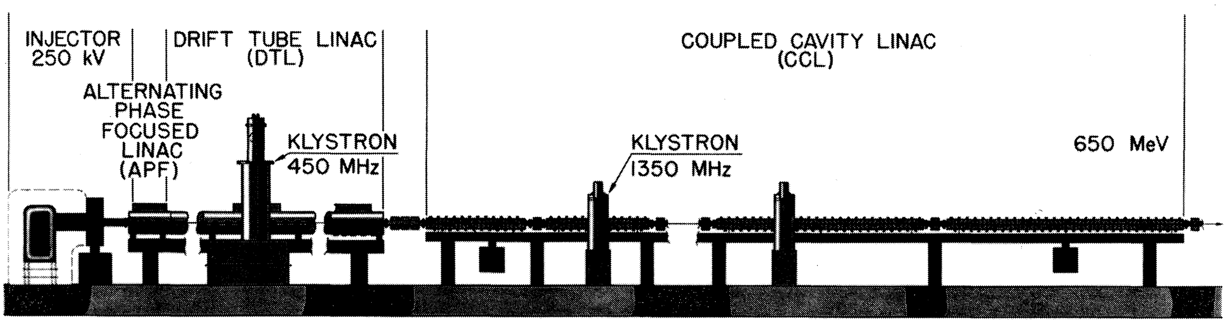
The Weapons Neutron Research Facility was the last major research area to come into use on the machine. It is used for work on national defence problems, for neutron transport measurements, and for a wide range of solid state physics experiments with low energy neutrons. It is hoped to extend the potential of this Facility considerably in a few years' time with the addition of a storage ring (see below).

Other work related to medical use of accelerated particles or accelerator techniques includes proton computed tomography, muonic X-ray analysis (which can give information on element composition), and the r.f. heating device for tumour control (covered in the January issue, page 22) which is now being manufactured by five companies.

The side-coupled accelerator structure developed in the course of building LAMPF is now standard in radiation therapy units used in almost every hospital in the USA. More recently, the design of a pion generator for therapy has been studied with the aim of optimizing it in terms of cost and of appropriateness for use in a hospital environment.

Work of the Accelerator Technology Division

The pion generator project is under study in the Accelerator Technology Division. It is known as PIGMI (PIon Generator for Medical Irradiation), a name which also reflects the effort to ensure small size. The first technological innovation is to have a very low injection energy, 250 keV, so as to reduce the size of the high voltage unit. This introduces difficulties with the focusing of the low energy beam and 'alternating phase focusing' will be used while the beam is accelerated to 750 keV. An Alvarez linac section follows with permanent



MAJOR TECHNICAL INNOVATIONS

HIGHER FREQUENCY
HIGHER GRADIENT
ALTERNATING PHASE FOCUSING
LOWER INJECTION ENERGY
DOUBLE HARMONIC BUNCHER
PERMANENT-MAGNETIC QUADRUPOLES
DISK & WASHER LINAC STRUCTURE
RF MANIFOLD POWER DISTRIBUTION
DISTRIBUTED MICROPROCESSOR CONTROL

PROTON BEAM PARAMETERS

INJECTION ENERGY	250 keV
FINAL ENERGY	650 MeV
PEAK BEAM CURRENT	30 mA
PULSE LENGTH	10 μs
REPETITION RATE	360 Hz
AVERAGE BEAM CURRENT	100 μA

PROTON LINAC PARAMETERS

FREQUENCY	APF & DTL SECTION	450 MHz
	COUPLED CAVITY SECTION	1350 MHz
GRADIENT	APF & DTL SECTION	6 MV/m
	COUPLED CAVITY SECTION	8 MV/m
TRANSITION ENERGIES	APF/DTL	7 MeV
	DTL/CCL	150 MeV

magnet quadrupoles in the drift tubes (see August issue 1977, page 231).

The r.f. frequency will be increased to 450 MHz compared to the usual 200 MHz and the accelerating gradient to 6 MV/m compared to the usual 2.5 MV/m. Bright copper plating of the drift tubes (as in the Japanese KEK linac) and cambered drift tube faces (so as not to have parallel surfaces which are multi-pactor-prone) help towards achieving the higher gradients. These ideas have been successfully tried in a six-cell test cavity, PIGLET, which reached 8 MV/m, limited only by the power supply.

Beyond about 150 MeV, costs make the Alvarez structure undesirable — hence the side-coupled structure in LAMPF. However the side-coupled structure does not have efficient coupling to its r.f. power source and, because of this, PIGMI has gone for the 'disc and washer' structure which originated in the Soviet Union.

It is intended to operate a PIGMI prototype in 1979 with 650 MeV output energy which would be adequate for pion production. A lower energy around 40 MeV would be adequate for neutron production and neutron therapy. Such a machine, built on the basis of the Los Alamos ideas, would only be some 7 m long and probably cost less than $2 million. The pion generator would be about $12 million. It is expected that the designs would be taken up by some commercial manufacturer and produced in quantity for hospitals.

The Accelerator Technology Division has other major projects en route. The first is the design of the proton storage ring to be added in the Weapons Neutron Research Facility. It will effectively be a tap with which to change the pulse lengths and pulse rates of the neutron flux which are at present necessarily tied to the LAMPF operating rhythm.

The storage ring beam could be topped up at a rate of about 100 μA by taking 10% of the LAMPF beam and could climb to some tens of A. The injection of negative hydrogen ions is an ideal way to reach high currents. The Facility would be comparable with the projects at Rutherford and Argonne in its abilities to provide intense neutron beams. The total cost is estimated at $16 million to be distributed over four years and it is hoped to start in the next Fiscal Year.

Another project is the design of the Fusion Materials Irradiation Test facility (FMIT) to be built at Hanford. The idea, which originated at Brookhaven, is to accelerate a current of 100 mA of deuterons to 35 MeV and strip them to yield a high flux of 14 MeV neutrons, such as will be experienced in fusion reactors, so as to investigate the materials problems which will be encountered in the reactors. A prototype is to be built at Los Alamos.

A similar project to FMIT has been proposed in Moscow by I.V. Chuvilo. An idea of I.M. Kapchinskii of ITEP and I. Teplekov of Serpukhov, to inject d.c. beams in a special accelerating structure which will focus and bunch ready for the subsequent r.f. cavities, will be investigated at Los Alamos. Alternating Phase Focusing will be used at the low energy end if this idea is not successful.

Finally, the Accelerator Technology Division is taking a one year look at the possibility of using accelerators for the breeding of fissile material for nuclear reactors (see May issue 1978). The study is concentrating on a 1 GeV, 300 mA proton linac.

The major costs in such a machine (about three quarters of the total) are associated with the r.f. system and work is therefore largely concentrated on achieving higher efficiency r.f. This includes a klystron optimization programme (where 60% efficiency has already been reached) and the building of a gyrocon as at Novosibirsk (where efficiencies of 90% could be possible).

Around the Laboratories

DESY
DORIS reaches upsilon prime

Just in time for the Tokyo conference, two groups working at DORIS announced the observation of a narrow peak in the electron-positron hadronic total cross-section at an energy about 560 MeV higher than the upsilon. According to the earlier results of the Lederman group at Fermilab, the first excited state of the upsilon meson, the upsilon prime, is expected in this region.

This also agrees with theories introducing particular potentials for the forces acting between the quark and the antiquark, of which the upsilon meson is assumed to be built up. The exact measurement of the mass difference between upsilon and upsilon prime is of great importance for these quark theories.

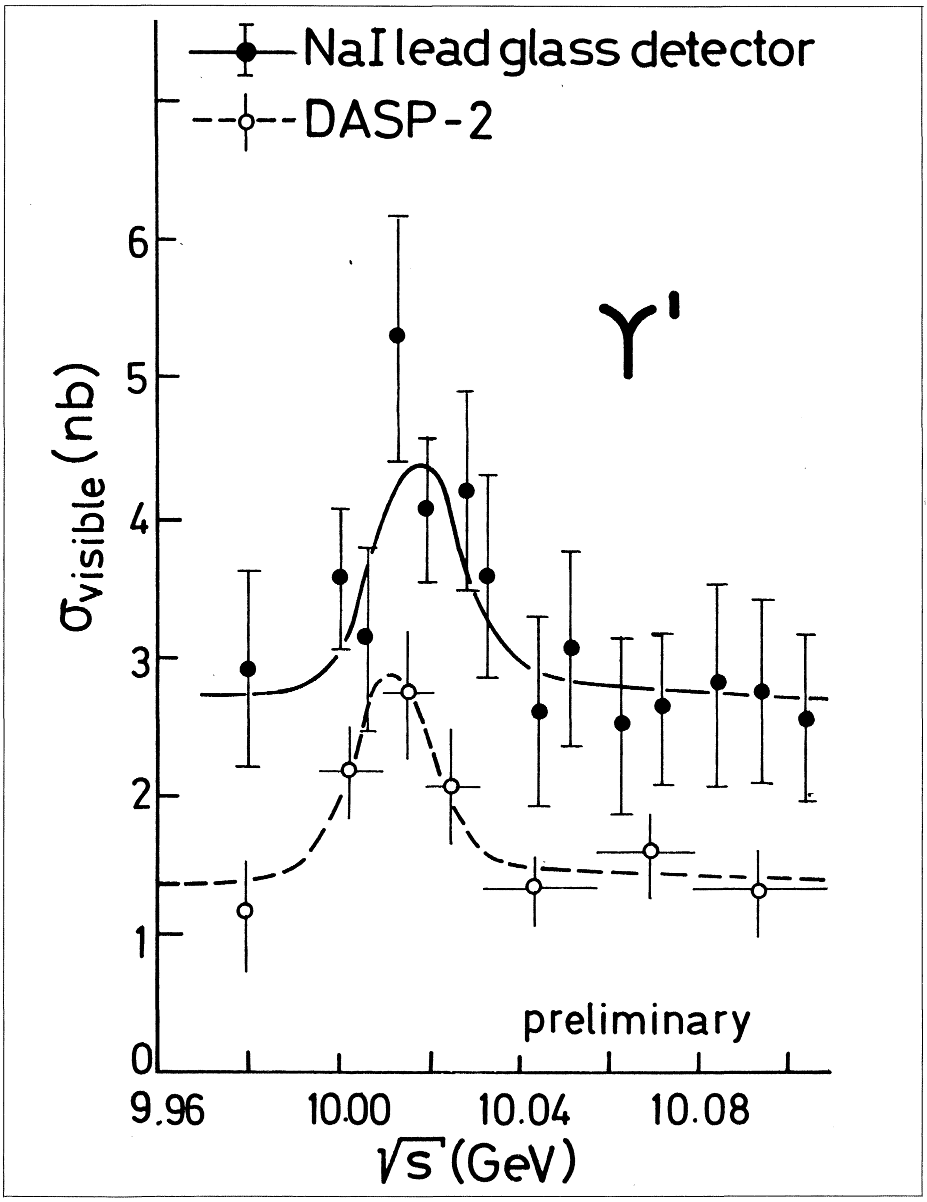
For the experimentalists who achieved this measurement, things happened in a quite dramatic way. Everything went as wrong as it could for several weeks. Apart from natural accidents like high temperatures and strong rains (which flooded the linac), they were also unlucky in the choice of the energies for the resonance scan. They started at a total energy of 10 GeV and continued in small steps of less than 10 MeV with 8 points from 10.034 upwards. With still no resonance after the ninth point, they turned back to investigate the region jumped on the first day. There it was — the peak seems to be near to 10.020 GeV.

The first point on the resonance was found exactly 26 hours before the scheduled end of the running period. However, agreements with other users and some delay for PETRA positron tests made it possible to continue measurements for another 48 hours and produce the curves presented at Tokyo.

Altogether the two groups have seen more than a hundred upsilon prime events (background subtracted). The conditions to select events used by both groups are rather similar and the results are compatible, though the acceptance of the detectors is different.

