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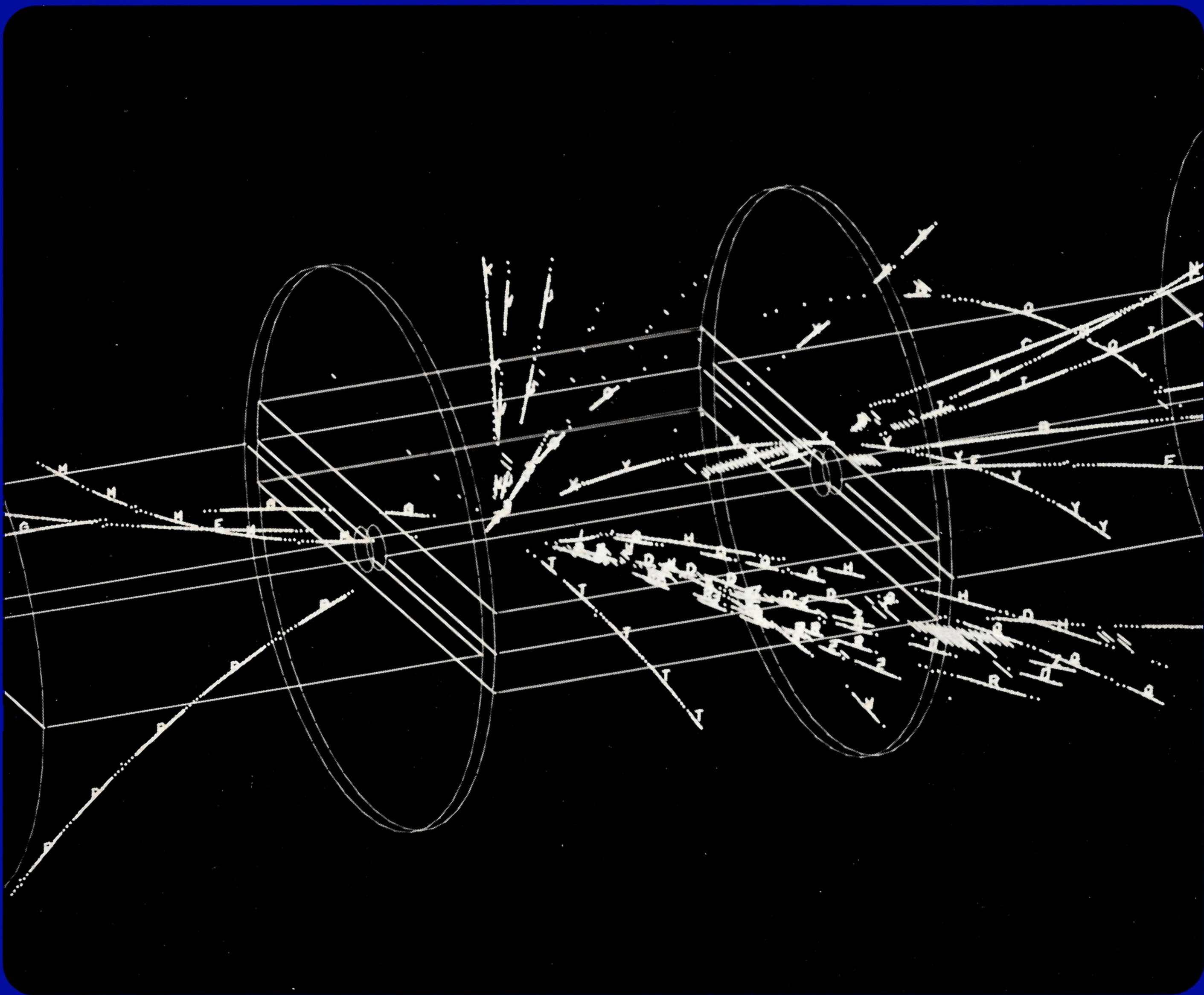

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CERN COURIER

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Cover photograph: A 540 GeV proton-antiproton collision, as it might be seen in the central detector of the UA1 experiment now being assembled at the CERN SPS. The 'event' was generated by a computer simulation, and the hits in the image chambers are displayed together with segments of tracks found by the pattern recognition program. In the picture, there are no signs of intermediate weak bosons, although the experimenters hope that this will be quickly rectified when the SPS collider goes live.

A decade of colliding proton beams

ISR Control Room, 27 January 1971, 13.40 hrs. Kjell Johnsen, leader of the ISR construction team, announces that experimental teams watching two of the intersection regions had for the first time observed proton-proton interactions in colliding beams.

(Photo CERN 248.1.71)

Ten years ago at the Intersecting Storage Rings at CERN, two proton beams collided for the first time. On 27 January 1971 physicists with detectors installed at intersection regions I4 and I5 saw signals coming from colliding protons — the ISR was giving access, in controlled experimental conditions, to particle interactions at energies previously observed only in cosmic rays.

In a field liberally sprinkled with outstanding achievements, the ISR is widely regarded as the finest example of the accelerator builders' art. This article celebrates the ten year history of the machine and reviews the physics programme which it has made possible.

Commissioning days

Now that proton-proton storage rings have their regular place in the catalogue of accelerators, it is easy to forget that, in the early 1960s when the ISR project was first mooted, there were many who doubted the feasibility of high luminosity performance and the possibility of extracting good physics. Despite the positive results from the preceding work in CESAR (CERN Electron Storage and Accumulation Ring), the building of the ISR was something of an act of faith.

This degree of risk, coupled with the CERN tradition of thoroughness in its machine construction, led to great care being taken in the preparation of all the ISR components. In this way the anticipated battle with the physics of stored proton beams would not be made more difficult by problems related to unreliable components. This meticulousness in the building of the machine led to dramatically impressive commissioning days.

On 3 September 1970, the first attempt to transfer a pulse from the proton synchrotron to the ISR saw protons hitting the beamstop at the ISR, over 500 m away, within a few millimetres of the desired location. On 29 October the first pulse fed into one of the rings went around and around. Instead of the usual coaxing process to achieve circulating beams, the 'theoretical' machine settings (and the components' response to those settings) were so good that stored beam was achieved immediately. On 25 January 1971 the same story was repeated in the second ring.

On 27 January both rings were fed with protons for the first time and it was early in the afternoon that the machine physicists knew they had won. The presence of fairly intense beam in one ring did not seriously perturb a more modest beam in the other ring. 'Beam-beam effects' were not as troublesome as people had anticipated. The construction team then knew that they could deliver a machine in which useful physics could be done. A few minutes later the physicists in the counting rooms rang through with the news of observation of the first-ever collisions. The ISR was on its way.

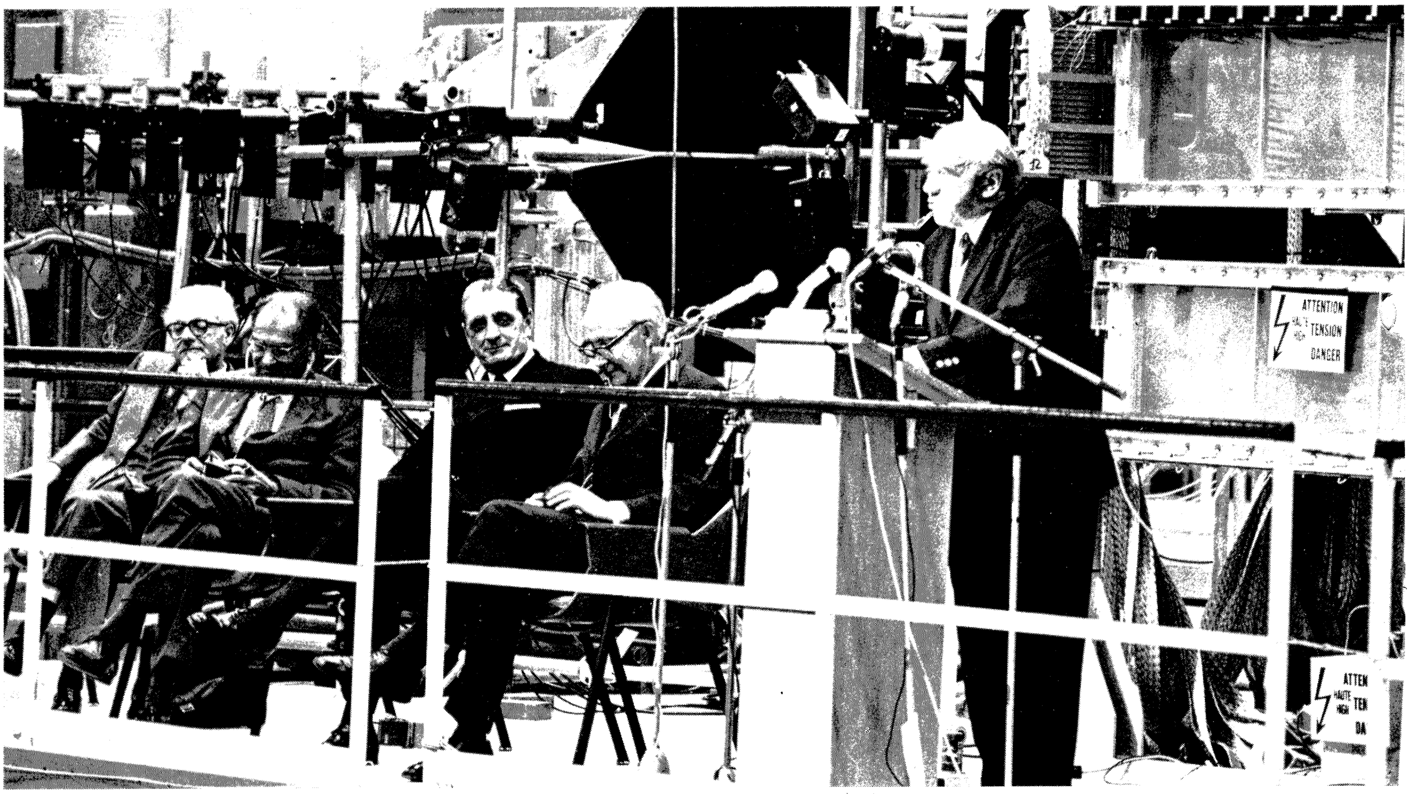
Ten years of improving performance

In terms of its usefulness for physics the important parameter of the ISR is its luminosity. This figure is directly proportional to the number of proton-proton collisions occurring in a given time and thus to the number of interactions which the physicists can observe in their detection systems.

The design value for the ISR luminosity was 4×10^{30} per cm^2 per s. This value was reached for the first time on 20 December 1972 (with

Werner Heisenberg speaks at the official inauguration of the ISR on 16 October 1971. With him on the platform are (left to right) Edoardo Amaldi, Viki Weisskopf, Marcel Antonioz and Willi Jentschke.

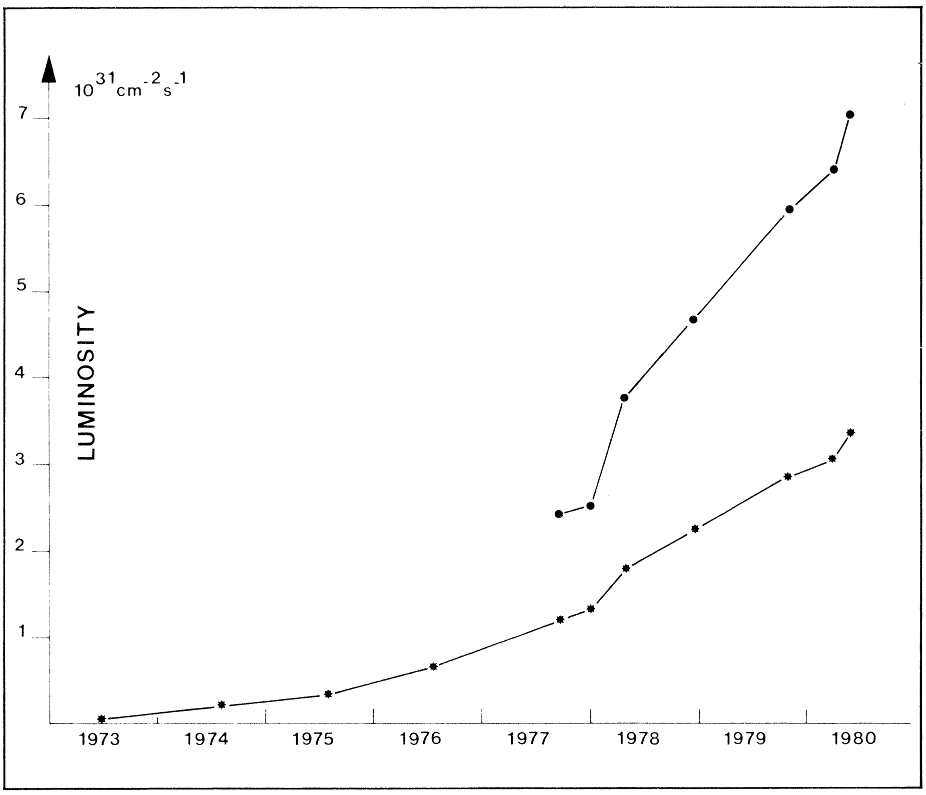
(Photo CERN 348.10.71)



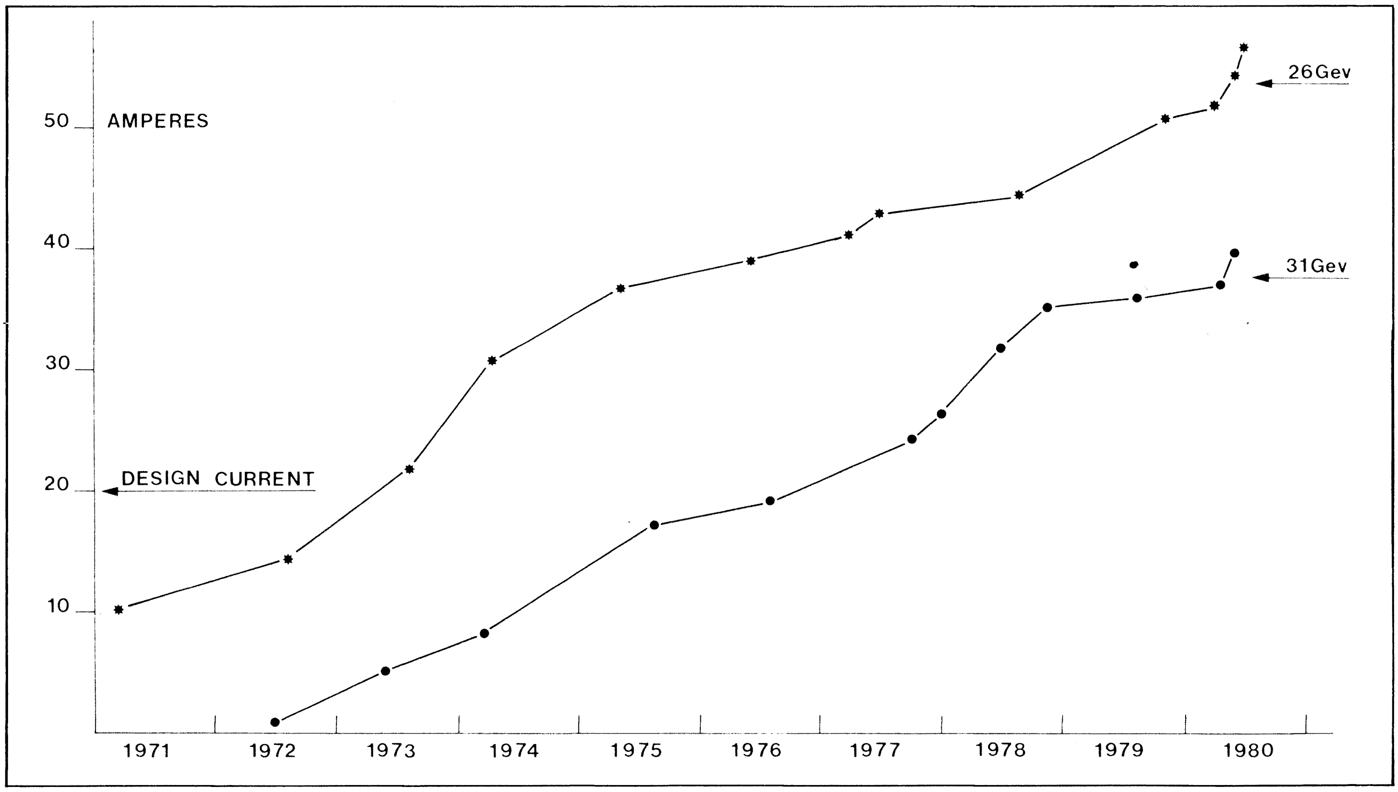
currents of 12.2 A and 11.3 A at 22 GeV in the rings). It has since been significantly surpassed reaching a peak of 3.5×10^{31} even in physics runs at 31.4 GeV and without the low beta insertions. The evolution of the luminosity over the years of machine operation is shown in the accompanying graph and is a good indication of how far ISR performance has exceeded expectations.

Another significant parameter from the machine physics point of view is the peak current stored in the rings. In June 1974, the design value

Luminosities achieved during ten years of ISR operation with beams accelerated to 31.4 GeV in the storage rings. The lower curve is from a standard intersection, the upper one from an intersection fitted with a 'low beta insertion' using conventional steel focusing magnets. In both cases, even with the current losses involved in accelerating beams in the ISR, the design luminosity of 4×10^{30} per cm^2 per s has been comfortably surpassed.



Peak stored currents in the ISR over the past ten years. The top curve shows the values achieved with 26 GeV beams injected from the proton synchrotron, while the bottom one indicates performance with beams accelerated to 31 GeV in the ISR itself. In both cases the design value of 20 A has been greatly exceeded.



of 20 A per ring was reached for the first time, bringing with it another np in luminosity to over 10^{31}. The evolution of stored peak currents up to remarkable value of 57 A is also shown in the graph. This demonstration of the ability to hold such intense beams in storage rings has had great influence on the thinking on subsequent colliding beam projects in high energy physics and on the ideas of using intense heavy ion beams in inertial fusion devices (see, for example, September issue 1976, page 291).

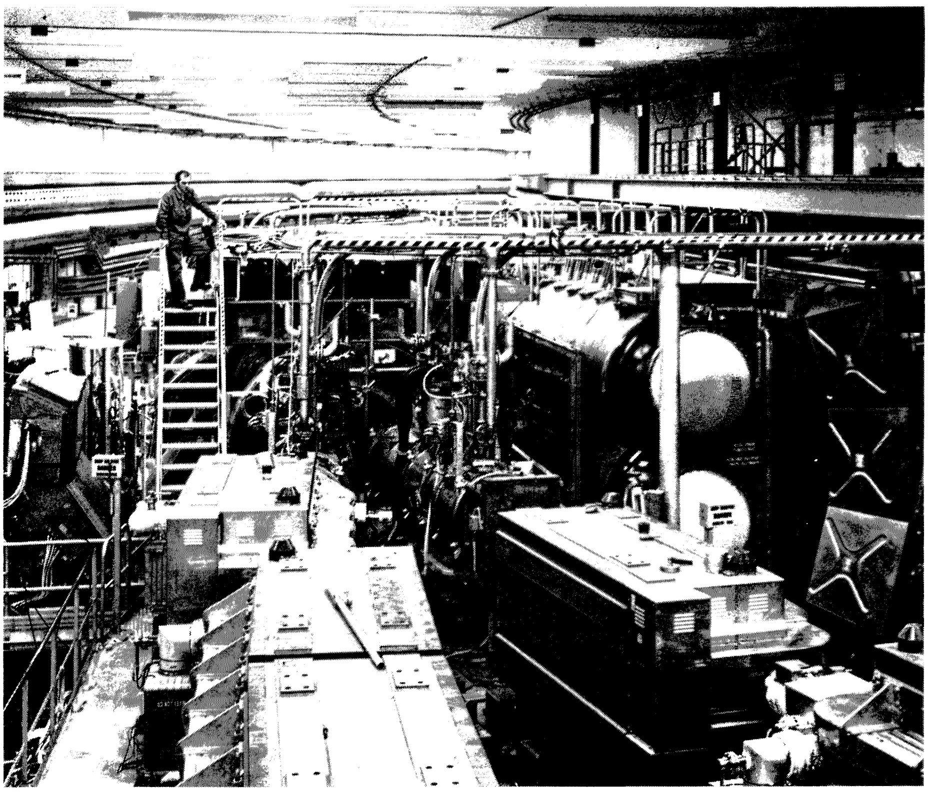
We now pick out, in no particular order of priority, several other major performance achievements of the ISR. In 1972 the radio-frequency systems in the rings were used for the first time to accelerate the injected beams (using the phase displacement technique) to higher energies. (Up to this point, the ISR had stored its proton beams at the energy supplied by the PS.) Beams injected at 26 GeV were taken to 31.4 GeV with some loss in intensity. At these beam energies the 'centre-of-mass' collision energy is equivalent to that which would be achieved using a 2000 GeV accelerator to fire protons onto a stationary target. By now it has proved possible to accelerate currents as high as 38 A to 31.4 GeV.

One of the vital aspects of the ISR in relation to the physics programme which it has supported is the reliability of the machine. This is all the more noteworthy because the storage rings were, at the time of their construction, the most complex accelerator systems ever built. To pick out just one moment when reliability made news — during the International Conference on High Energy Accelerators at Stanford in May 1974, the CERN participants were able to announce that during the Conference the ISR had had a continuous run of 34 hours for physics. It began with a luminosity of 6.6 × 10^{30} and the rings were closed down with the luminosity at 5 × 10^{30}. This corresponds to protons being lost at the rate of one per million per minute. If the 'off' button had not been pressed some of the same protons could have been still orbiting the rings two years later.

One of the major technological achievements behind the success of the ISR as a machine has been the mastery of the vacuum system. This proved necessary to an extent which had not been anticipated in the construction. It had of course been realized that ultrahigh vacuum would be necessary in the beam tubes to avoid significant loss of protons due to collisions with molecules of residual gas during their millions of orbits around the rings. The requirement was still more stringent in the beam

Intersection region I8 at the ISR, where the superconducting quadrupoles have recently come into operation to increase the luminosity for the experiments. At the centre of the photograph it is just possible to see the cylindrical cryostats containing the magnets. These are the first superconducting magnets to be brought into operation actually in an accelerator.

(Photo CERN 242.11.80)



collision regions to reduce 'background' due to proton-gas collisions when the experimenters were looking for true proton-proton collisions. Thus the design parameters were initially set at an average pressure of 10^{-9} torr around the rings and 10^{-11} torr in the intersection regions.

Even these tough requirements, a thousand times more stringent than was then common in accelerators, proved insufficient. The first serious limitations in machine performance were traced to phenomena which became known as 'pressure bumps'. As the beam reached a particular intensity it caused a correspondingly increased degree of ionization of the residual gas. The liberated ions bombarded the chamber walls liberating gas molecules which became the source of further ions. An avalanche effect developed, killing any attempt to take the beam intensity higher.

This discovery led to a methodical attack on improving vacuum conditions — an addition of pumping capacity and the development of new techniques in vacuum vessel surface treatment. (Further information on this work can be found, for example, in the April 1974 issue, page 124.) Now the average vacuum around the ring is about 10^{-11} torr and in the intersection regions as low as 10^{-13} torr. The ISR has the largest ultrahigh vacuum system in the world and these new techniques have made it ultrahigher than ever.

In 1975, the ISR was the scene of the first tests of the idea of 'stochastic cooling' which aims to concentrate a stored beam around desired parameters. It was pursued in an attempt to push the luminosity higher. The idea is to observe the spread of the beams and then act on the beam with appropriate fields so as to nudge the majority of the orbiting particles towards the desired values. Repeating this process very many times achieves beam concentration. Since the first tests, the technique has been refined considerably both in the ISR and in the specially-built ICE storage ring (see, for example, the October 1979 issue, page 309).

Some people regard beam cooling as the greatest development in accelerator technology since the invention of alternating gradient focusing. It is now a key element in the production of intense antiproton beams, via the Antiproton Accumulator ring, which will be used in major CERN physics experiments in the near future, and there are probably many other applications of beam cooling yet to be thought of.

The precision of the ISR has also been demonstrated by its use in the acceleration of particles other than protons. At the request of the physicists, the machine was tuned in 1975 to receive deuterons from the PS. The particles were stacked at the first attempt, in accordance wi tradition, and very high energy deuteron-deuteron and proton-deuteron collisions could be studied. In 1980 the exercise was repeated with alpha particles from the faithful PS. Again the runs went well and they had the added distinction of establishing a new world record for centre-of-mass energies (with two colliding beams of alpha particles each at 62 GeV). In the near future, it is hoped that antiprotons will be the fourth type of particle to be received into the ISR. The range of physics which the storage rings have made possible is still growing even after ten years of operation.

Physics at the ISR

The colliding proton beams in the Intersecting Storage Rings provide an as yet unrivalled collision energy, equivalent to a fixed target proton accelerator producing beams of some 2000 GeV. With the availability of such high collision energies, some people had dared to hope that the machine would either reveal the 'asymptopia' of hadronic physics, a dreamland where all interaction details would be smoothed out and the observed behaviour would approach a limiting value, or else produce free quarks!

While this was not to be, the ISR opened up a wide energy range for hadronic physics, where previously only fragmentary information was available from cosmic ray studies.

In the ten years of work at the ISR, many phenomena have been discovered and extensively studied. Landmarks are the energy dependence of the total reaction rate in proton-proton collisions, the behaviour of proton-proton elastic scattering, the features of particle production, violent collisions involving large transverse momenta where the colliding protons interact violently, and 'prompt' lepton production.

Broadly speaking, the results obtained at the ISR fall into two categories. Firstly, there are the processes which occur relatively frequently and whose behaviour appears to be dependent on the logarithm of the energy, rather than the energy itself. This behaviour appears to be the results of interactions between entire protons, and is characteristically 'soft', with little debris emerging at large angles to the collision axis. This physics covers the investigation of the proton-proton total reaction rate, proton-proton elastic scattering, and the dominant features of particle production.