The width of the observed peak is compatible with the energy spread of the storage ring beams. The size of the peak, usually expressed in terms of leptonic width, is of the order of one third of the same number obtained at the upsilon itself. This, and the mass, are provisional numbers which may be improved after a more accurate analysis of the data. But there is no chance of more running time at DORIS in the next few months.

As was the case with the upsilon, the DORIS machine group made an extraordinary effort so that the upsilon



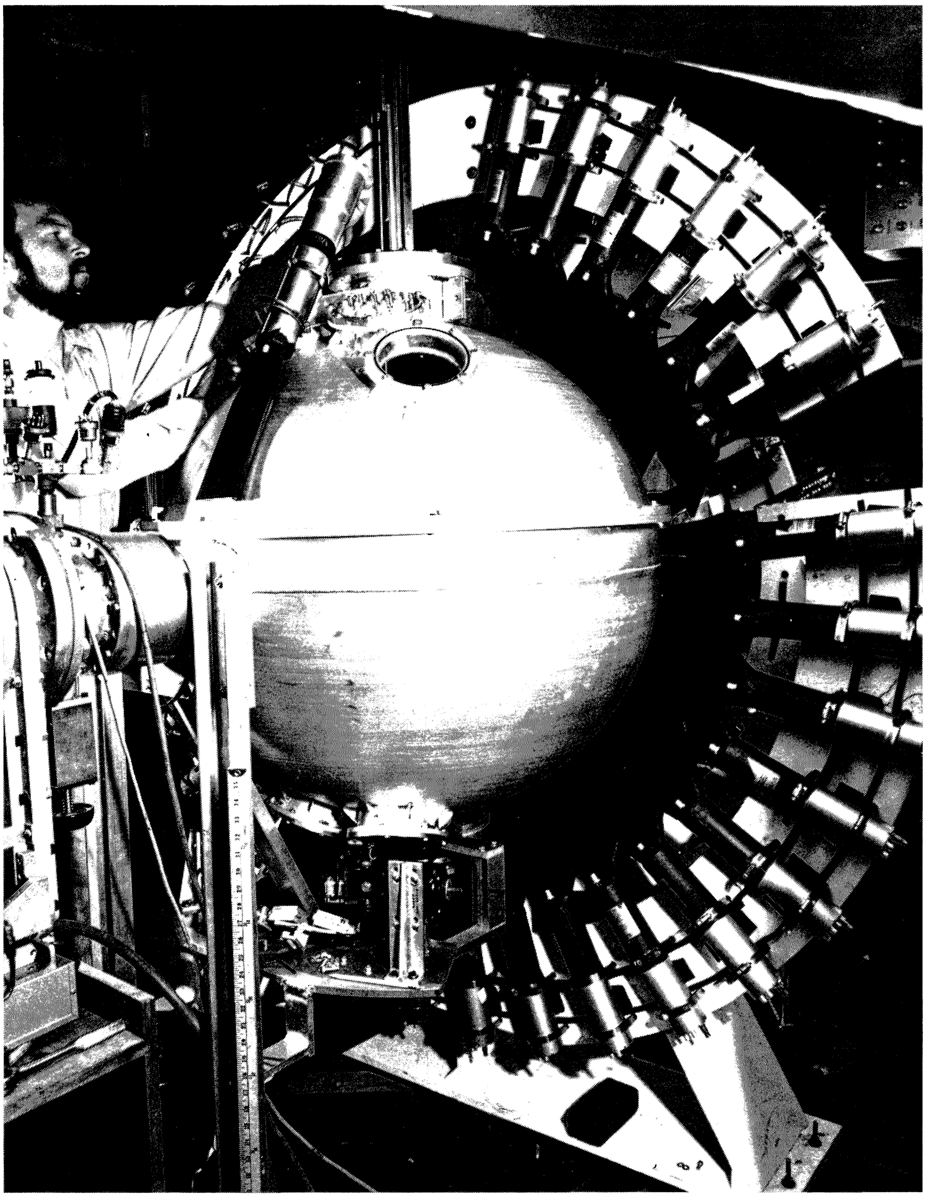
First data obtained in August in the scan for the upsilon prime at the DORIS storage ring at DESY.

The 1 m diameter scattering chamber surrounded by eighty plastic scintillators used by the Berkeley / Darmstadt / Marburg collaboration led by Art Poskanzer and Hans Gutbrod at the high energy heavy ion accelerator, Bevalac, at Berkeley.

(Photo Berkeley)

prime scan became possible and they have the highest merit in its observation. The two groups which simultaneously measured the reaction rate are: the already well-known DASP-2 group (a collaboration of DESY with the Universities of Dortmund, Heidelberg, Lund and South Carolina) and the new group running the DESY/Heidelberg detector, now called the 'NaI lead-glass detector' which includes physicists from DESY, the Universities of Erlangen, Hamburg, Heidelberg, Munich and Wuerzburg, the Max Planck Institute of Physics of Munich, and the Institute of Nuclear Physics of Krakow. In the latter group most members have very recently joined in a crash effort just devoted to investigating this highest energy obtainable with the DORIS storage ring.

The next measurements in this energy region are expected to be done at PETRA where the first experiments may start in October. The magnetic detector PLUTO is already in place and its crew are waiting impatiently to start measurements. Also the group called 'MARK-J' led by Sam Ting, is anxious to begin as soon as possible.



BERKELEY
Relativistic nuclear collisions

From 24-28 July, 175 scientists gathered at the Lawrence Berkeley Laboratory to review the recent developments in the field of high energy (about 1 GeV/nucleon) nuclear collisions. In addition to 75 participants from LBL itself, 100 participants came from other Laboratories including 45 from 14 countries outside the USA.

In contrast to earlier conferences in this field, the emphasis was not on exotic phenomena which might be expected in high energy nuclear collisions but rather on the physics behind the vast amount of new data. This shift in emphasis was clearly expressed by Hans Gutbrod in an introduction to his presentation of new data. He compared the development of the field of relativistic nuclear collisions to Columbus' search for the gold mines of the West Indies; Columbus did not find the alluring gold mines but did find a land abundant in other natural resources — America. Similarly, no experiment to date has conclusive evidence for spectacular phenomena associated with highly excited, dense nuclear matter but the wealth of new data provides a resource of knowledge which is only now beginning to be appreciated.

Among the recent data described by Gutbrod were single particle inclusive cross sections, such as neon (of 0.25 to 2.1 GeV/nucleon) colliding with neon, gold or uranium nuclei to give a proton, deuteron ...+ X with associated multiplicities of charged fragments. By triggering on high multiplicities, central collisions (rather than peripheral or glancing collisions) can be studied and the big surprise is that as the multiplicity increases, a broad peak emerges in the angular distribution of the emerging protons. In particular, Ne + U → p + X at 400 MeV/nucleon, shows a peak at about 30° for 50 to 200 MeV protons in high multiplicity events. This is in sharp contrast to the structureless distribution obtained previously when high multiplicity was not taken into account.

A further trend is that this peaking with high multiplicity gets weaker for lower beam energies, such as 250 MeV/nucleon, and for lighter targets such as aluminium. The suppression of proton yields at forward angles as a function of multiplicity (discovered by Gutbrod, Poskanzer, Stock, et al.) was also seen in a different experiment by Shoji Nagamiya in the reaction Ar + Pb → p + X at 800 MeV/nucleon.

Another significant result presented by Nagamiya was evidence for direct (knock-on) protons. This has important consequences for theoretical models of nuclear collisions. As emphasized by Jörg Hüfner in a critical review of thermal models, the 'non-thermal' (knock-on) proton yield may be up to 50 % of the total yield. In future, thermal models will have to include this significant non-thermal component. Data from Gutbrod also confirmed the non-thermal component. Finally, new data of Poskanzer et al. on Ne + U → p + X shows a significant discrepancy between the most extensive firestreak calculations (by Gosset, Westfall, Kapusta) and the data for low energy protons in the forward direction, which again points to the importance of non-thermal components.

A surprise contribution at the conference was the first data on $\pi^-\pi^-$ correlation from a streamer chamber experiment of Fung (Riverside)et al. This is the first of a new generation of data measuring pion correlations from central collisions ; the data are taken in a trigger mode which requires that the average negative pion multiplicity is about ten. The data clearly show an enhancement in the correlation at low relative momentum due to Bose statistics (known as the GGLP effect in high energy physics).

In his review of this effect, Steve Koonin described how the correlation function is expected to measure the space-time evolution of the pion source (the nuclear fireball). The data of Fung are consistent with a source radius of about 5 fm and, as more data become available, it is hoped that the degree of coherence of the pion field can also be determined.

The emphasis of the Conference was certainly on the new data but there was also room for theoretical speculations on exotic forms of nuclear matter that may occur in nuclear collisions. Mannque Rho presented a 'critical review of critical phenomena' wherein the models for pion condensation and density isomers were dissected and the theoretical uncertainties analyzed. On the more speculative side, Arthur Kerman discussed possible phase transitions into quark matter ending with a lively debate with T.D. Lee on quark sausages. At this point the conference adjourned for lunch !

Many other interesting talks were given during the week and will appear in the proceedings in a few months. The proceedings will, however, not capture the spirit of international cooperation that prevailed throughout the conference. This 4th LBL Summer Conference showed that the field of relativistic nuclear collisions is in a period of fast growth and is maturing rapidly.

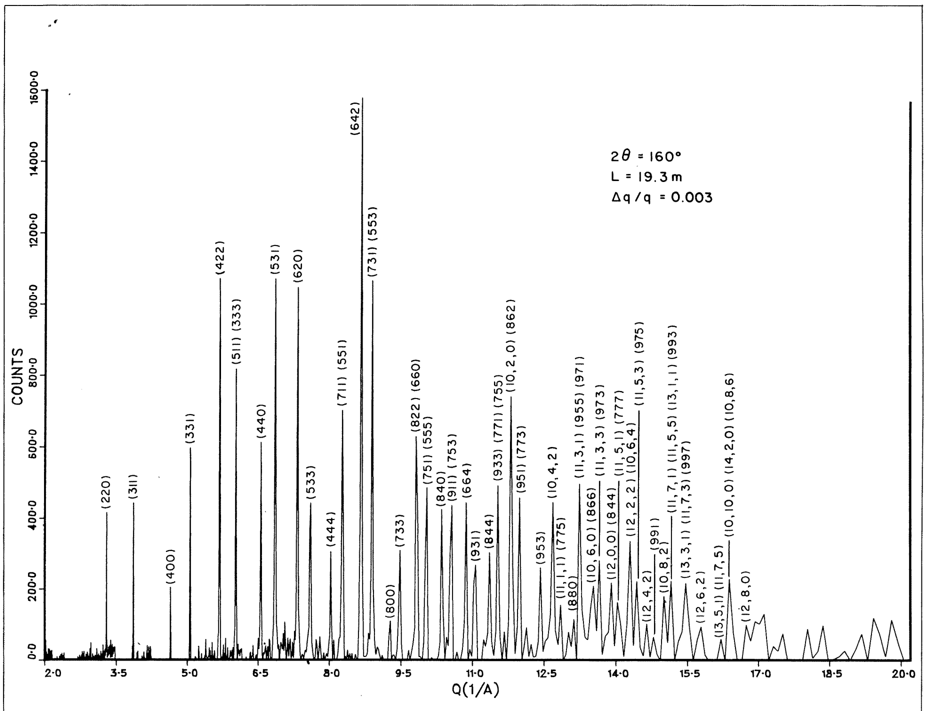
Beefing up Bevalac

Much of the growth in this field has been centred on the Bevalac at Berkeley — the combination of Superhilac and Bevatron which has made possible heavy ion beams of GeV energies. There is an improvement programme at the Bevalac, to be implemented during the next two years at a cost of $6 million, to make it possible to accelerate uranium ions to an energy of 1.2 GeV per nucleon. (The heaviest ions currently accelerated regularly are argon with intensities of about 10^9 per pulse and iron with intensities of a few 10^5 per pulse which are used in calibrations for cosmic ray experiments.)