Secondly, there are the interactions which occur much more rarely, but whose effects can change by an order of magnitude over the ISR

Superconducting success

The latest machine achievement at the ISR occurred at the end of November 1980.

One way of improving luminosity at the ISR is squeeze together the beams at their intersection regions. The luminosity is inversely proportional to the vertical height of the beams where they cross and the technique, known to the specialists as 'introducing a low beta insertion' involves using quadrupole magnets around the intersection to reduce the height of the beam.

This was tried first with conventional magnets in intersection I7 in 1974 (later moved for experiments to I1). The quadrupoles squeezed the beams by a factor of 2.3 and the observed luminosity was boosted by this amount to a new record. It was obvious that if the beams could be squeezed still harder by applying the higher fields available from superconducting magnets, then more gains could be achieved. However high intensity storage rings are 'hostile' environments for sensitive superconducting magnets and it needed careful work to ensure that their introduction would not disrupt the reliable ISR operation.

After successful operation of a prototype magnet, in 1979 the decision was taken to build eight quadrupoles for installation in intersection I8 with the aim of a sixfold boost in luminosity.

The major parameters of the magnets are: gradient of 43 T per m over a diameter of 173 mm, current of 1680 A and maximum field of 5.8 T, four magnets of length 1.15 m and four of 0.65 m, conductor of rectangular solid composite wire 1.8 × 3.6 mm² containing about 1250 twisted niobium-titanium filaments, each 50 microns in diameter, in a copper matrix. The magnets were built by industrial firms and installed in I8 during Autumn 1980.

Their first tests on 24 November went well. Beams were stored without problem (although initially at low intensity) and the measurements of beam height showed that the anticipated increase in luminosity was being achieved. Since then the usual high currents have been stored, the magnets are working up to their design performance and are an integrated part of the ISR magnet system.

This is the first time superconducting magnets have been used as part of a routinely operating accelerator/storage ring (although of course there have been notable achievements in the use of superconducting magnets in beamlines). It is also the first time that industry, rather than the operating Laboratory, has provided the magnets. A fine achievement to round off ten highly successful years of ISR operation.

energy range. These 'hard' processes include large transverse momentum collisions and the production of prompt leptons. These effects seem to derive from interactions between the inner constituents of protons. This area of research has received much attention in recent years and has provided valuable information on what goes on inside the proton.

Initial experiments used relatively simple detectors and gave rapid results. As time went on, larger and more sophisticated detectors were built to study rare events, or to study the correlations between several particles produced in the same reaction. In particular, a lot of work went into the construction of detectors to look for leptons produced in the proton-proton collisions. Although this effort began before the discovery of the J/psi, it only bore fruit after the discovery of the upsilon. The ISR's latter-day preoccupation with rare events has been greatly assisted by the steady increase over the years in the machine's luminosity.

Some of the earliest experiments at the ISR concentrated on measuring the total cross-section (yield) of proton-proton collisions in the ISR energy range. Earlier experiments at other accelerators, such as the CERN 28 GeV proton synchrotron, showed that the probability of a proton undergoing any interaction at all decreased as the energy of the proton increased. At the end of the 1960s, results from an experiment at the Serpukhov 76 GeV synchrotron, at the time the highest energy accelerator in the world, showed that this probability decreased more slowly at these higher energies. The proton's total reaction probability seemed to be approaching an asymptotic value, so that little further change in the behaviour of the proton, and therefore in physics as a whole, could be expected at higher energies. This had to be checked out, and the ISR appeared on the scene at an opportune time to provide the answer!

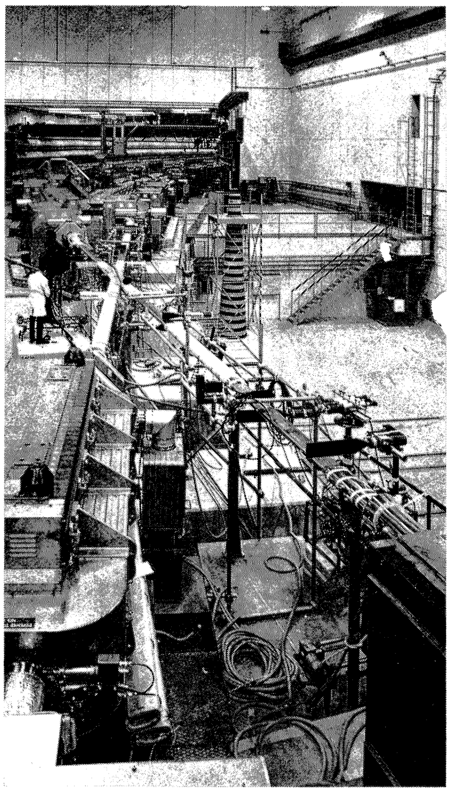
Experiments by CERN / Rome and Pisa / Stony Brook collaborations soon showed that the probability of protons interacting increases at ISR energies, so that the proton still had much more to tell us. While the Pisa / Stony Brook experiment determined the reaction rate directly, the CERN / Rome group measured proton-proton elastic scattering at very small angles and obtained the total reaction rate using the Optical Theorem, which relates the total cross-section with the (imaginary part of the) forward elastic scattering amplitude. Later experiments made more precise measurements.

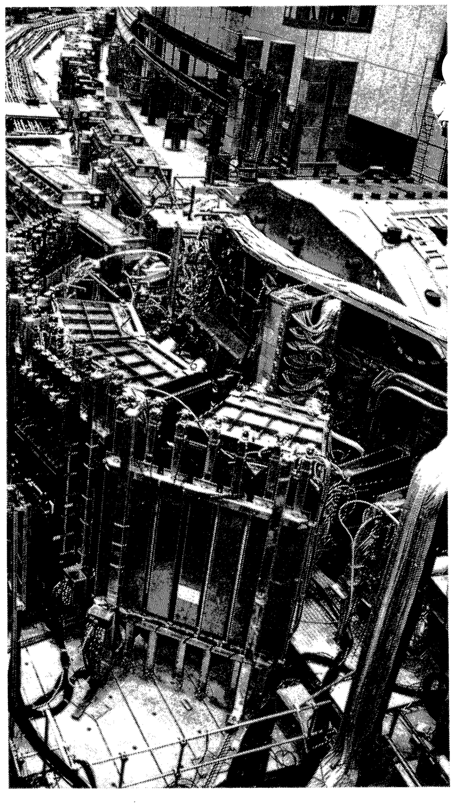
As well as the total cross-section which measures the probability of anything at all happening in proton-proton interactions, another important parameter is the cross-section for elastic scattering, which measures the way protons simply bounce off each other without any other particles being formed. The proton can be considered as a semi-opaque disc-shaped obstacle. Because of the wave nature of the proton, one expects that when these discs encounter each other, they will produce diffraction patterns with maxima and minima, similar to those seen in the diffraction of light.

Before the ISR came into operation, such behaviour had never been seen in proton-proton scattering, but early experiments by an Aachen / CERN / Genoa / Harvard / Turin group saw a diffraction-type 'dip' in the elastic scattering spectrum. Subsequent experiments confirmed this effect and studied how the dip moved with energy. This provides very accurate information on the interaction mechanism of the proton.

Top, early days when the two ISR beam pipes could be clearly seen in intersection I4. Below, six years later, and the intersection had become totally submerged by the big detection systems of the Split Field Magnet.

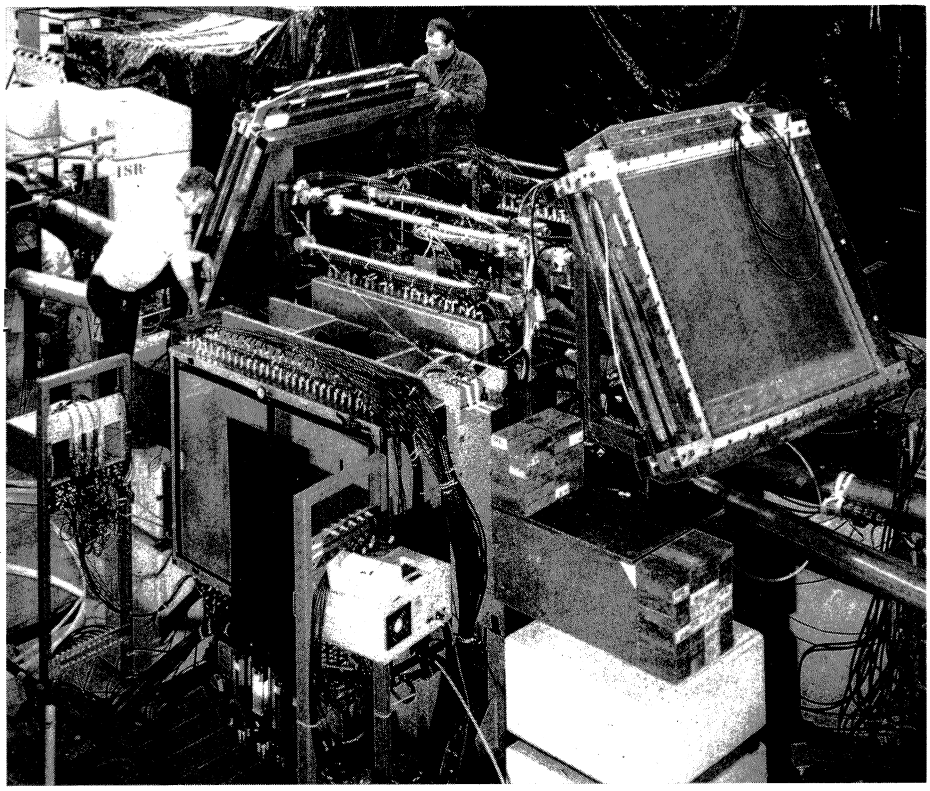
(Photos CERN 37.2.71 and 325.11.77)





Apparatus used by a CERN / Columbia / Rockefeller team which in 1972 saw particles emerging at wide angles to the proton-proton collision axis. This was one of the first experiments which saw evidence in proton-proton interactions for the existence of hard scattering centres deep inside the proton.

(Photo CERN 123.11.72)



The mechanism which produces elastic scattering also produces 'diffractive dissociation' where one (or ven both) of the initial protons is converted into an excited state with the same quantum numbers and then quickly decays. This had been seen at lower energies, but its importance has been underlined by experiments at the ISR, which cover proton excitation energies up to ten times its rest mass.

While the elastic scattering of protons is interesting, the bulk of the interactions in the ISR are inelastic, producing additional particles. The dominant features of these particle production processes and the correlations between the different produced particles have been extensively studied at the ISR by many different experiments, and have provided a wealth of data on the properties of the proton as a whole. Of particular importance was the discovery of a 'rapidity plateau' where many particles are produced with relatively small energies in the centre-of-mass system, but which can show significant correlations. This demonstrated the existence of 'short range order' effects where particles appear to originate from independent clusters.

Looking inside the proton

In the late 1960s, high energy scattering experiments with electron beams at SLAC had shown that the proton does not invariably behave as a single particle. Just as Rutherford's epic experiments earlier in the century revealed the nuclear atom, these studies showed that deep inside the proton there are small, hard grains, now identified as quarks. When the incident particles penetrate the outer layers of the proton and hit these grains, violent collisions occur, producing fragments at wide angles to the collision axis.

For hadron-hadron collisions, this behaviour was first seen at the ISR as an anomalously large yield of particles with large transverse momentum. It was seen by Saclay / Strasbourg / CERN / Columbia / Rockefeller and British / Scandinavian collaborations in 1972. Its continuing study has led to the development of large detectors to try and catch as many of these rare wide-angle events as possible.

One aspect of these proton constituent interactions is the emergence of hadron 'jets', where fairly well-defined sprays of particles are produced. These jets, which were first seen at the ISR in 1975, appear to be the products of proton constituents (quarks and gluons) torn from their parent particles. The behaviour and configuration of these jets provides important clues to the properties of hadron constituents.

The production of 'prompt' leptons which emanate from or very close to the proton-proton collision has been a highly profitable field of study world-wide, which among other things has led to the discovery of the J/psi and the upsilon particles. At the ISR, background and luminosity limitations could only slowly be overcome using the newer large and highly instrumented detectors. Although too late for the J/psi and the upsilon, these detectors have still made valuable contributions to the study of lepton pair production. Away from resonances, the observed spectrum of lepton pairs provides a deep insight into the interactions of quarks, and here the ISR has provided valuable data at the highest collision energies available.

Recent ISR experiments (see September 1979 issue, page 247) have given evidence for the production of charmed particles, in particular charmed baryons. Another important latter-day accomplishment is the observation and study of single photons. These were long expected as a result of quark-gluon collisions within protons. These photons proved difficult to isolate, but have now been seen by Athens / Brookhaven / CERN / Syracuse (also in collaboration with Brookhaven / CERN / Copenhagen / Lund / Rutherford / Tel Aviv) and by CERN / Columbia / Oxford / Rockefeller collaborations.

The ISR has also provided considerable data on deuteron collisions. In addition, the machine was also used last year to study the collisions of alpha particles, which because of their double electric charge enabled the collision energy to be effectively doubled for a minimum of effort. For the future, runs are scheduled with colliding beams of protons and antiprotons. This will revisit many of the major proton-proton landmarks and provide valuable comparisons (or contrasts) of the behaviour of particles and antiparticles, and of quarks and antiquarks.

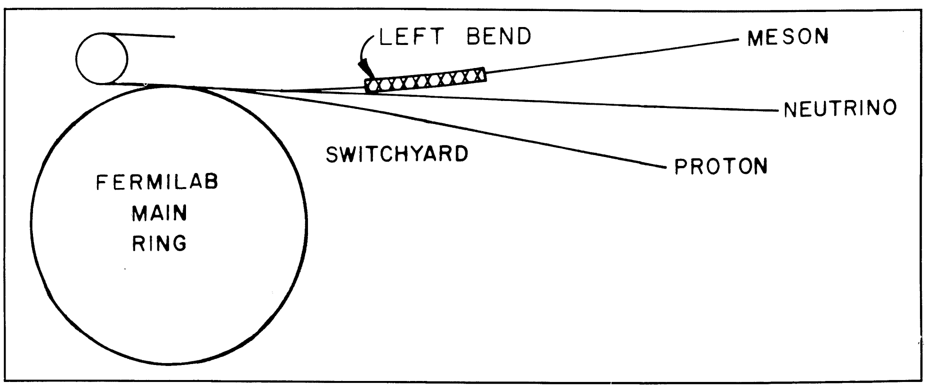
(In a brief review such as this, it is impossible to cover in any detail the vast amount of information which has emerged from the ISR, scene of over 50 experiments. For a detailed account, the interested reader is referred to the review paper by G. Giacomelli and M. Jacob, published in Physics Reports, Volume 55, No 1, in September 1979.)

Roger Dixon, leader of the beam switchyard Group of Fermilab's Accelerator Division, inspects the newly-operating superconducting 'left bend' which now supplies beam to the Meson Laboratory. As a precaution against helium leaks, he carries an oxygen monitor and emergency 'airpac'.

(Photo Fermilab)

FERMILAB
'Left bend' goes superconducting

The world's largest energy-saving superconducting system — the 'left bend' beamline at Fermilab — has begun successful operations. A string of 21 superconducting magnets, occupying a length of 450 feet, takes beam from the main ring to the Meson Laboratory. The magnets are also Tevatron-compatible and their successful operation means that a significant landmark has been passed in the development and construction work for the Energy Saver/Doubler. As a portent of things to come, the new beamline uses only one-fifth of the electrical power of its predecessor, which was based on 56 conventional magnets.



A London plane tree was planted during the ground-breaking ceremony for the new National Superconducting Cyclotron Laboratory. Participating (left to right) are Cornelius Browne of the National Science Foundation, Enloe Ritter of the Department of Energy, Chairman of the MSU Board of Trustees John Bruff, Laboratory Director Henry Blosser, Robert Bauer of the Department of Energy and University President Cecil Mackey.

(Photo Michigan)

MICHIGAN
Cyclotron progress

A ground-breaking ceremony was held at the National Superconducting Cyclotron Laboratory on 5 December 1980 to mark the beginning of construction of a building to house an 800 MeV superconducting cyclotron with its associated experimental areas and to provide additional office space for University faculty and researchers. The new building on the Michigan State University campus will double the existing high bay area of 14 000 square feet; office space will be increased by approximately fifty per cent from the existing 30 000 square feet. Construction is scheduled for completion in May 1982.

The $30 million project, funded by the U.S. Department of Energy, is the second phase of the Laboratory's heavy ion programme. Phase I, funded by the National Science Foundation, includes the construction of a 500 MeV superconducting cyclotron, in the existing building. This accelerator, scheduled for first operation later this year, replaces the 50 MeV room temperature machine, which was closed down in the summer of 1979 after fifteen years of productive operation for very precise, light ion physics. When the 800 MeV cyclotron is completed, it will be able to operate either coupled to the 500 MeV machine or independently.

Phase II (and the designation of the Laboratory as the National Superconducting Cyclotron Laboratory) officially started in late 1979. Many items for the 800 MeV cyclotron are now on order including the superconductor for the main coil, the bobbin assembly, the magnet core, the helium liquefier, and the anode power supply. First beam tests are scheduled for late 1983.

In the past year, considerable progress has been made in preparing the 500 MeV machine for operation. The superconducting magnet, which operated successfully as a prototype for more than two years, was modified and reassembled. The geometry of the pole tips was finalized with the addition of a number of details such as holes for trim coil leads, phase selection slits, extraction system actuating arms, etc. The magnet is now cooled down again and final field maps are being taken.

The design of the extraction system has also been finalized, based on a pair of electrostatic deflectors with further focusing provided by a series of inert iron bars. The magnetic elements of this system have been installed so that their effect is included in the field maps. The room temperature coils (trim coils), which shape the field to match the isochronous requirements of the various particles to be accelerated, are also operational. The effect of each of these coils will be measured individually in the mapping.

For the r.f. system, major improvements in the reliability of the full power prototype resonator have been made and construction of the remaining two amplifiers and resonators is proceeding. A cryopanel system for vacuum pumping has been constructed and successfully operated in a test stand. Internal ion sources have been tested in the high field magnet using a special electrode system to identify charge states. Electrostatic deflectors have been tested in the 50 MeV cyclotron magnet to confirm their voltage holding capability. Installation of all of these elements in the cyclotron is the major task for the coming months.

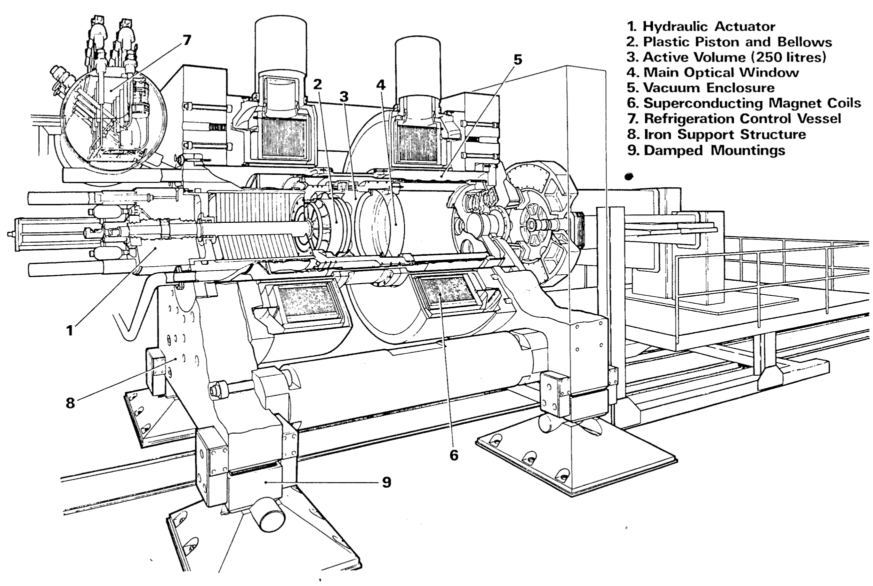
The 800 MeV cyclotron will be

used to provide a second stage of acceleration for beams emerging from the 500 MeV superconducting cyclotron. A stripping foil at the injection point of the second cyclotron will increase the ion charge by a factor of two to four (depending on the ion) and this, in combination with the larger energy constant of the second cyclotron, will give a total energy increase by a factor of up to twenty (see December 1976 issue page 431). The coupled cyclotron system will then produce energies of 200 MeV per nucleon for ions lighter than calcium and a decreasing energy per nucleon for heavier ions, down to a value of about 20 MeV per nucleon for uranium.

A new spectrograph is being constructed from existing magnets and is tailored to provide analysis up to the full magnetic rigidity of the 500 MeV cyclotron. This 'low budget' spectrograph will have relatively poor resolution (one part in a thousand) but will be ideal for a number of important programmes such as elastic scattering and giant resonance investigations. Design studies are also in progress on a large new spectrograph for Phase II, with a maximum bending limit the same as the 800 MeV cyclotron and major design features resembling the High Resolution Spectrometer (HRS) at Los Alamos.

Recently, a mailing list was set up to provide information for prospective users of the 500 MeV cyclotron and is being used as an information channel to solicit comments and advice on the design of experimental facilities for the coupled 500 + 800 MeV cyclotron system. On a number of occasions future users have visited the Laboratory to work on devices of interest to them or to work independently on experimental devices in which they are particularly interested.

The main elements of the vertex detector (a rapid cycling bubble chamber) of the European Hybrid Spectrometer.



A Users Executive Committee was also recently elected consisting of J.X. Saladin (Pittsburgh) — Chairman, A. Galonsky (Michigan State), J.R. Huizenga (Rochester) and S.G. Steadman (MIT). G.M. Crawley of Michigan State liaises between users and the Laboratory.

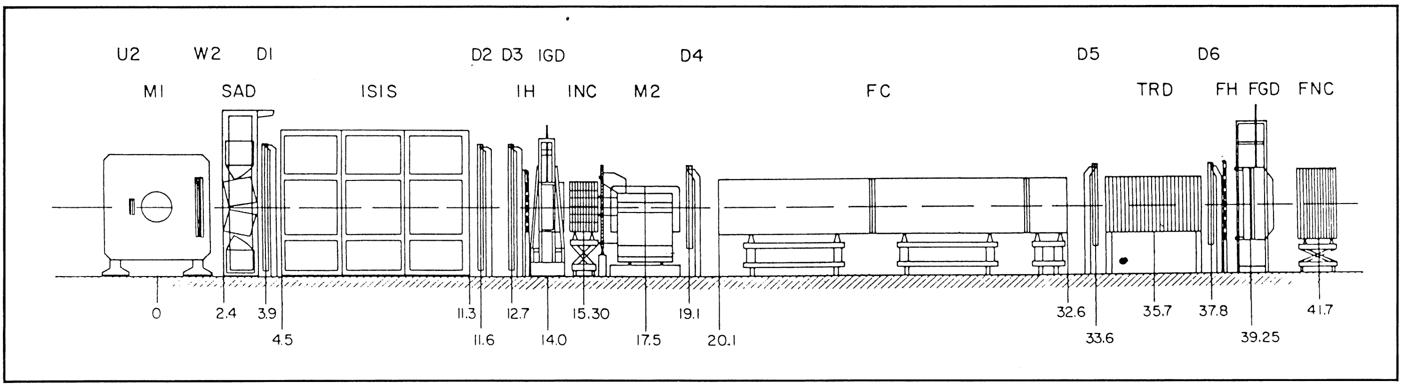
CERN
European Hybrid Spectrometer shapes up

Finishing touches are now being put to the new European Hybrid Spectrometer (EHS) in the North Experimental Area of the SPS. The first physics experiments have been approved, and are scheduled to start taking data later this year when the SPS resumes operation after its present long shutdown.

Built by a large collaboration of European Laboratories including a strong CERN contribution, EHS is a versatile detector which combines the use of bubble chamber and electronic techniques for particle detection, measurement and identification. At the heart of the detector is a 250 l rapid cycling liquid hydrogen bubble chamber, designed and built by the Rutherford Laboratory for expanding at rates of up to 30 Hz. It uses a 3 T magnet built by Saclay.

This magnet (M1, see figure) consists of two separate circular coils assembled with their axes horizontal in a massive iron structure. It provides a central field of up to 3 T in a useful volume of 1.4 m diameter and 0.82 m gap. It uses the classical pancake structure and bath cooling from a 100 l/h helium liquefier/refrigerator. Nominal current is 4000 A, resulting in a stored energy of 55 MJ. Special features include a

The array of detectors for the European Hybrid Spectrometer. The distances indicated are in metres. For an explanation of this complex detection system, see text.



relatively high average current density (2500 A/cm²) and an elaborate support structure, which is needed because of the particular force configuration within the iron frame. After assembly at CERN early in 1980, the magnet was cooled and operated three times for test purposes and field mapping.

The rapid cycling bubble chamber (RCBC) is in a cylindrical stainless steel assembly designed for easy installation into the iron frame along the horizontal magnet axis. The active volume is a cylinder, 80 cm in iameter and 40 cm deep, between the optical window and the scotchlite-covered piston-bellows assembly made of fibreglass-reinforced plastic. All vacuum, cooling, filling and expansion systems are concentrated on the left end of the cylinder, leaving the right end for optical components, in particular the three fast (up to 25 Hz) CERN-built cameras with bright field illumination. The RCBC is cooled from a 17 K/1 kW helium refrigerator and filled by gas condensation into the central volume. As liquid hydrogen is only used inside its vacuum tank, the hydrogen safety requirements could be met by having a ventilated enclosure only around the expansion end of the iron frame, thus giving free access to the beam windows for trigger equipment and wire chambers. The CERN-built expansion motor is a hydraulic servo-system providing the flexibility required for reproducible track formation in bursts of up to 60 expansions every SPS cycle.

The RCBC main components arrived at CERN last July, and, with a concerted effort by Rutherford and CERN staff, were finished, tested and installed within three months. Although still unfinished by the manufacturer, the inflatable gasket for the main window was mounted for a first trial cooling and filling in November. In the absence of an SPS beam, good quality cosmic ray tracks were photographed at 10 Hz, despite strong boiling around the gasket. A better situation is expected in the next RCBC run with a healthy gasket.