The two major elements in this programme are — the addition of a third injector to the Superhilac, so as to make more ion species available with usable intensities, and the replacement of the vacuum system in the Bevatron, so as to establish a vacuum high enough to allow the acceleration of beams of partially stripped ions. The improved vacuum will result in beams of better quality and intensity and allow the machine to be operated at lower output energies so as to make contact with the data from heavy ion cyclotrons, etc.

The experimental facilities are also being upgraded. One project is a superconducting spectrometer (HISS — Heavy Ion Spectrometer System) which responds to the interest in collecting data on heavy ion interactions in a large volume magnetic field. For $1.9 million it will provide a multipurpose detector with a 3 T field in a 2 m diameter, 1 m gap. Another project under construction is a low energy beamline (below 250 MeV per nucleon) which will have very good momentum resolution (1 part in 2000). It will give some information in this energy range before the advent of the Michigan and GANIL cyclotrons.

These facilities will carry further our knowledge of nuclear matter at high temperature and density — the study of 'central collisions' — which is being pioneered at the Bevalac.



A silicon high-resolution powder diffraction graph from a short period of running with the neutron beams generated by the proton Booster at Argonne. The traditional source of such diffraction graphs (high flux beam reactors) would have cut-off around the (10,2,0) line for lack of neutron intensity. The first runs with neutron beams at Argonne have made the neutron physicists very happy with what is already achieved and very enthusiastic about what is to come.

ARGONNE
Research with neutrons and polarized protons

The 500 MeV Booster, initially intended to increase the proton intensity in the 12 GeV Zero Gradient Synchrotron at Argonne, mounted a physics programme with neutron beams for the first time in July. The machine ran for two weeks at 10 Hz providing about 8 × 10^{11} protons per pulse into a zinc target to generate the neutrons. It gave a foretaste of what can be expected with the ambitious neutron facilities planned for the Laboratory in the coming years.

It is intended to move to 15 Hz operation in October and 30 Hz operation next year, but it is already obvious that fast cycle operation in this way can flood experiments with neutrons to the great satisfaction of physicists accustomed to working at the neutron fluxes available from reactors. It is also already obvious that, from the accelerator point of view, the big problem of such operation will be associated with materials damage and handling in high radiation environments.

Over the next year, operation of the Booster for neutron research will be parasitic on a crowded ZGS high energy physics programme but, with the close-down of the ZGS in a year's time, neutron research on accelerators will be a central feature of the Laboratory's work. $6.4 million will probably be made available via the Department of Energy Materials Sciences budget in fiscal year 1979 to implement IPNS-I (Intense Pulsed Neutron Source) around the Booster.

The aim is to have a fully instrumented facility in operation early in 1981 catering for a community of physicists, metallurgists, chemists and other scientists to the tune of some 400 experiments a year. The machine will feed two targets. One, of uranium surrounded by a water moderator, will be the source of thermal and epithermal neutrons for diffraction and inelastic scattering experiments. The other, of tungsten surrounded by a heavy metal deflector, will yield fast neutrons (MeV range) for materials damage studies.

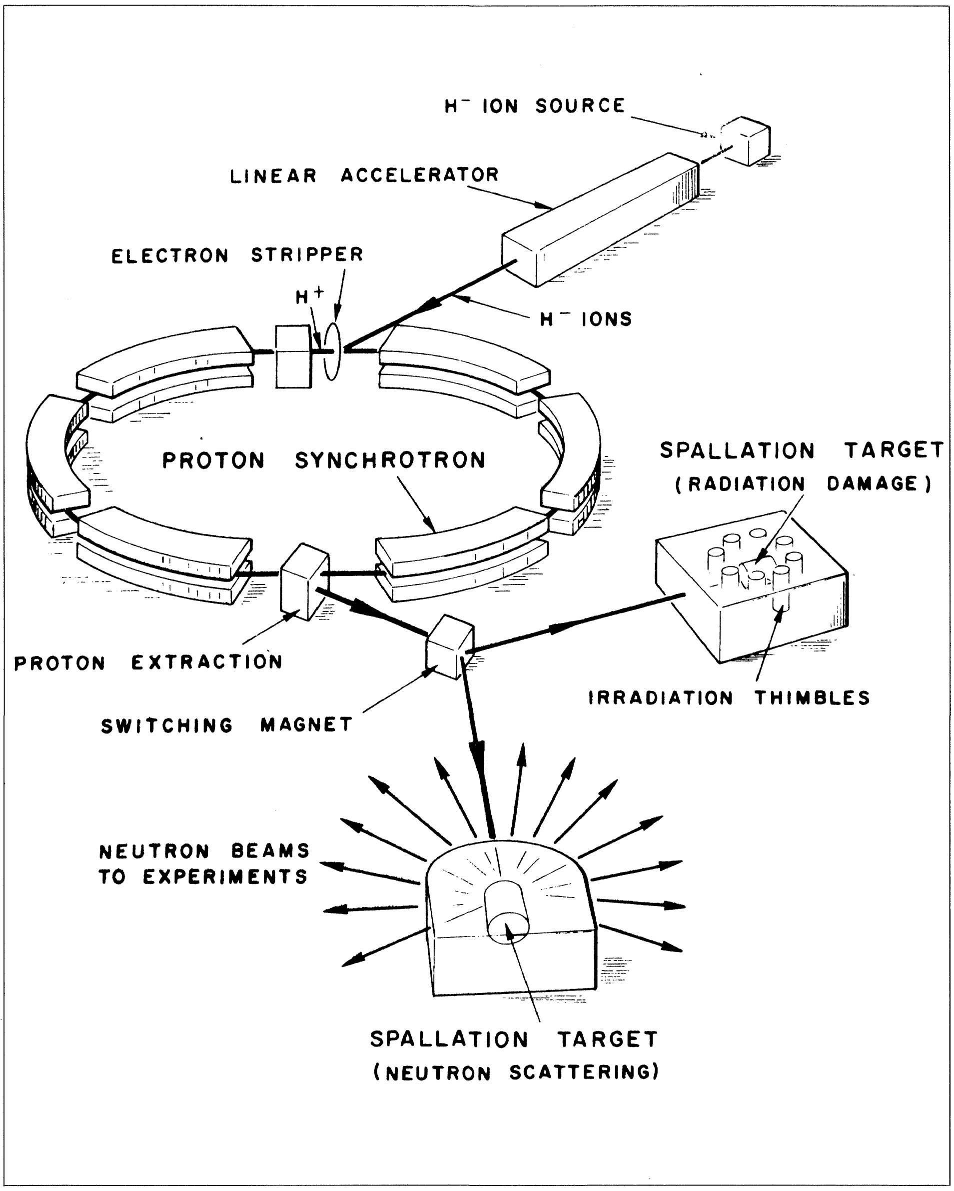
The major instruments are likely to be one or two chopper spectrometers for inelastic work, one or two diffractometers for powder diffraction experiments, a single crystal diffractometer, a small angle scattering instrument, and one or two cryogenic irradiation facilities for the study of fast neutron damage.

IPNS-I will be available to provide 2 × 10^{15} thermal, 2 × 10^{15} epithermal (1 eV) and some 10^{13} fast neutrons per square centimetre per second. It is hoped to follow this with the construction of IPNS-II — a high intensity synchrotron, using the ZGS building and experimental areas, to increase these fluxes by another order of magnitude (which would retain competitivity with the Spallation Neutron Source being built at Rutherford Laboratory).

It seems unlikely at present, however, that money for IPNS-II will be forthcoming before some experience has been gained operating IPNS-I. The total cost of the complex of the two machines and experimental facilities is estimated at $68 million.

ZGS swan song

At the ZGS, pressure is on to squeeze as much as possible out of the unique ability to accelerate polarized protons before the machine is shut down at the end of September 1979. The polarized proton experiments, many with polarized targets also, and the dibaryon studies (reported in the April issue, page 118) are the only remaining items in the programme now that the neutrino experiments are finished.



Schematic diagram of the Intense Pulsed Neutron Source at Argonne. IPNS-I is being funded to provide high flux neutron beams at the ZGS Booster with fully instrumented experimental facilities as from the beginning of 1981.

The accelerator has achieved a peak intensity of 4.67 × 10^{10} polarized protons and runs regularly with intensities near 3 × 10^{10}. There are no problems in operating with high polarization up to 6 GeV and polarization as high as 70 % has been achieved at 12 GeV after an extensive programme of development.

To continue the work on understanding the behaviour of polarized proton beams in accelerators and storage rings, so as to keep this option open for future machines, Argonne has proposed the construction of a 50 MeV (to 3 GeV) storage ring using components of the old Princeton-Pennsylvania Accelerator. (The vacuum system is not good enough to carry out this sort of research in the ZGS.) The scheme includes the development of a high intensity negative hydrogen ion polarized source and the use of the 'Siberian snake' polarization reversal technique (developed at Novosibirsk) in the storage ring.

It is also hoped that a collaboration will develop with Brookhaven on the application of polarized protons at the 33 GeV Alternating Gradient Synchrotron. Here, much is likely to depend on the success of the negative ion source and whether it proves possible in this way to achieve the same intensity with polarized protons as with normally accelerated particles.

It is intended that the strong high energy physics groups at the Laboratory will stay together when the ZGS programme comes to an end. The nearby Fermilab is an obvious base for future research and polarized protons feature again in one of two areas of work involving Argonne physicists at Fermilab. They have presented a proposal to establish a high energy polarized proton beam via lambda decay and have been encouraged to develop it further. The other area is the building of the detector for colliding beam experiments when the superconducting Energy Doubler ring is in action.

Another major effort is participation in the High Resolution Spectrometer experiment which, it is hoped, will come into action on the PEP electron-positron storage ring early in 1980. Argonne is providing, in particular, the large superconducting magnet of the former 12 foot bubble chamber. The iron has already been shipped to California, the poletips are being reworked and the superconducting coils are being modified to operate horizontally. Because of the size of the magnet, the particle path length which can be observed could give five times the energy resolution of other detection systems around PETRA and PEP. It may be able to do some unique work, for example in sorting out details around the heavy quark particle masses.

MICHIGAN
Progress on superconducting cyclotron

Work on the new 500 MeV superconducting cyclotron at the Michigan State University Cyclotron Laboratory is moving steadily towards completion. NSF funding for construction of this cyclotron was approved shortly after the first successful operation of the superconducting magnet in June 1977 showed the feasibility of the project (see August 1977 issue, p. 243).