The bubble chamber is complemented by a 40 m long, two lever arm spectrometer. The first arm uses the fringe field of the bubble chamber magnet and consists of a proportional chamber (W2), a silica aerogel Cherenkov (SAD) and a series of drift chambers for momentum measurement at 1 per cent precision level and particle identification in the 2–50 GeV range. ISIS is a special large drift chamber achieving particle identification by ionization sam-

European Hybrid Spectrometer Constructors

Detector	Constructors
RCBC	CERN, Rutherford Laboratory
M1	Saclay, CERN
Prop. chambers	CERN, Padova
Drift chambers	Amsterdam, Vienna
SAD	Brussels, Mons, Strasbourg
ISIS	Oxford
FC	CERN, Madrid, Strasbourg
TRD	Aachen
IGD, FGD	CERN, Heidelberg, Padova, Paris, Rome, Serpukhov, Trieste
INC, FNC	Madrid, Mons, Paris, Serpukhov, Strasbourg, Vienna
LEBC	CERN

pling (see May 1978 issue, page 160) and which is now being finally assembled at CERN. The second lever arm, which accepts most of the secondary particles above 50 GeV, consists of a spectrometer magnet (M2), three drift chambers, a variable temperature/ density gas Cherenkov (FC) and a transition radiation detector (TRD).

Downstream of the particle identification system are the photon detectors to pick up the decay products of the large numbers of neutral particles, mainly pions, which are produced at SPS energies. The so-called intermediate gamma detector (IGD) is installed just downstream of ISIS, while another gamma detector (FGD), to pick up the photons produced in the narrow forward cone, is some 25 metres further away. Now also approved for construction are two calorimeters (INC and FNC) which will be mounted in the shadow of the photon detectors to measure the energy and position of neutral hadrons.

Already many research centres in the CERN Member States are involved with EHS, and it has attracted collaborators from other countries, notably Spain, India, Japan, the USA and the USSR. Its first three experiments cover complementary fields of physics and exploit the different SPS beams available. A Bombay / Cambridge / Collège de France / Liverpool / Mons / Paris / Serpukhov / Strasbourg / Vienna team will carry out a high statistics study of proton-antiproton annihilation. An Aachen / Brown / Brussels / Mons / Cracow / Helsinki / MIT / Nijmegen / Serpukhov / Haifa / Warsaw collaboration will look at the influence of parton structure in hadronic collisions using beams of protons and positive kaons and pions. The study of diffractive dissociation, especially into strange and charmed particles, will be the subject of a study by a Bombay / CERN / Frascati / Genova / Madrid / Pavia / Serpukhov / Tokyo / Vienna group.

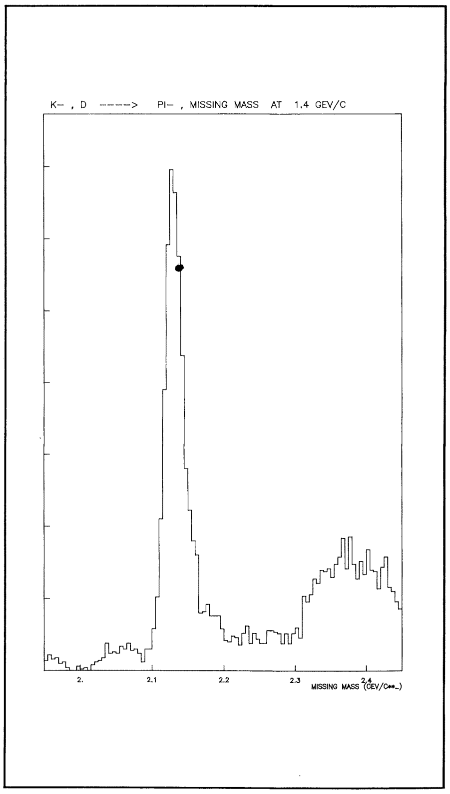
While the whole of EHS has yet to be used for physics, last summer the elements of the electronic detection system already in place were used in an experiment on hadronic charm production, using the LEBC mini bubble chamber as vertex detector (see June 1980 issue, page 159). Many groups are interested in continuing this physics with EHS. The RCBC would again be replaced by a mini bubble chamber, using new holographic techniques for achieving a resolution of less than 10 microns without depth of field illumination. Two such prototype experiments have recently been approved.

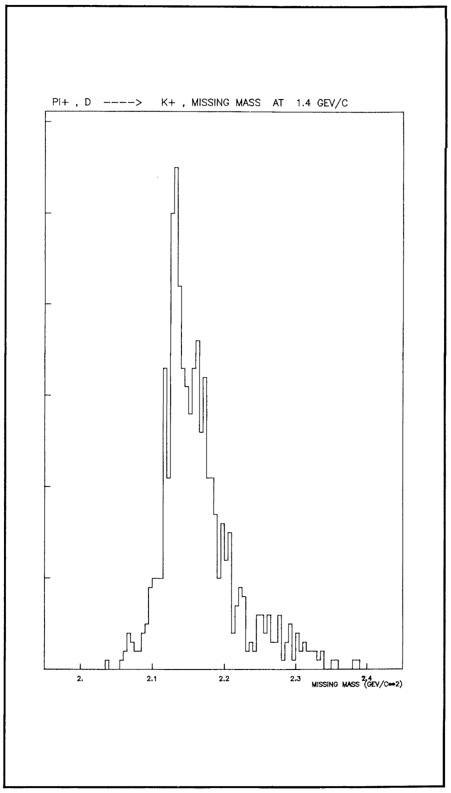
EHS will be a powerful new addition to the armoury of detectors exploiting the SPS. It is also a fine example of international scientific collaboration.

Strange dibaryon

The best-known dibaryon, the deuteron, is the only known bound state of two nucleons. However recent data, for example from Argonne (see September 1980 issue, page 252) and from SIN (see December 1980 issue, page 399), have revealed signs of transient two-nucleon resonances. In addition, experiments using negative kaon beams in the energy range up to 1.6 GeV have seen signs of a strange dibaryon (strangeness −1, mass 2130 MeV, width 10 MeV). This is produced, together with a negative pion, in the interaction of the kaon with a deuteron and subsequently decays into a lambda and a proton (see May 1977 issue, page 152).

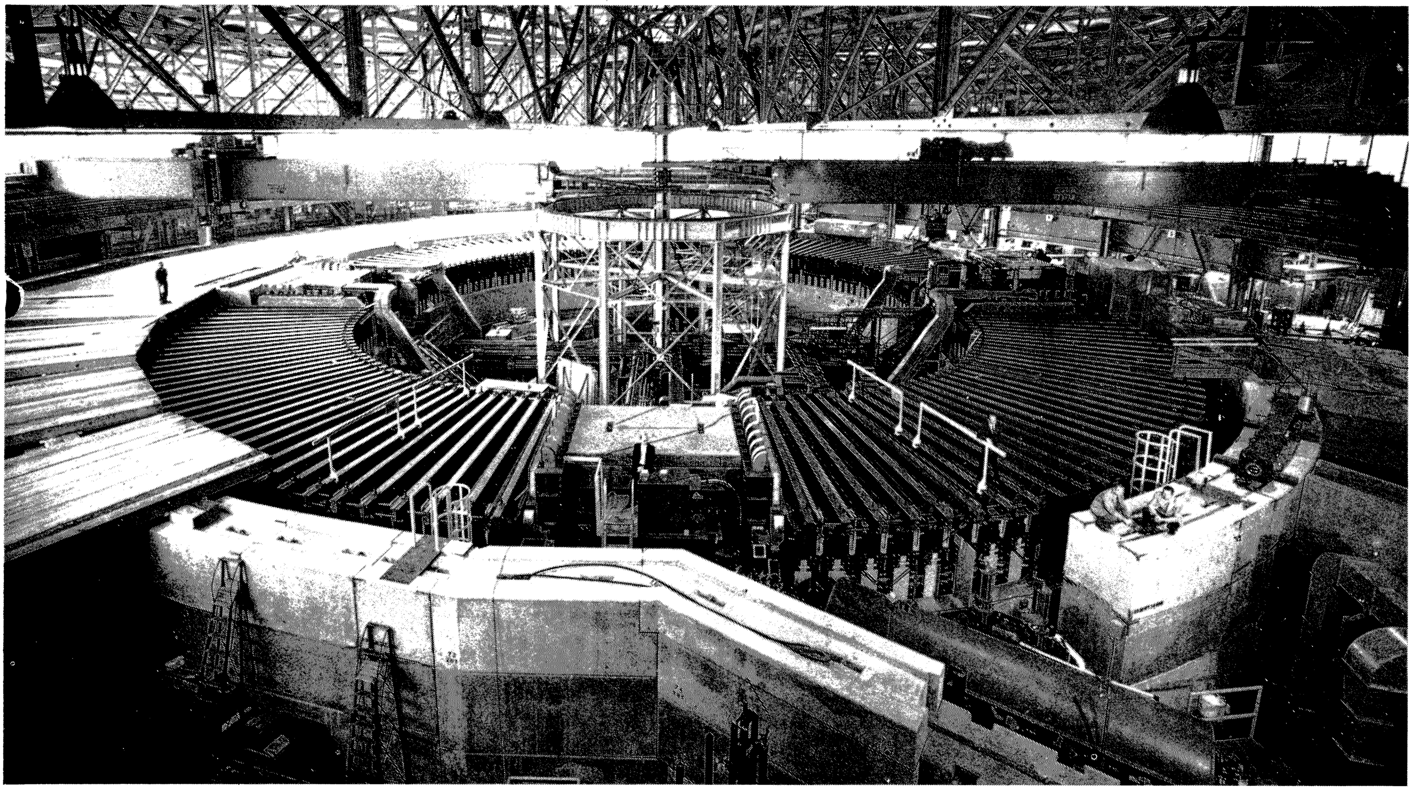
A Rome / Saclay / Vanderbilt collaboration working at the CERN PS and using a missing-mass spectrometer has seen a strangeness-carrying dibaryon of mass 2130 MeV and width 10 MeV in experiments using beams of negative kaons and positive pions.





The Berkeley Bevatron, built to accelerate protons, but which now accelerates heavier ions as part of the Bevalac system. With these heavy ion beams, signs of unexplained new nuclear behaviour have been seen.

(Photo Berkeley)



Now a counter experiment carried out by a Rome / Saclay / Vanderbilt ollaboration at the CERN PS using a missing mass spectrometer has seen this dibaryon both in the production process with negative kaons and, for the first time, in the interaction of positive pions with deuterons. The spectrometer had excellent mass resolution (two parts in a thousand) and benefitted from a very intense kaon beam at the PS, providing twenty thousand negative kaons per pulse at 1.4 GeV.

The experiment began with a search for dibaryons in the mass range 2 – 2.5 GeV carrying two units of strangeness. No such state was observed down to a production cross-section of 50 nb per steradian. The detection system, using aerogel Cherenkov counters and refined time-of-flight measurement, then turned its attention to a search for dibaryons with strangeness –1, and clearly revealed the 2130 MeV state in the two production processes studied. The forward production rates were very different in the two cases — 200 μb per steradian with incident kaons and 5 μb per steradian with pions.

The signal could be due to a lambda-proton resonance, a sigma-nucleon bound state, or some new configuration of six quarks. The experiment hopes to clarify this by studying the variation of the dibaryon production rate with the incident kaon and pion energies.

BERKELEY New nuclear behaviour

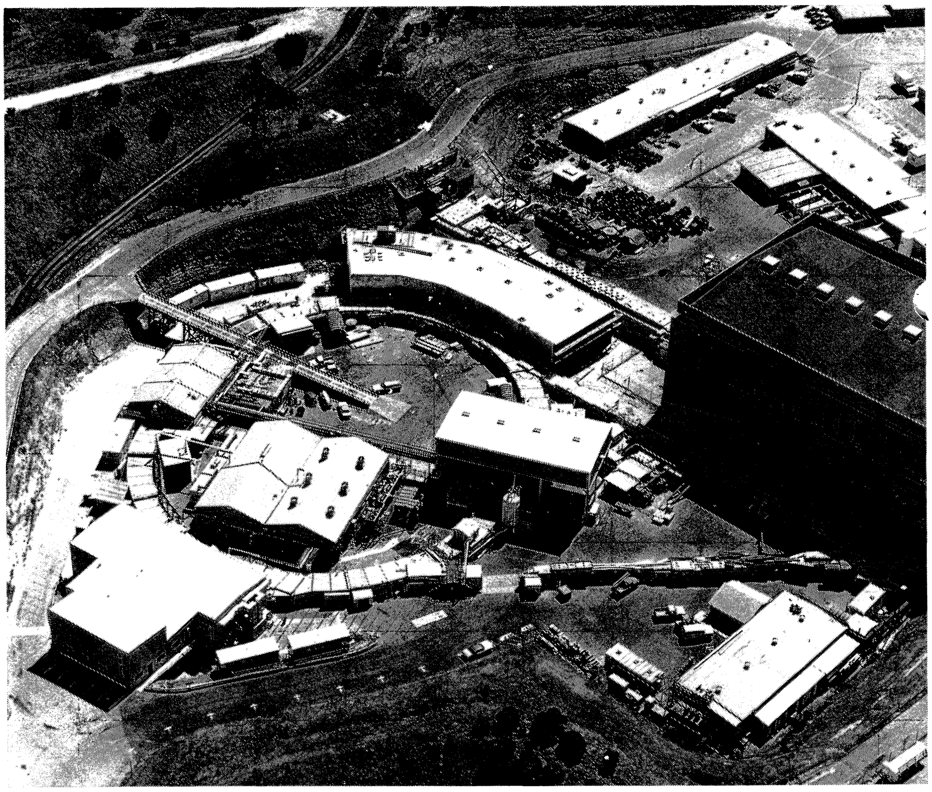
Results from studies at the Berkeley Bevalac using beams of iron and oxygen ions at energies of up to 2 GeV per nucleon have revealed new nuclear behaviour, as yet unexplained. In central collisions between nuclei, evidence is found for short-lived states of high particle and energy density. A similar phenomenon was first seen some thirty years ago in cosmic ray experiments, but the slim evidence was dismissed as a chance occurrence.