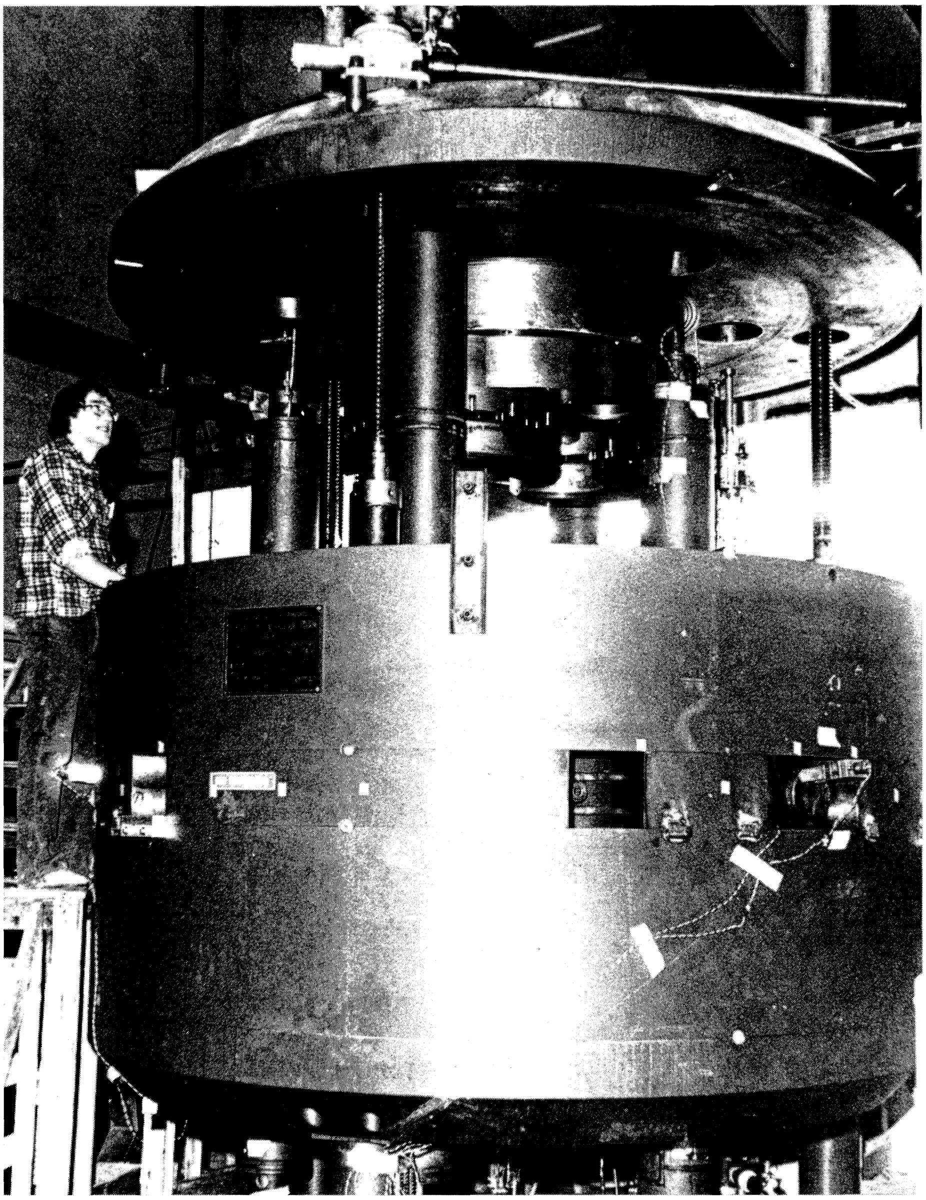
Construction of a 3000 ft^2 addition to the high bay wing of the laboratory building was completed in January of this year and in March the magnet was reinstalled in its new permanent location. The magnet was back in operation in May and in June a cold cathode Philips Ionization Gauge (PIG) heavy ion source, using nitrogen gas, was successfully operated for the first time at full field (700 A).

Design of the r.f. system has been completed. The prototype transmitter and a vacuum test stand consisting of two of the final dee stems and a simulated dee are under construction. Full power tests will begin in November and the r.f. system is scheduled to be completed by July 1979.

The extraction system for the superconducting machine will consist of three electrostatic deflectors together with three sets of focusing bars, the third set being divided into six subsets to provide more focusing power and greater flexibility. When completed, the 500 MeV cyclotron will be connected to existing experimental facilities. First test beams are expected in October 1979, with heavy ion research beginning in early 1980.

Funding prospects for a second stage cyclotron to work in tandem with the 500 MeV machine seem bright. The Nuclear Science Advisory Committee (NUSAC) recently made funding recommendations, giving the second stage of the Michigan coupled superconducting cyclotron project a 'highest priority' rating for fiscal year 1980. (NUSAC is a joint committee of NSF and DOE whose function in nuclear physics planning parallels that of HEPAP for high energy physics.) Interestingly, all of the four cyclotron proposals considered by NUSAC for fiscal year 1980 were superconducting designs.

In the meantime, the 50 MeV cyclotron continues to be effectively used for light ion research, recently yielding scattering data with a resolution of 3 keV at 30 MeV bombarding energy per nucleon. Shutdown of the 50 MeV machine has been tentatively scheduled for March 31, 1979, when a major rearrangement of the experimental halls will begin ready for use of beams from the 500 MeV cyclotron.



The superconducting magnet (seen here with the top raised) for the new 500 MeV cyclotron at Michigan State University.

(Photo Michigan)

Physics monitor

25 years of the renormalization group

The technique of renormalization was introduced into physics through quantum electrodynamics, where it enabled theoreticians to handle the otherwise troublesome infinities which kept cropping up in their calculations. In this technique, the infinities are removed by a well-documented mathematical procedure, enabling highly accurate calculations to be made. The physical ideas behind this renormalization prescription in quantum electrodynamics are less clear, but the success of the method, which produces some of the most accurate predictions in the whole of physics, cannot be doubted.

In 1953, E. Stueckelberg and A. Peterman first drew attention to the freedom in 'renormalizable' field theories, such as quantum electrodynamics, of choosing any one of an infinite number of different renormalization prescriptions, each equally valid as the conventional one. This is known in the trade as 'convention independence'.

Each of these prescriptions defines its own coupling constants and other parameters, so that although individual calculations change, the final physical predictions remain independent of the renormalization scheme used.

Like other invariances found in physics (for example rotational or translational invariance), finite renormalizations can be expressed in terms of repeated infinitesimal operations, and described by the mathematical apparatus of group theory.

For some twenty years, this idea remained an intellectual curiosity, but recently it has found uses in new problems in field theory, such as in quantum chromodynamics, the candidate theory of inter-quark forces. There, renormalization group techniques for scale transformations introduce a 'running coupling constant' which gets smaller as the interacting quarks get closer together. (See November 1977 issue, p. 380.)

This produces the idea of 'asymptotic freedom', where quarks interact little when close together, but bind together more strongly as the distance between them increases. This apparently perverse phenomenon could result in the perpetual confinement of quarks and account for their consequent non-appearance as free particles in the laboratory.

The techniques of the renormalization group have also been used successfully in areas of physics which at first (or even second) glance might seem totally unrelated to field theory — for instance in the description of abrupt phase transitions in condensed matter.

In the attempt to cover more and more aspects of the behaviour of matter, the equations of physics have to contend with more and more variables. Luckily it is not necessary to write down all the variables in every case — by considering the behaviour of relatively few atoms, for example, the physics of gases can be understood without having to write down the quantum mechanics of every atom in a large gas sample.

Modern physics, as well as having to deal with continuous systems where quantities can change smoothly from one point to the next, also has to deal with more complex systems where variables, although continuous in principle, do not necessarily vary smoothly from point to point.

Such behaviour is found in the quantum fluctuations of the electromagnetic field in quantum electrodynamics. In this theory one cannot calculate the exact value of the electromagnetic field at every point. Instead one uses correlation functions to predict expectation values.

Similar difficulties arise in the physics of condensed matter, where one is faced with the problem of describing an obviously discrete system such as a lattice of atoms, in term of bulk properties. For instance, physicists try to arrive at a description of the onset of ferromagnetic behaviour of a sample at its Curie point without having to worry about individual interatomic effects.

At such critical points, the system becomes extremely (actually infinitely) sensitive, and small changes in the external conditions cause the whole system to change its configuration abruptly. The sample appears to ignore individual interatomic forces. Microscopic degrees of freedom are 'frozen out' to give a system which depends on just a few bulk variables. This is to be contrasted to the conventional theory of gases, for example, where the observed behaviour can be explained as an aggregate of smaller samples.

A sample at its critical point thus becomes invariant under scale transformations. In mathematical language, the critical point is a fixed point — no matter what group operations are carried out, the system stays the same.

The renormalization group has provided a tool to handle the study of critical phenomena. The technique involves the successive summation of a series of individual steps, each of which involves a successive reduction in the remaining number of degrees of freedom of the sample, until a stable solution — the fixed point — is reached.

Perhaps the main goal of physics is to describe a maximum of phenomena with a minimum of variables. The renormalization group appears to offer the mathematical apparatus to do just this. With important applications in field theory and in the study of critical phenomena already to its credit, its use could become more widespread in the future.

People and things

Superconducting linac progress at Argonne

In July, beam was run through a superconducting linac section installed at the output of a heavy ion tandem Van de Graaff at the Argonne National Laboratory. The linac cavity has a split ring structure of niobium and tests of six resonators earlier in the year achieved 3.8 MV/m accelerating field gradients. It is intended to build up the linac progressively in order to add some 20 MV or more to the existing 20 MV output of the tandem so as to extend the physics potential at the facility with precise beams of heavy ions. The project is known as ATLAS — Argonne Tandem-Linac Accelerator System — and the cost is estimated at $ 5.6 million for operation in 1982.

On people

On 1 September Christoph Schmelzer, Director of GSI Darmstadt, retired. For the past 30 years he has been one of the most active physicists in the accelerator community. Following the design of the Heidelberg cyclotron in the early 1950s, he worked at CERN until 1960 in charge of the r.f. system and beam orbit control during construction of the 28 GeV proton synchrotron. He then became Director of the Institute of Applied Physics at Heidelberg University and promoted studies for a heavy ion accelerator. His work contributed particularly to the knowledge of ionic charge exchange, ion sources and r.f. accelerating structures for heavy ions. It resulted in a proposal for a universal heavy ion accelerator facility (UNILAC) in 1968. After this project was funded, he became Director of the new Laboratory (GSI) where his knowledge and influence were of great value. When UNILAC was operational he turned his mind to the future and again to a circular machine — a heavy ion synchrotron with UNILAC as injector. Having retired from his executive duties, Professor Schmelzer intends to remain active in physics. The new director of GSI is Gisbert zu Pulitz, formerly Professor in the Physics Department of the University of Heidelberg.

The fund which was set up in memory of the late John Rutherglen is being used to finance an annual award to a postgraduate student in experimental particle physics from one of the Universities associated with the electron synchrotron NINA. The first recipient of the award, the John Rutherglen Memorial Prize, is George Lafferty, a Glasgow student who began his research career under Professor Rutherglen's supervision.

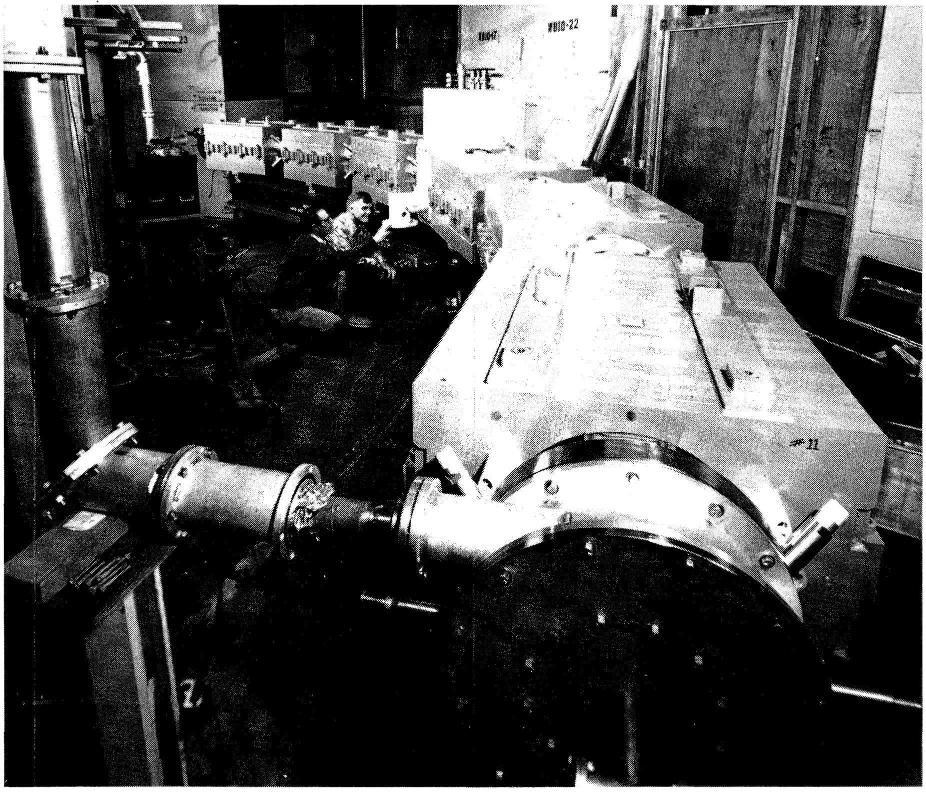
The Institut universitaire des hautes études internationales, Geneva, has published a book of articles of Lew Kowarski under the title 'Réflexions sur la science', edited by Gabriel Minder. Spanning the years 1947-1977, the articles present Kowarski's thinking (in his elegant prose in both English and French) on 'nuclear energy — its role and technology' and 'scientists — their tasks, ways and means'. This second group of articles has much to say on high energy physics and on CERN in particular.