In the analysis of some 1500 heavy ion collisions in nuclear emulsion at the Bevalac, the Berkeley/ Ottawa collaboration finds secondary fragments close to the initial collision point which apparently interact much more readily with target nuclei than do the primary heavy ion beams. This behaviour is not seen further away from the initial collision.

While many different nuclei are known, the bulk properties of all these are much the same, so that the range of nuclear matter available for study is limited. Recently, specula-

The SPEAR electron-positron storage ring at SLAC. After first generation detectors discovered charmonium, new experiments are now uncovering the details of the rich charmonium spectroscopy.

(Photo SLAC)



tion has been mounting that under different conditions, new forms of nuclear matter are possible (see December 1980 issue, page 404).

The behaviour seen in the heavy ion experiments at Berkeley cannot be explained if the secondary fragments are ordinary particles, and one suggestion is that evidence is being seen for a new type of nuclear matter. While still made up of quarks, this new metastable nuclear material has its component quarks in configurations very different to those of normal particles. Experiments are continuing to study the behaviour of these short-lived collision fragments.

STANFORD
Tidying up charmonium

Charmonium is the family name given to mesons composed of a charmed quark bound to a charmed antiquark. The discovery in 1974 of the first charmonium state, the J/psi, at Brookhaven and at SLAC heralded the arrival of a new era in the study of elementary particles, the so-called 'New Physics'. The existence of this new quantum number was one vital clue which radically changed our understanding of the basic forces in Nature. Since then the careful study of charmonium spectroscopy has gone on to provide much valuable information on quark dynamics.

Charmed quarks and their antiparticles each carry intrinsic angular momentum (spin) of half a unit, and according to the rules can combine together either with their spins parallel (a triplet state), giving a meson of spin one, or with their spins antiparallel (a singlet state), forming a spin zero particle. The J/psi has spin one, and since 1974, a rich spectroscopy of triplet charmonium states has been uncovered.

However their singlet counterparts have proved to be much harder to find, and for good reasons. Charmonium normally comes from energetic photons, produced for example from the annihilation of colliding electrons and positrons. Because the photon itself carries spin one, the selection rules for these reactions say that only spin one charmonium states can be formed directly. In experiments with colliding electron-positron beams, singlet charmonium shows up only in the subsequent decays of the triplet variety, and is correspondingly more elusive.

Preliminary reports of the ground state spin zero charmonium, now called the eta-c, came from experiments at the DORIS electron-positron ring at DESY. Theoreticians had already deduced much from the unfolding spectrum of triplet charmonium. They had definite ideas for the mass of the eta-c, which did not agree with the preliminary information from DORIS.

Then new data began to come through from new detectors at the SPEAR electron-positron ring at SLAC (see September 1979 issue, page 246). Playing a prominent role in this search was the Crystal Ball detector (a Caltech / Harvard / Princeton / SLAC / Stanford collaboration). This spherical array of 672 sodium iodide crystals, each viewed by a photomultiplier, gives good angular coverage of the electron-positron collision region, and good measurement of low energy photons produced in the decay of triplet charmonium.

These 'radiative' decays can produce a variety of secondary charmonium states, and the photon spectrum from the Crystal Ball showed sharp peaks corresponding to transitions between different triplet charmonium levels, in much the same way that sharp spectral lines show up when ordinary atoms are excited. In addition, a small but statistically significant peak was seen in the spectrum corresponding to a new charmonium state of mass 2983 MeV. Some months later, the Mark II group (Berkeley / SLAC), announced the first evidence for a specific eta-c decay mode, while another decay mode was found by the Crystal Ball shortly afterwards. This was already sufficient to make theoreticians feel better, but to pin down this new candidate charmonium state, its quantum numbers first had to be fixed.

The Crystal Ball is well suited to measure electromagnetically showering particles like electrons and photons. To handle charged hadrons required more work, and further evidence in favour of an eta-c assignment for the new state came from analysis of channels containing appropriate combinations of hadrons. At present, the characteristics of the state are highly suggestive of the eta-c, but further work is needed.

Elsewhere in the photon spectrum from radiative charmonium decays, the Crystal Ball shows evidence for decays producing a meson of mass 1420 MeV. A small sample of specific decay modes for a meson of this mass was also reconstructed by both Mark II and the Crystal Ball. A spin one meson of this mass, the E, has been known for some time through the analysis of bubble chamber exposures to hadron beams.

In the Crystal Ball, the radiative transitions producing E-mesons appeared to be quite copious, and this led some people to speculate that the E, rather than being a conventional meson built up of a quark and an antiquark, could be an example of a 'glueball' — a new type of matter much talked about but never before seen.

Current thinking says that quarks interact through the 'colour' force mediated by the exchange of so-called gluons, similar in some respects to the photon exchange responsible for the familiar electromagnetic force. As well as transiently flitting between quarks, these gluons should also be able to stick together to form 'gluonium' or 'glueballs'. Whether the E-meson signal seen in radiative charmonium decays is a glueball or not remains to be settled.

With Mark II having already moved to the bigger PEP ring, the Crystal Ball is presently the only detector operating at SPEAR. Even though its move to PEP has been approved, this will not take place for at least a year. An important task remaining at SPEAR is to continue to search for the F-meson, carrying both charm and strangeness. F candidates have now been reported from experiments at several Laboratories, but as yet none from SPEAR. Other objectives include more eta-c data and a scan of the SPEAR energy regions so far largely neglected.

Physics monitor

Ultrahigh energy cosmic rays

Cosmic ray experiments have traditionally provided physicists with glimpses of behaviour beyond the energy range attainable with artificial particle beams. However with the CERN antiproton project promising to provide collision energies equivalent to those of 155 000 GeV beams, and with the prospect of ISABELLE at Brookhaven going even higher, physicists hope that some of the exotic behaviour reported from cosmic ray studies will soon come within the reach of laboratory experiments.

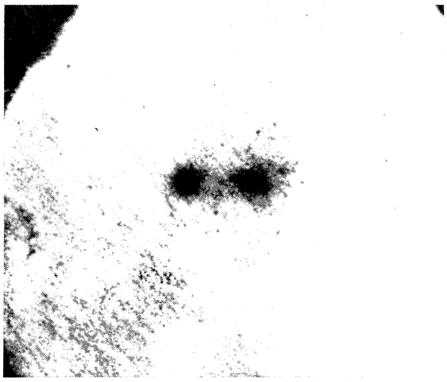
Meanwhile the cosmic ray specialists continue their studies, and from 20–29 October, the city of Nakhodka in the Soviet Far East was host to a Soviet-Japanese symposium on processes at ultrahigh energies in cosmic rays, investigated using emulsion chambers exposed at altitude. There were participants from the Japanese/Brazilian collaboration at Mount Chacaltaya in the Andes, from the group carrying out experiments on Mount Fuji, Japan, and from the 'Pamir' Soviet-Polish collaboration.

Various characteristics of the fragmentation region of inelastic hadron-nucleus interactions were covered, and detailed comparison of the comparable data obtained by all three groups shows quite reasonable agreement in a number of respects.

1. The cross-section of the hadron inelastic interaction with an air nucleus still increases at least up to energies of 10^{15} eV at nearly the same rate as at accelerator energies.

2. At ultrahigh energies there is considerable deviation of scaling not only in pionization but also in the

A 'binocular' event seen by the 'Pamir' collaboration looking at the effects of ultrahigh energy cosmic rays passing through a 5 cm lead plate. The spot on the left contains more than sixty quanta while that on the right is due to a single quantum with an estimated energy of over 500 TeV.



fragmentation region. Here it is assumed that the composition of the primary cosmic radiation does not change at ultrahigh energies.

3. The energy dissipation of the incident hadron in the strong interaction collision increases considerably. Apparently the number of secondary particles in the fragmentation region at ultrahigh energies is growing with the energy of the primary cosmic ray, E, as fast as $E^{1/4}$, and maybe even faster at energies above 10^{16} eV. The inelasticity increases correspondingly and the role of leading particles in the development of nuclear cascades is considerably diminished. The energy spectrum of secondary particles becomes softer.

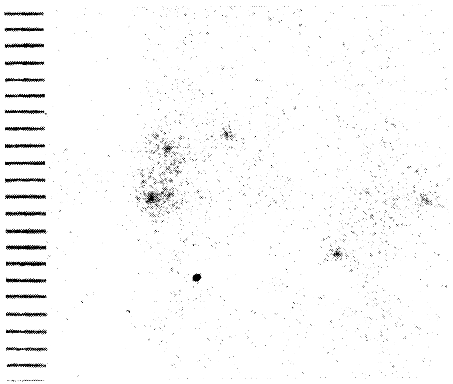
4. Among the different so-called 'families' of ultrahigh energy events, there is a significant number of secondary particles with large (over 5 GeV) transverse momenta. Sometimes these events are also anisotropic in the plane perpendicular to the primary direction. There are events of a pronounced jet structure with a comparatively large number (more than five) of jet particles and comparable energies of the separate jets (for two-, three- and many-jet events). The percentage of unusual events grows with increasing energy of the primary particle. The study of this type of event makes for useful comparisons with the predictions of quantum chromodynamics.

5. At ultrahigh energies, some peculiar processes exist which produce exotic events, particularly of the so-called 'Centauro' type, where most, if not all, of the energy goes into producing long-lived secondary hadrons with few neutral pions. The Japanese-Brazilian collaboration has found about half a dozen reliable examples of Centauros, while the Pamir group has also seen a few events of this type, but less clean. Simulations based on standard physics models indicate that these events cannot be due to fluctuations. A few examples of other exotic events have also been seen which likewise await an explanation. The study of these phenomena is of great interest and could lead to the need for new types of quark or new baryon states.

Results using present cosmic ray techniques show that the behaviour seen at ultrahigh energies is not a simple extrapolation of the detailed and reliable results obtained at accelerators. This provides clear motivation for higher energy projects and suggests possible directions for future studies.

At the same time, cosmic ray specialists are anxious to extend their present experiments with emulsion chambers and accumulate more data in the interesting ultrahigh energy region. For this, good collaboration between different experimental groups will be important, and the Symposium was a move in this direction.

(We are grateful to S.A. Slavatinsky of the P.N. Lebedev Institute, Moscow, for transmitting news of this Symposium.)



Dark spots recorded in X-ray film from the 'Centauro-1' cosmic ray event seen by a Japanese-Brazilian collaboration. The top picture is taken in the upper chamber, under 7.8 cm of lead. The lower picture is from the lower chamber, under 3 cm of lead and a carbon hadron converter. (The unit on the attached scale is 1 mm.) The big surprise is the asymmetry between the patterns recorded in the top and bottom chambers — hence the name Centauro. This is interpreted as an absence of neutral particles (producing electromagnetic showers) in the initial interaction.

The goal of theoretical physics – 2

Werner Heisenberg, discoverer of the famous Uncertainty Principle. Physics becomes even more uncertain when black holes are involved.

(Photo Pfeiffer)

Last month we published the first part of Stephen Hawking's inaugural lecture as Lucasian Professor of Mathematics in the University of Cambridge. In the second part of the lecture, which follows here, Hawking turned to the subject of gravity. After Einstein's monumental work on gravitation earlier this century, efforts to unite this force with the other mechanisms found in Nature have been consistently unfruitful. But there are indications that this is beginning to change.*

'So far most of the effort has been devoted to unifying the first three categories of physical interactions, the strong and weak nuclear forces and electromagnetism. The fourth and last, gravity, has been neglected. One justification for this is that gravity is so weak that quantum gravitational effects would be large only at particle energies way beyond those in any particle accelerator. Another is that gravity does not seem to be renormalizable: in order to obtain finite answers it seems that one may have to make an infinite number of infinite subtractions with a correspondingly infinite number of undetermined finite remainders.

Yet one must include gravity if one is to obtain a fully unified theory. Furthermore the Classical Theory of General Relativity predicts that there should be space-time singularities at which the gravitational field would become infinitely strong. These singularities would occur in the past at the beginning of the present expansion of the Universe (the Big Bang) and in the future in the gravitational collapse of stars and, possibly, of the Universe itself. The prediction of singularities presumably indicates that the Classical Theory will break down. However, there seems to be no reason why it should break down until the gravitational field becomes strong enough so that quantum gravitational effects are important. Thus a quantum theory of gravity is essential if we are to describe the early Universe and to give some explanation for the initial conditions beyond merely appealing to the Anthropic Principle, which can be paraphrased as 'things are as they are because we are'.

Such a theory is also required if we are to answer the question 'Does time really have a beginning and, possibly, an end as is predicted by Classical General Relativity or are the singularities in the Big Bang and the Big Crunch smeared out in some way by quantum effects?'

This is a difficult question to give a well-defined meaning to when the very structure of space and time themselves are subject to the Uncertainty Principle. My personal feeling is that singularities are probably still present though one can continue time past them in a certain mathematical sense. However any subjective concept of time that was related to consciousness or the ability to perform measurements would come to an end.

What are the prospects of obtaining a quantum theory of gravity and of unifying it with the other three categories of interactions? The best hope seems to lie in an extension of general relativity called supergravity. In this the graviton, the spin-2 particle that carries the gravitational interaction, is related to a number of other fields of lower spin by so-called supersymmetry transformations. Such a theory has the greater merit that it does away with the old dichotomy between 'matter' represented by particles of half-integer spin and 'interactions' represented by integer-spin particles. It also has the great advantage that many of the infinities which arise in quantum theory cancel each other out. Whether or not they all cancel out to give a theory which is finite without any infinite subtractions is not yet known. It is hoped that they do because it can be shown that theories which include gravity are either finite or non-renormalizable, that is, if one has to make any infinite subtractions, then one will have to make an infinite number of them with a corresponding infinite number of undetermined remainders. Thus if all the infinities in supergravity cancel each other out, we could have a theory which not only fully unified all the matter particles and interactions, but which was also complete in the sense that it did not have any undetermined renormalization parameters.

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

The main computer centre at CERN. According to Stephen Hawking, the recent rapid rate of development of computers could mean that machines will take over theoretical physics!

(Photo CERN 186.12.80)

Although we do not yet have a proper quantum theory of gravity, let alone one which unifies it with the other physical interactions, we have an idea of some of the features it should have. One of these is connected with the fact that gravity affects the causal structure of space-time, that is, gravity determines which events can be causally related to each other. An example of this in the classical theory of General Relativity is provided by a black hole, which is a region of space-time in which the gravitational field is so strong that any light or other signal is dragged back into the region and cannot escape to the outside world. The intense gravitational field near the black hole causes the creation of pairs of particles and antiparticles, one of which falls into the black hole and the other of which escapes to infinity. The particle that escapes appears to have been emitted by the black hole.

An observer at a distance from the black hole can measure only the outgoing particles and he cannot correlate them with those that fell into the hole because he cannot observe them. This means that the outgoing particles have an extra degree of randomness or unpredictability over and above that usually associated with the Uncertainty Principle. In normal situations the Uncertainty Principle implies that one can definitely predict *either* the position *or* the velocity of a particle *or* one combination of position and velocity. Thus, roughly speaking, one's ability to make definite predictions is halved. However, in the case of particles emitted from a black hole, the fact that one cannot observe what is going on inside the black hole means that one can definitely predict *neither* the position *nor* the velocities of the emitted particles. All one can give are probabilities that particles will be emitted in certain modes.

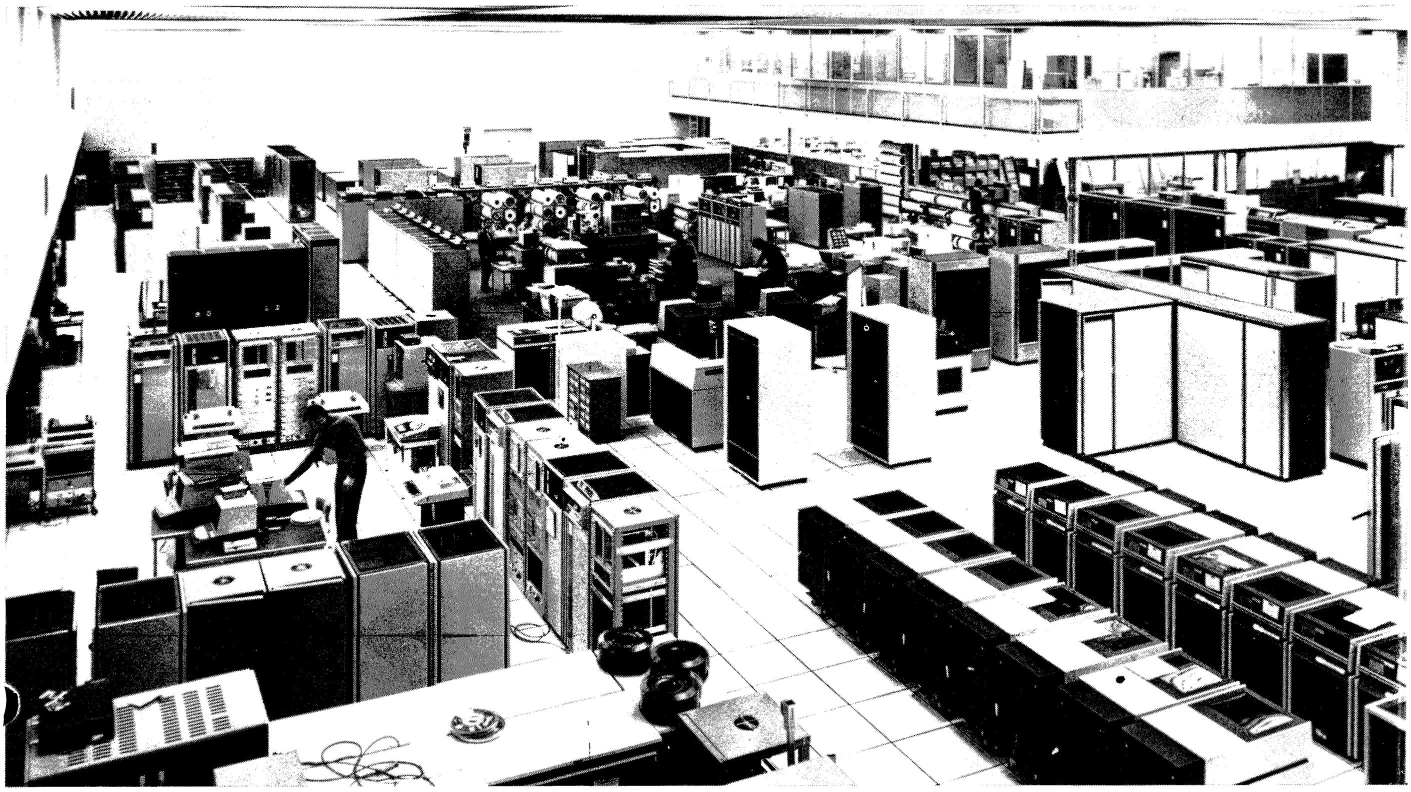
It seems therefore that, even if we find a unified theory, we may be able to make only statistical predictions. We would also have to abandon the view that there is a unique universe that we observe. Instead we would have to adopt a picture in which there was an ensemble of all possible universes with some probability distribution. This might explain why the Universe started off in the Big Bang in almost perfect thermal equilibrium because thermal equilibrium would correspond to the largest number of microscopic configurations and hence the greatest probability. To echo Voltaire's philosopher Pangloss, 'we live in the most probable of all possible worlds.'

What are the prospects that we will find a complete unified theory in the not too distant future? Each time we have extended our observations to smaller length scales and higher energies, we have discovered new layers of structure. At the beginning of the century the discovery of Brownian Motion with a typical energy particle of 3×10^{-2} eV showed that matter was not continuous but was made up of atoms. Shortly thereafter it was discovered that these supposedly indivisible atoms were made up of electrons with energies of the order of a few electronvolts revolving about a nucleus. The nucleus in turn was found to be composed of so-called elementary particles, protons and neutrons, held together by nuclear bonds of the order of 10^6 eV. The latest episode in this story is that we have found that the proton and the neutron are made up of quarks held together by bonds of order 10^9 eV. It is a tribute to how far we have come already in theoretical physics that it now takes enormous machines and a great deal of money to perform an experiment whose results we cannot predict.

Our past experience might suggest that there is an infinite sequence of layers of structure at higher and higher energies. Indeed, such a view of an infinite regress of boxes within boxes was official dogma in China under the Gang of Four. However it seems that gravity should provide a limit but only at the very short length scale of 10^{-33} cm

The Lucasian Chair at Cambridge

Gravity specialist Stephen Hawking is the present Lucasian Professor of Mathematics at the University of Cambridge. His immediate predecessor was Sir James Lighthill, and before that, Paul Dirac. One of the earlier holders of this prestigious Chair was Isaac Newton, the founder of the theory of gravitation, which makes Hawking's appointment especially apt. Back in the 1660s, Newton's predecessor as Lucasian Professor was Isaac Barrow, a remarkable character who was also Regius Professor of Greek and Gresham Professor of Geometry. While Newton was withdrawn and introvert, Barrow was a swashbuckler who among other things was a fighter of some repute. Again in contrast to Newton who seldom ventured far, Barrow was a seasoned traveller who once successfully defended his ship against attack by pirates. In these days of tight budgets, this particular attribute remains valuable in any senior position in science.



or the very high energy of 10^{28} eV. On length scales shorter than this, one would expect that space-time would cease to behave like a smooth continuum and that it would acquire a foam-like structure because of quantum fluctuations of the gravitational field.

There is a very large unexplored region between our present experimental limit of about 10^{10} eV and the gravitational cut-off at 10^{28} eV. It might seem naive to assume, as Grand Unified Theories do, that there are only one or two layers of structure in this enormous interval. However, there are grounds for optimism: at the moment at least it seems that gravity can be unified with the other physical interactions only in some supergravity theory. There appear to be only a finite number of such theories. In particular, there is a large such theory, the so-called $N=8$ extended supergravity. This contains one graviton, eight spin-3/2 particles called gravitinos, twenty-eight spin-1 particles, fifty-six spin-½ particles and seventy particles of spin 0. Large as these numbers are they are not large enough to account for all the particles that we seem to observe in strong and weak interactions. For instance the twenty-eight spin-1 particles in the $N=8$ theory are sufficient to account for the gluons that carry the strong interactions and two of the four particles that carry the weak interactions, but not the other two. One would therefore have to believe that many or most of the observed particles such as gluons or quarks are not really elementary as they seem at the moment but that they are bound states of the fundamental $N = 8$ particles. It is not likely that we shall have accelerators powerful enough to probe these composite structures within the foreseeable future, or indeed ever, especially if one makes a projection based on the current economic trends. Nevertheless the fact that these bound states arose from the well-defined $N = 8$ theory should enable us to make a number of predictions that could be tested at energies that are accessible now or will be in the near future. The situation might thus be similar to that for the Salam-Weinberg Theory unifying electromagnetism and weak interactions. The low energy predictions of this theory are in such good agreement with observation that the theory is now generally accepted even though we have not yet reached the energy at which the unification should take place.

There ought to be something very distinctive about the theory that describes the Universe. Why does this theory come to life while other theories exist only in the minds of their inventors? The $N = 8$ supergravity theory does have some claims to be special. It seems that it may be the only theory:

1. which is in four dimensions,
2. incorporates gravity,
3. which is finite without any infinite subtractions.

I have already pointed out that the third property is necessary if we are to have a complete theory without parameters. But it is difficult to account for properties 1 and 2 without appealing to the 'Anthropic Principle'. There seems to be a consistent theory which satisfies properties 1 and 3 but which does not include gravity. However, in such a universe there would probably not be sufficient in the way of attractive forces to gather together matter into the large aggregates which are probably necessary for the development of complicated structures. Why space-time should be four-dimensional is a question that is normally considered to be outside the realm of physics. However there is a good Anthropic Principle argument for that too. Three space-time dimensions, that is, two space and one time, are clearly insufficient for any complicated organism. On the other hand, if there were more than three spatial dimensions, the orbits of planets round the Sun or electrons round a nucleus would be unstable and they would tend to spiral inwards. There remains the possibility of more than one time dimension but I, for one, find such a universe very hard to imagine.

So far I have implicitly assumed that there is an ultimate theory. But is there? There are at least three possibilities:

1. There is a complete unified theory.
2. There is no ultimate theory, but there is an infinite sequence of theories which are such that any particular class of observations can be predicted by taking a theory sufficiently far down the chain.
3. There is no theory. Observations cannot be described or predicted beyond a certain point but are just arbitrary.

The third view was advanced as an argument against the scientists of the seventeenth and eighteenth centuries. 'How could they formulate laws which would curtail the freedom of God to change his mind?' Nevertheless they did, and got away with it. In modern times we have effectively eliminated possibility 3 by incorporating it within our scheme: quantum mechanics is essentially a theory of what we do not know and cannot predict.

Possibility 2 would amount to the picture of an infinite sequence of structures at higher and higher energies. As I said before, this seems unlikely because one would expect that there would be a cut-off at the Planck energy of 10^{28} eV. This leaves us with possibility 1.