*Recent appointments at CERN:
G. Ullmann has become Member of the Directorate for staff policy and staff planning for three years from 1 July. M.C. Crowley-Milling will become Member of the Directorate for Accelerator Programmes for three years from 1 January 1979. S. Fubini will continue as Member of the Directorate for two years from 1 January 1979. V. Soergel will become Member of the Directorate for three years from 1 March 1979.*

*1. Chris Schmelzer
2. Lew Kowarski*

1.

2.



A sector of six superconducting dipoles, complete with its cryogenic cooling system which worked very well, for the ESCAR small superconducting ring project. It has now been decided to run down this project and concentrate on the development of high-field superconducting magnets.

(Photo LBL)

G. Brianti will become Leader of the SPS Division for three years from 1 January 1979. A.J. Herz continues as Leader of the Health and Safety Division for three years from 1 July. H. Laporte continues as Leader of the Site and Buildings Division, A. Minten as Leader of the Experimental Facilities Division, G.L. Munday as Leader of the Proton Synchrotron Division and P. Zanella as Leader of the Data Handling Division for three years, all as from 1 January 1979.

ESCAR running down

The project to build a small superconducting accelerator at Berkeley (ESCAR - Experimental Superconducting Accelerator Ring) is being run down. Twelve dipoles had been built and were achieving fields over 3.5 T. A sector of six was operated but tests were halted some months ago by an accident when a power supply 'ran away' and caused two magnets to be damaged. It is now felt that the original aim of ESCAR, to provide experience with a complete accelerator system involving superconducting magnets, will be achieved too late to give valuable input to the big superconducting accelerator and storage ring projects (ISABELLE and the Energy Doubler). Effort at Berkeley is turning instead to research and development on high-field superconducting magnets, 6 T or above, with an eye particularly to the possible needs of the proton option for the future extension of the research potential with PEP.

One of the calves born to the buffalo herd at Fermilab being fed by Victor Kirkman. This photo prompted Tom Rossing of Northern Illinois University to the remark that he was happy to see the long-awaited Victor-bison interaction!

(Photo Fermilab)

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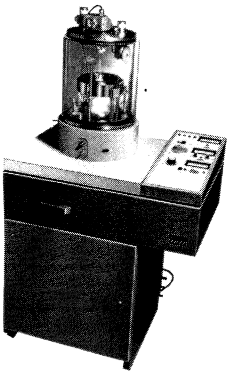

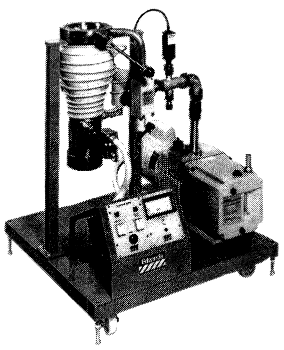

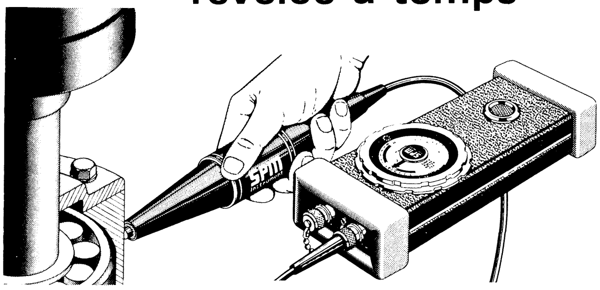
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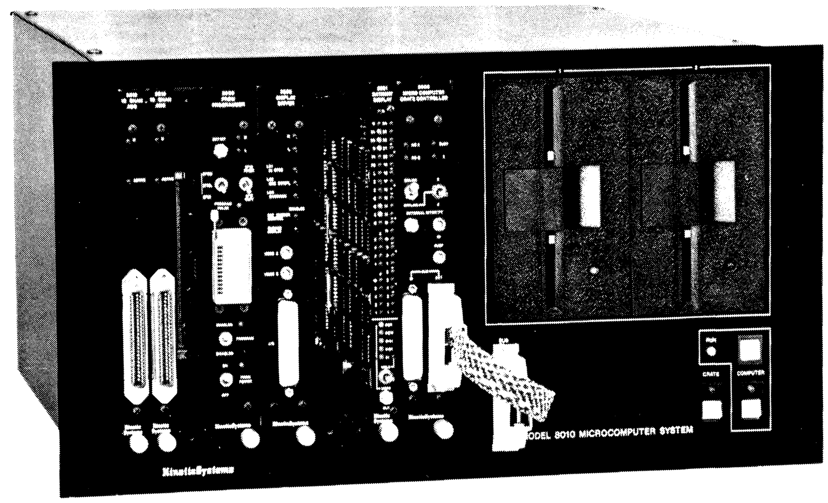

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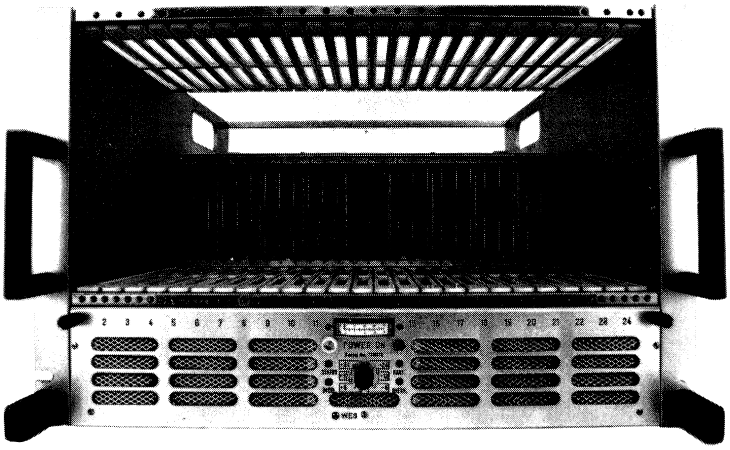
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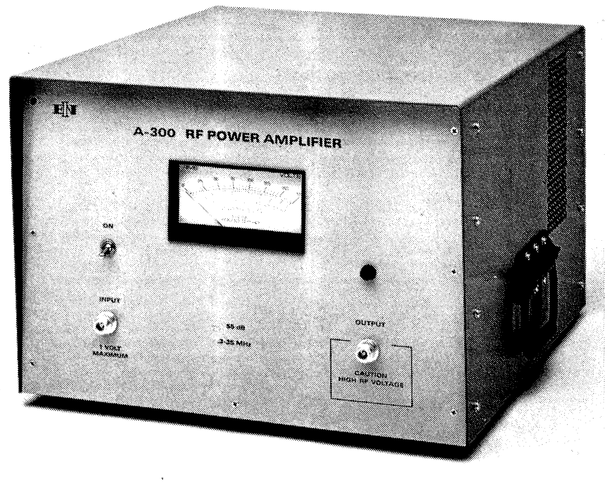
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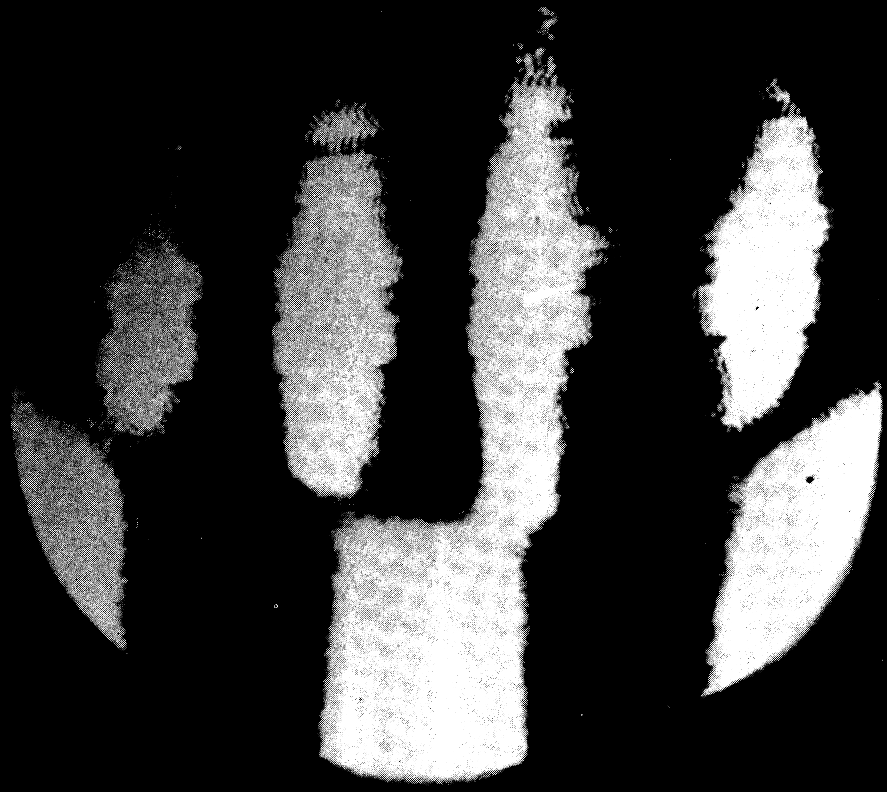

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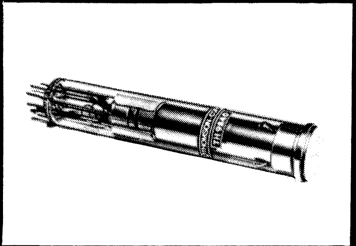

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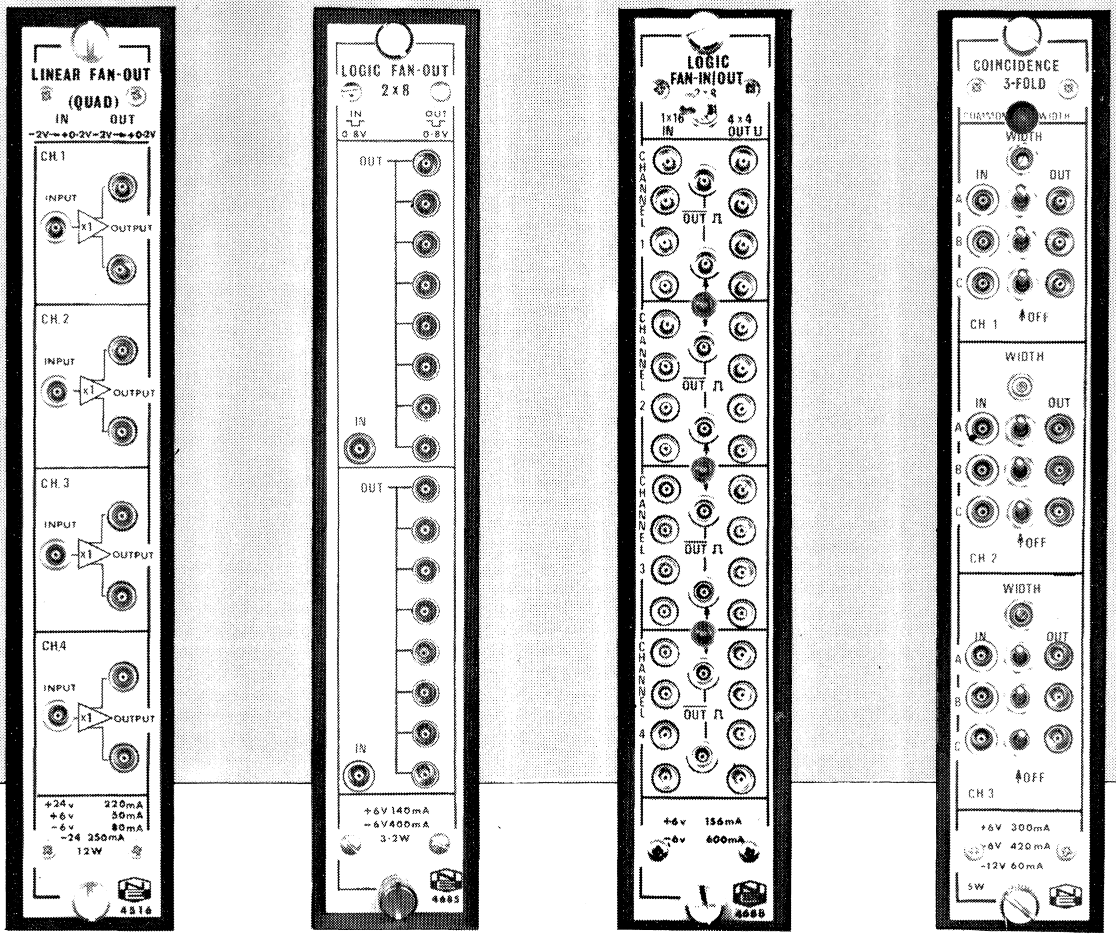

NE 4516 Linear Fan-out
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PROPAGATION DELAY 3.3ns; Differential delay, ‹ ±0.1ns.

MAXIMUM COUNTRATE 200MHz

POWER +6V, 140mA; -6V, 410mA; 3.3W

NE 4688 Logic Fan-in/out
4 sections selectable by front panel control to give quad 4-fold fan-in/fan-out, or dual 8-fold fan-in/fan-out, or single 16-fold fan-in/fan-out with LED indication of mode.

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OUTPUTS Fast NIM logic level, 4 per section non-inverting plus 2 per section complementary, 2.5ns rise and fall times, duration as per input.

PROPAGATION DELAY 8.5ns; Differential Delay, ±0.25 ns

MAXIMUM COUNTRATE 100MHz

POWER +6V, 150mA; -6V, 420mA; -12V, 90mA; 4.5W

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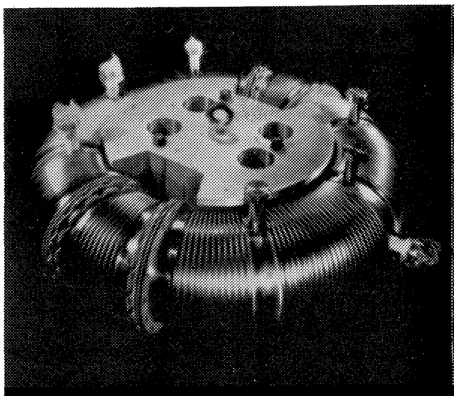

Tokamak for TOSCA experiment at
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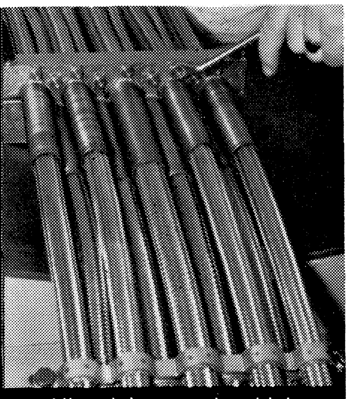

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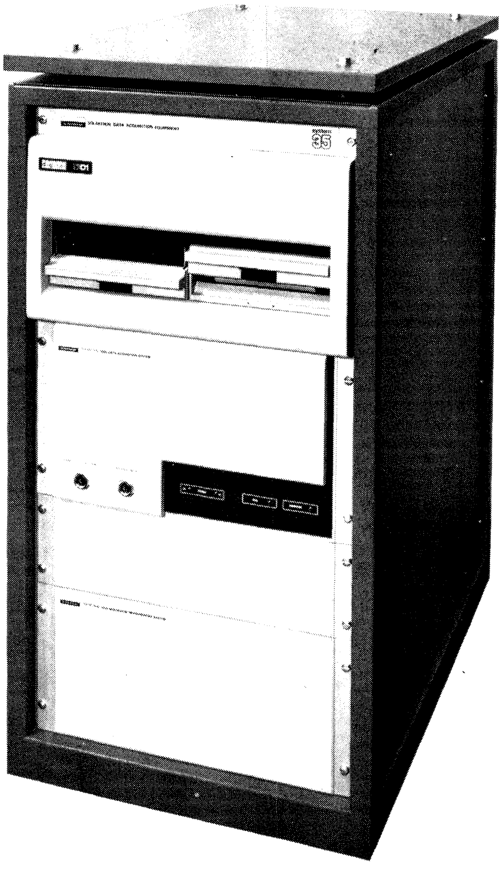
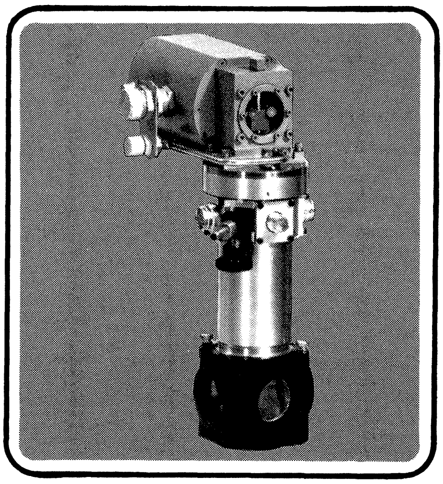

system 35



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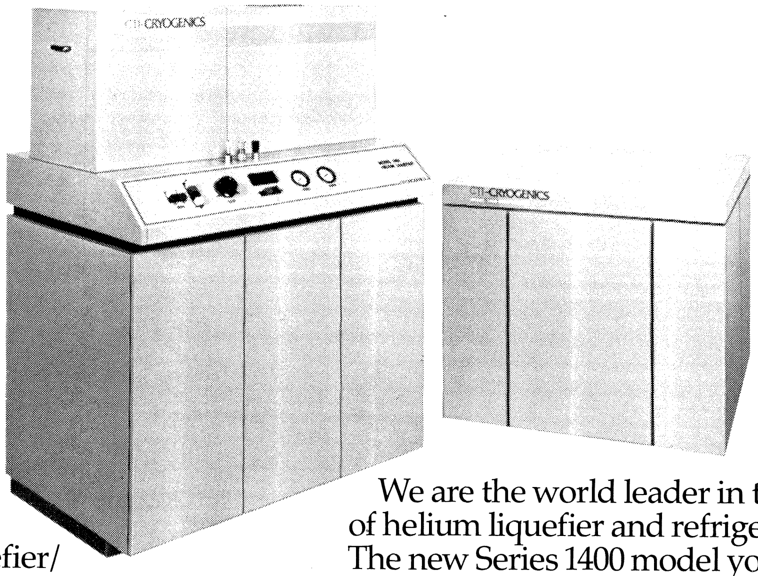

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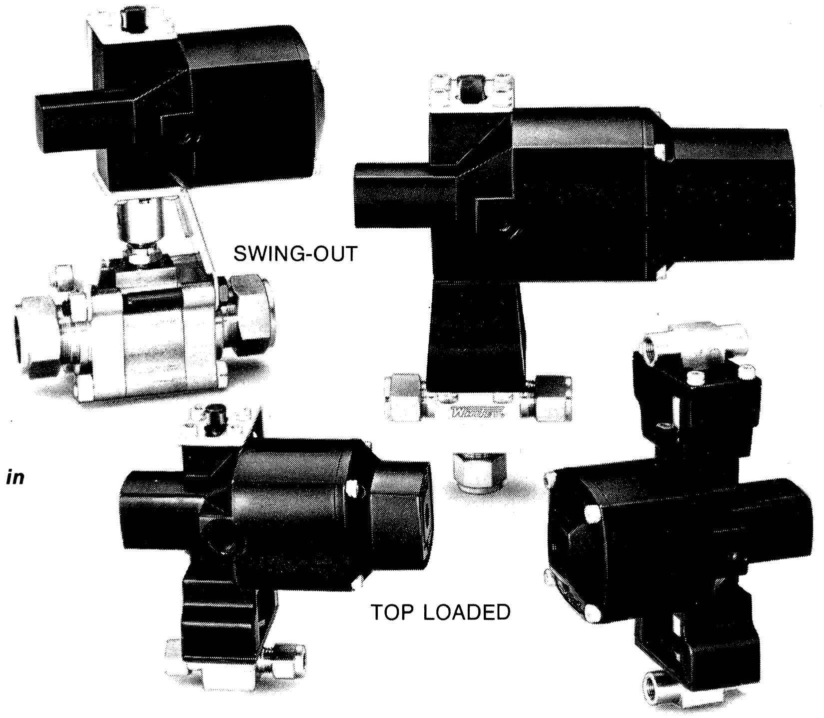
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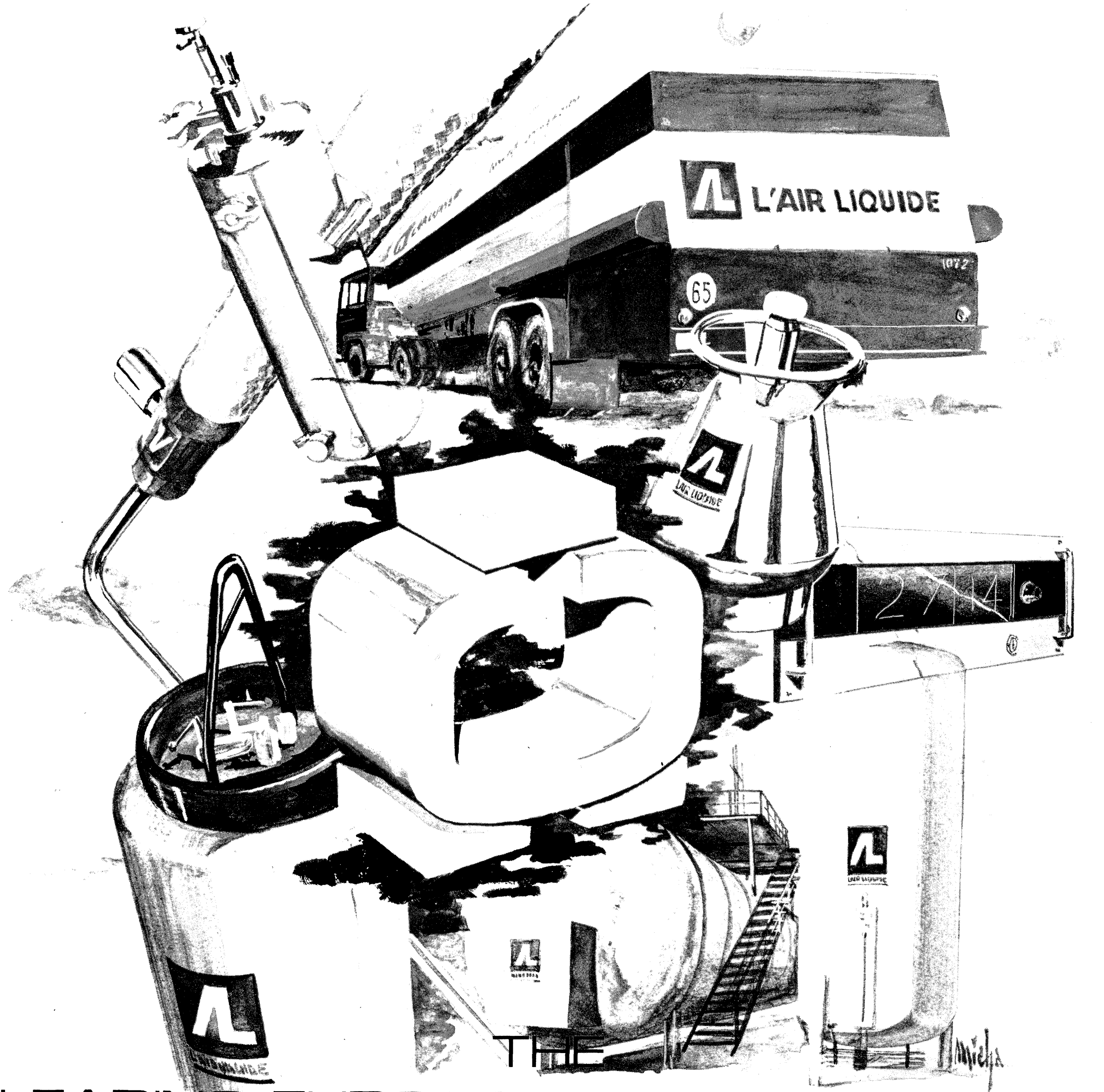
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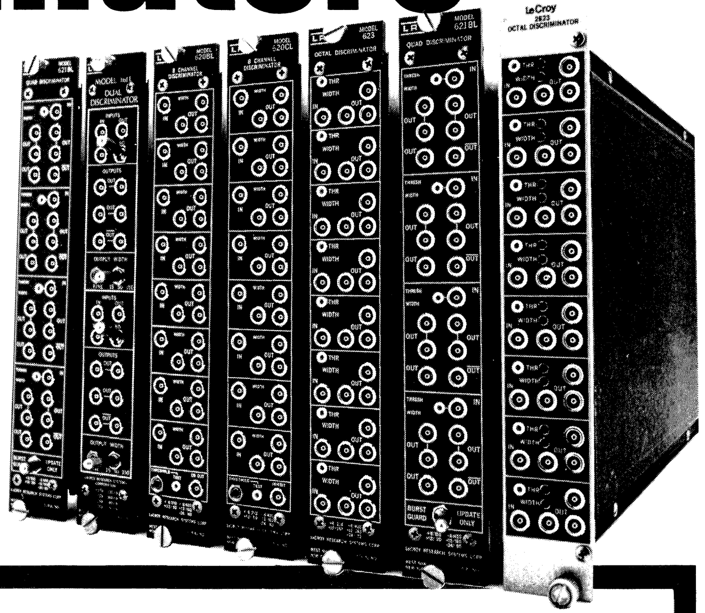

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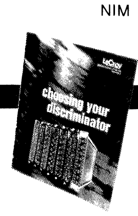
161L	NIM	2	Yes	− 100	3-150	4	2	Yes	150	No	Yes	Yes	± 12; ± 24
620BL	NIM	8	No	− 30 to − 1000 (common)	5-20	3	0	No	100	Yes	No	No	± 6; ± 12; − 24
620CL	NIM	8	No	− 30 to − 1000 (common)	5-20	3	0	Yes	100	No	No	No	± 6; ± 12; − 24
623	NIM	8	Yes	− 30 to − 1000	6-150	3	0	No	100	No	No	Yes*	± 6; ± 12; − 24
621BL	NIM	4	Yes	− 30 to − 1000	5-1000	5	1	No	100	No	Yes	Yes*	± 6; ± 12; − 24
2623	CAMAC	8	Yes	− 30 to − 1000	6-150	3	0	No	100	No	No	Yes*	± 6; ± 12; − 24
821	NIM	4	Yes	− 30 to − 1000	5-1000	5	1	Yes	100	No	Yes	Yes*	± 6; ± 12; − 24
826	NIM	6	No	Dual level for low slewing	4-50	3	0	Yes	100	No	No	No	± 6; ± 12;

*Hi-impedance bridged inputs are available at the expense of one normal output.



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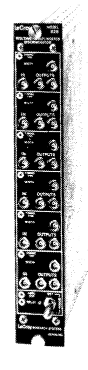

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- Variable threshold from − 10mV
- Low slewing — minimizes risetime effects
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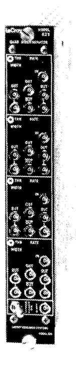

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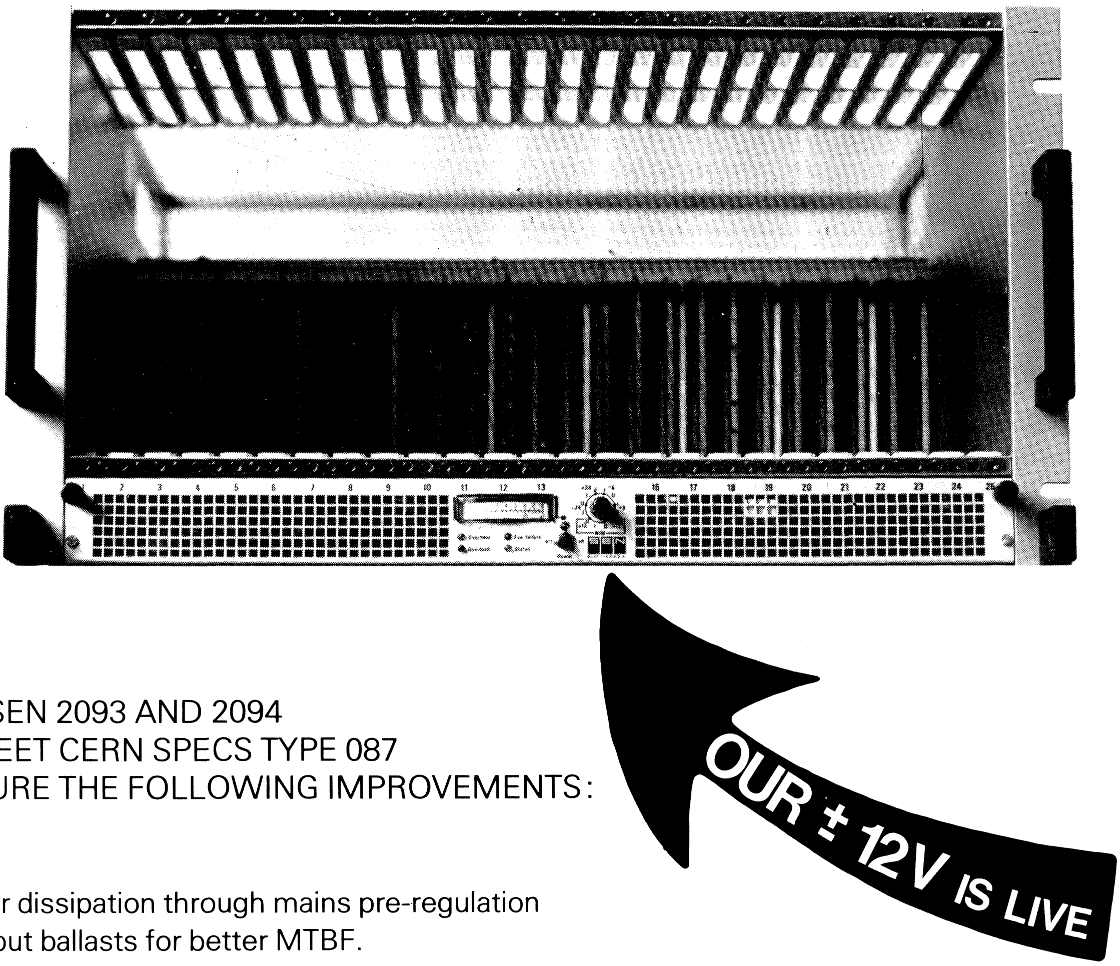

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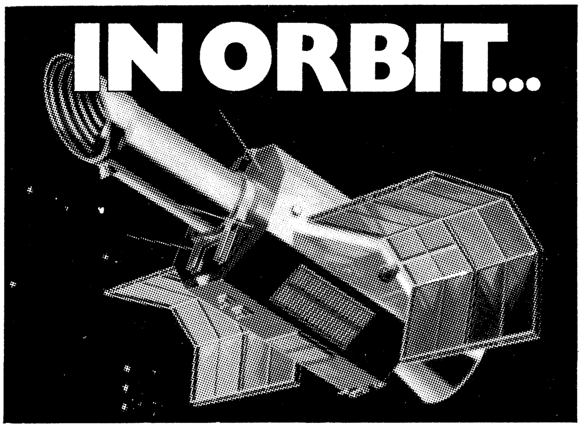

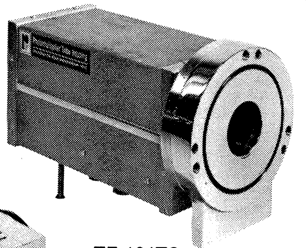

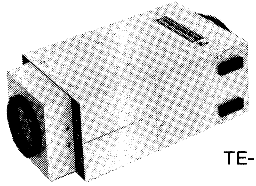

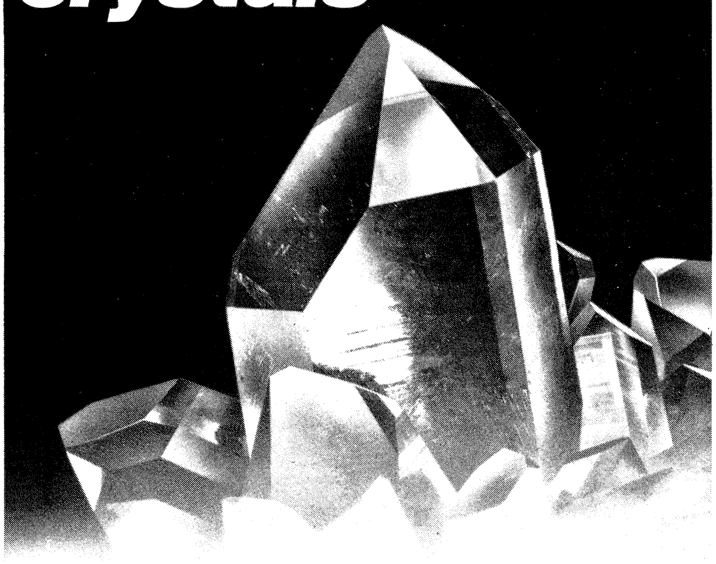

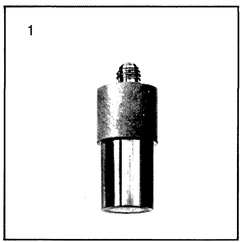

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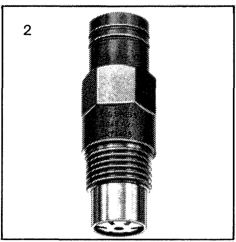

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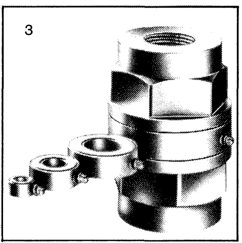

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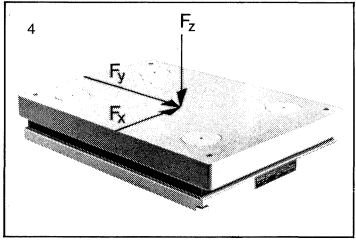

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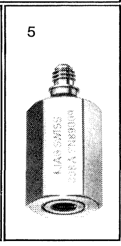
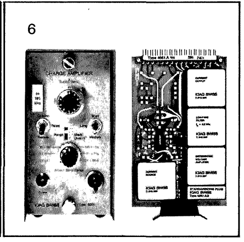


5



6

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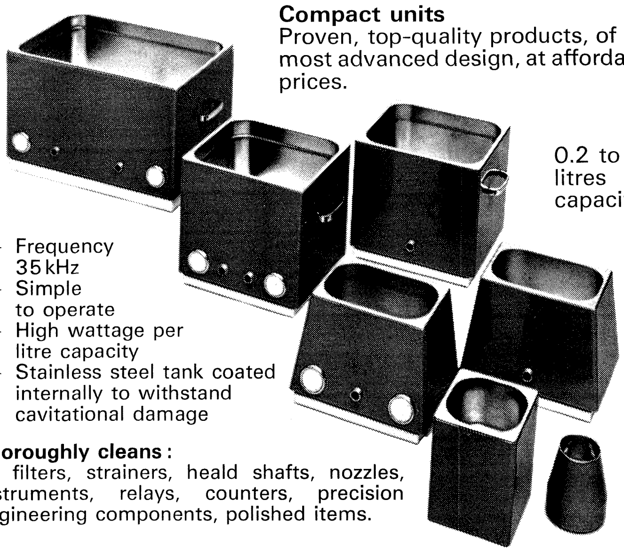

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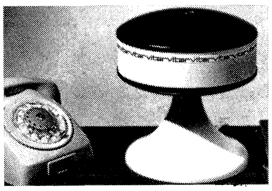

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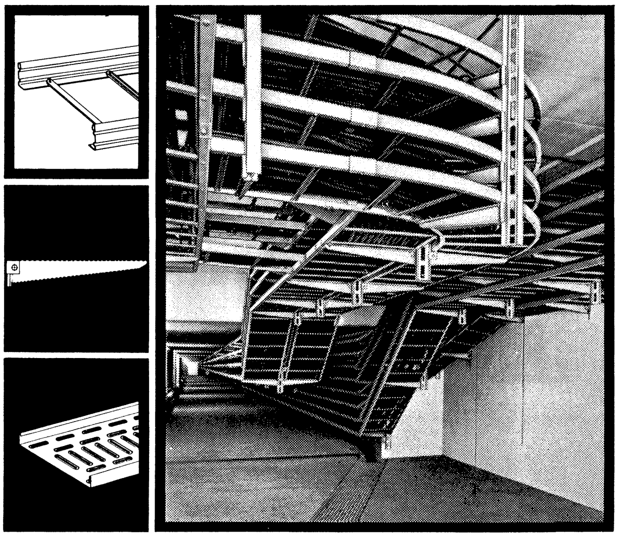

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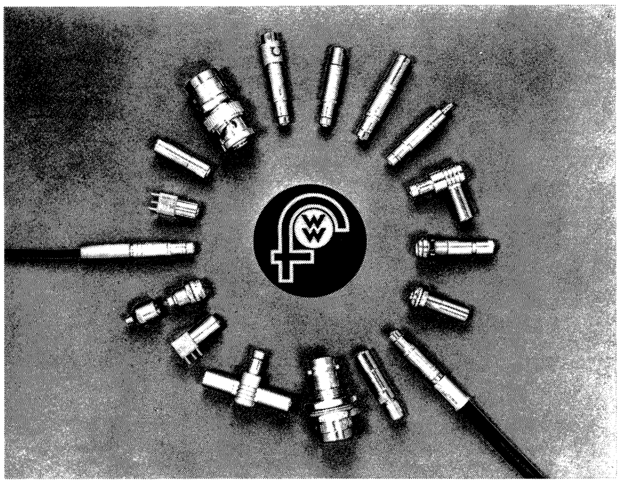

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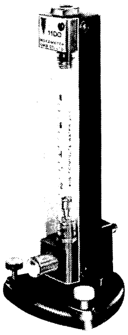

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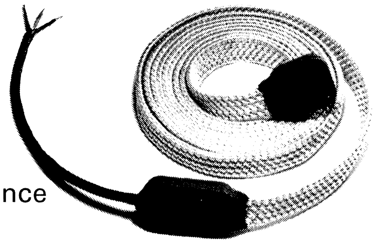

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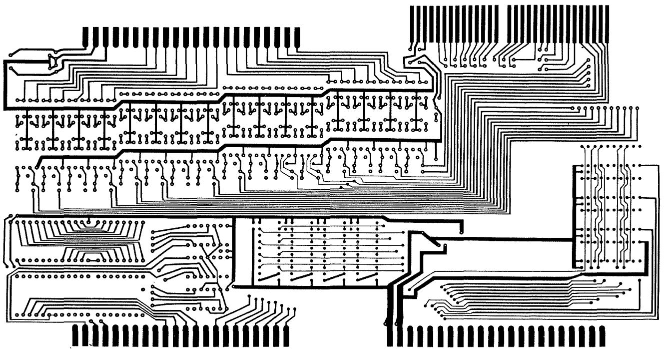

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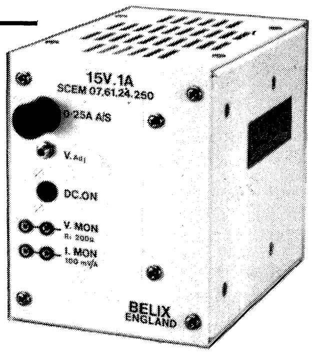
  Fours de laboratoire jusqu'à 1775°C
  Appareils de diffusion pour la fabrication d'hydrogène ultrapur
- **Terres rares**
  Métaux, oxydes, sels, Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sc, Sm, Tm, Tb, Y, Yb
- **Semis en platine, palladium, rhodium, iridium, tantale, niobium, tungstène, molybdène**
  en fil, baguette, anneau, feuillard thermocouples, thermocouples cryogéniques ainsi que thermocouples à gaine métallique
- **M 1000**
  Matériel de haute densité pour la protection antirayons
- **Produits pour usines chimiques**
  Catalyseurs sur base de platine, palladium et argent
  Disques de rupture, supports et supports à vide
- **Produits chimiques**
  Produits SPECPURE® et PURATRONIC® de très haute pureté pour le laboratoire et l'analyse
- **Brasures** à l'argent et **soudures** spéciales palladium, or, décapants, «Brazepaste»

JOHNSON MATTHEY &
BRANDENBERGER AG
Glattalstrasse 18
8052 Zurich
Téléphone 01/51 44 88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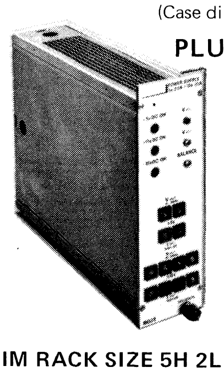

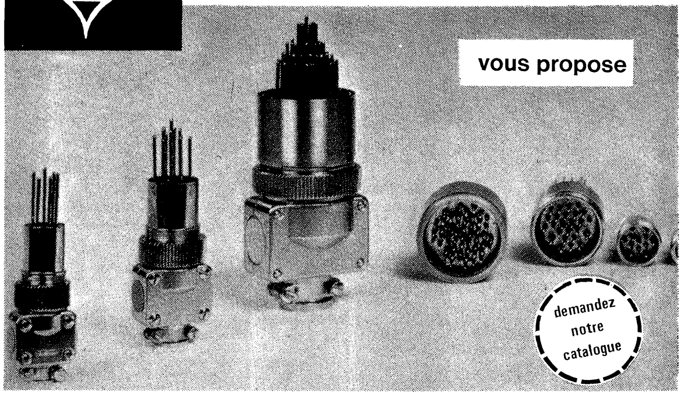
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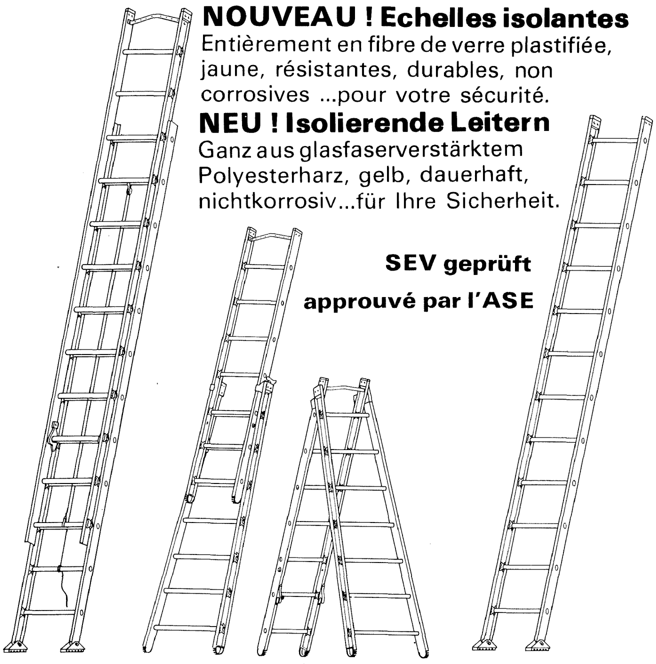

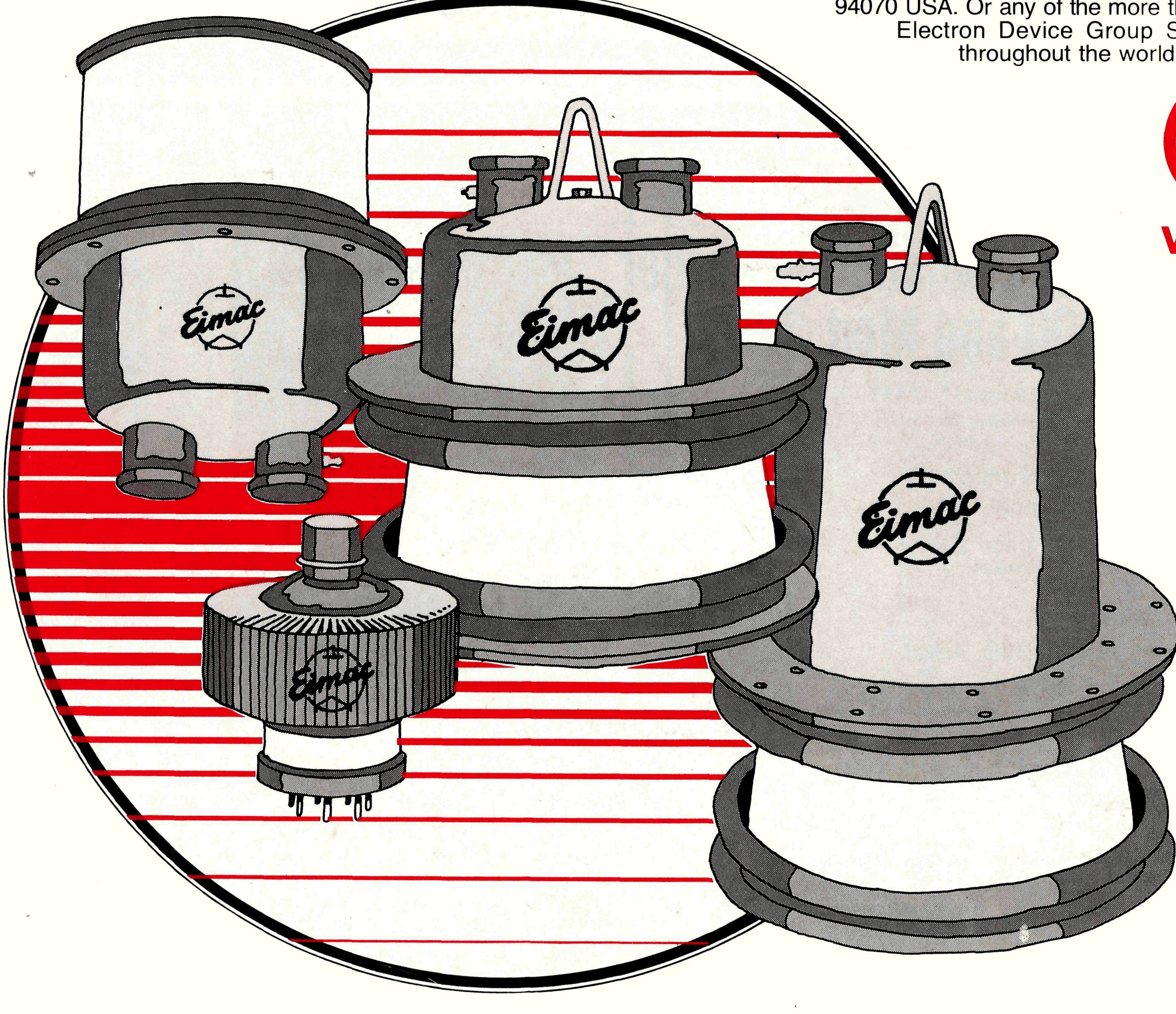
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