At the moment the $N = 8$ supergravity theory is the only candidate in sight. There are likely to be a number of crucial calculations within the next few years which have the possibility of showing that the theory is no good. If the theory survives these tests, it will probably be some years more before we develop computational methods that will enable us to make predictions and before we can account for the initial conditions of the Universe as well as the local physical laws. These will be the outstanding problems for theoretical physicists in the next twenty years or so.

But, to end on a slightly alarmist note, they may not have much more time than that. At present computers are a useful aid in research but they have to be directed by human minds. However, if one extrapolates their recent rapid rate of development, it would seem quite possible that they will take over altogether in theoretical physics. So maybe the end is in sight for theoretical physicists if not for theoretical physics.'

People and things

On people

At the Annual Meeting of the American Physical Society and the American Association of Physics Teachers, held in New York in January, retiring APS President Herman Feshbach awarded the Heinemann Prize to Jeffrey Goldstone of MIT for his work in nuclear physics, condensed matter physics and quantum field theory.

The UK Institute of Physics has announced the award of the Glazebrook Medal and Prize for 1981 to Godfrey Stafford, Director General of the Rutherford and Appleton Laboratories and until recently Chairman of the CERN Scientific Policy Committee. The award was made in recognition of his 'outstanding contribution to the organization of experimental high energy physics, particularly through the direction of the Rutherford Laboratory.'

R. Scrimaglio has been reappointed for another period of three years as Director of the Frascati National Laboratory of INFN (Italy). Professor Scrimaglio is a well-known experimentalist in intermediate energy and nuclear physics. He is at present collaborating in an experiment being prepared for the LEAR low energy antiproton ring at CERN.

P. Spillantini has been nominated as successor to A. Reale as Leader of the Research Division at Frascati. He is an experimentalist working mainly in the fields of photoproduction and electron-positron annihilation, and at present is involved in the NA1 and NA7 experiments at the CERN SPS.

Frank Solmitz, physicist from the Lawrence Berkeley Laboratory, died on 28 August last year following five years of incapacity after a tragic accident. He made major contributions in the early days of bubble chamber physics in developing the associated computational techniques. These techniques were crucial to the many particle discoveries made by Luis Alvarez' group at Berkeley. Frank Solmitz had succeeded Alvarez as group leader in 1970.

R. Scrimaglio (left) and P. Spillantini, Director and Research Division Leader respectively of INFN Frascati National Laboratory.

(Photo Frascati)

Second e+e- Workshop at Cornell

Following the first meeting held in November, the second in a series of Workshops on electron-positron physics at 100 GeV was held at Cornell in January. About 75 physicists from all over the US met for three days to discuss detectors for experiments at a 100 GeV electron-positron colliding ring. Working groups on track detectors, calorimetric detectors, specialized detectors, etc. presented their findings after two days of discussions. These groups will come together again in April to present their reports after continuing their work at home institutes. Meanwhile a Z^o-physics theory Workshop took place from 6-8 February, where many theorists met at Cornell for discussions on the standard model, and beyond, of weak interactions.

The General Meeting on LEP foreseen by ECFA (see January/February issue, page 11) will be held from 1–7 June at Villars-sur-Ollon in the Swiss Alps. Maurice Bourquin is Chairman of the Organizing Committee, and further information can be obtained from the Secretary, Christine Redman, ISR Division, CERN, 1211 Geneva 23, Switzerland.

US-USSR Joint Coordinating Committee

The US-USSR Joint Coordinating Committee on research on the fundamental properties of matter met in Moscow on 9–10 December. The purpose of the meeting was to seek reestablishment of collaboration on new initiatives. Delegation heads were Jim Leiss of the US Department of Energy and I.V. Chuvilo of ITEP. According to LAMPF Director Louis Rosen, who attended the meeting, areas of common interest were neutrino, pion and nucleon experiments, together with biomedical research, where new Soviet projects are understood to be imminent with pion therapy beams at Dubna, and with biomedical proton beams at ITEP and Gatchina. As a result of the meeting, resumption of personnel exchanges is expected. In particular, it is hoped that V. A. Nazarenko of Leningrad Nuclear Physics Institute and V. M. Lobashov of the Institute for Nuclear Research will visit LAMPF this year.

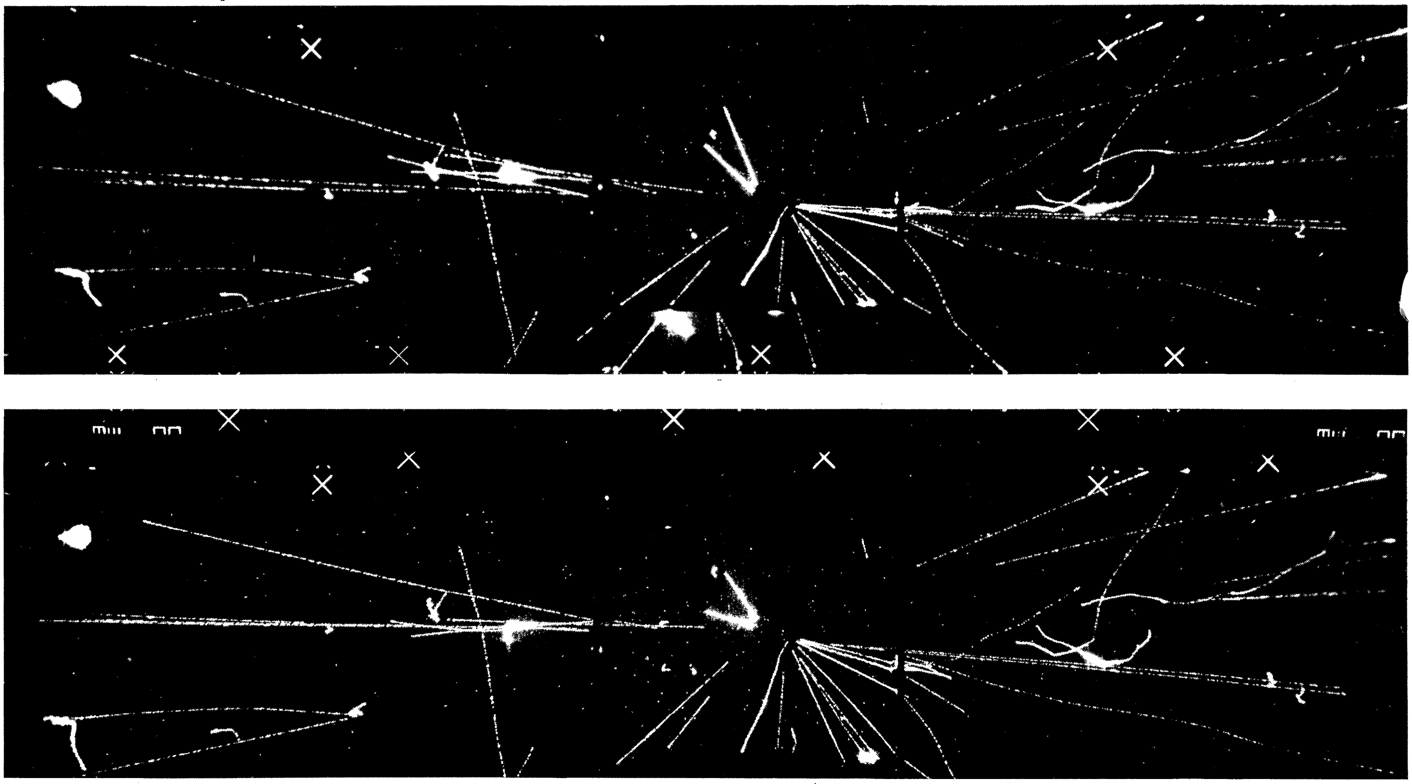
Darmstadt: Review meeting on Heavy Ion Fusion

One year after a study programme of heavy ion inertial confinement fusion was started in the Federal Republic of Germany as a collaboration of six university institutes and three national research centres, a review meeting was held at GSI Darmstadt on 4–5 December. After introductory talks on reactor design, pellet calculations and accelerator scenarios, the groups presented their progress reports on ion sources, accelerator experiments, storage ring problems, final focusing layout and pellet-related physics and computational effort.

Differing from some earlier concepts where the layout started from the ion source and shortcomings became clear at the target end, a closer look was given to the high energy end of the accelerator (for example, the final lenses) which were felt to have been somewhat neglected in the past.

The presented HIBALL (Heavy Ion Beam And Lithium-Lead) scenario started from the reactor environment and worked backwards through the accelerator aspects. The strong involvement of reactor issues came from the participation of the Nuclear Engineering Department of the University of Wisconsin, which contributed expertise in fusion reactor design to the accelerator skills of the German groups.

One of the GSI contributions to the programme is the study of a high current heavy ion low-velocity accelerator. After the start-up of a proton model, in cooperation with the University of Frankfurt, the design of a 30 mA, 50 keV per nucleon, 13.5 MHz radiofrequency quadrupole structure has begun. This follows the successful operation of radiofrequency quadrupole structures in linacs at Los Alamos (see May 1980 issue, page 108). The construction of the first section will begin this year. It will be tested with beam in 1982 to learn whether the necessary field strengths can be reached. The intention is to use



Two views of a 62 GeV proton-proton collision in the CERN ISR as recorded in the six metre streamer chamber of the UA5 Bonn / Brussels / Cambridge / CERN / Stockholm collaboration. The aim is to record the first proton-antiproton collisions in the ISR as a run-up to 540 GeV proton-antiproton studies in the SPS later this year. The UA5 detector is thought to provide the longest sensitive volume for visual recording of particle tracks.

the complete accelerator as a high current injector for the Darmstadt Unilac.

Name changes

As from 1 January the Los Alamos Scientific Laboratory has assumed the name of Los Alamos National Laboratory. The Laboratory continues to be operated by University of California for the USA Department of Energy.

Fermilab summer school

A summer school on high energy particle accelerators will be held at Fermilab from 13 to 24 July. The school will offer lectures, seminars, and work study periods on basic physics of high energy particle accelerators and colliders. Interested young scientists in particle physics and related fields should send requests with a brief resume to F. R. Huson, Fermilab (Mail Stop 306), Box 500, Batavia, Illinois, 60510 USA before 1 April.

Tentative topics and lectures include:

Introductory concepts — E. Courant,

Superconducting magnets — A. Tollestrup,

Radio-frequency power and linacs — P. Wilson,

Non-linear orbit dynamics — A. Dragt,

Collective-field acceleration — A. Sessler,

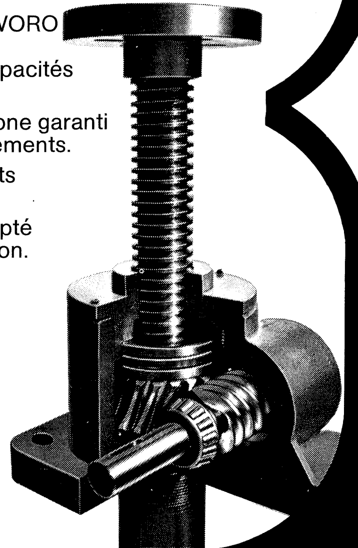
Coherent instabilities — C. Pellegrini,

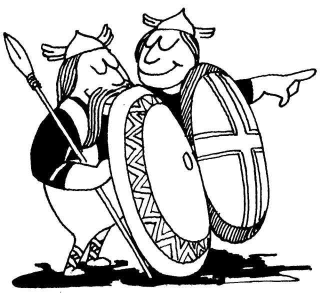
Interaction of electromagnetic fields and beams — R. Pantell,

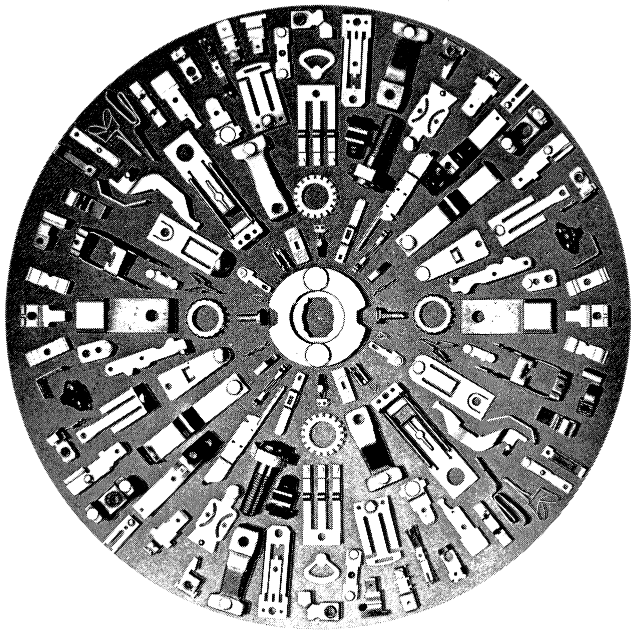
Polarized electron beams — A. Chao.

Leon Lederman is director of the school. The organizing committee is M. Month — DOE, J. Bjorken — Fermilab, R. Huson — Fermilab, C. Pellegrini — Brookhaven, B. Richter — SLAC, R. Schwitters — Harvard/Fermilab, A. Tollestrup — Fermilab, W. Willis — CERN/Brookhaven.

The school is sponsored by the United States Department of Energy and the National Science Foundation.

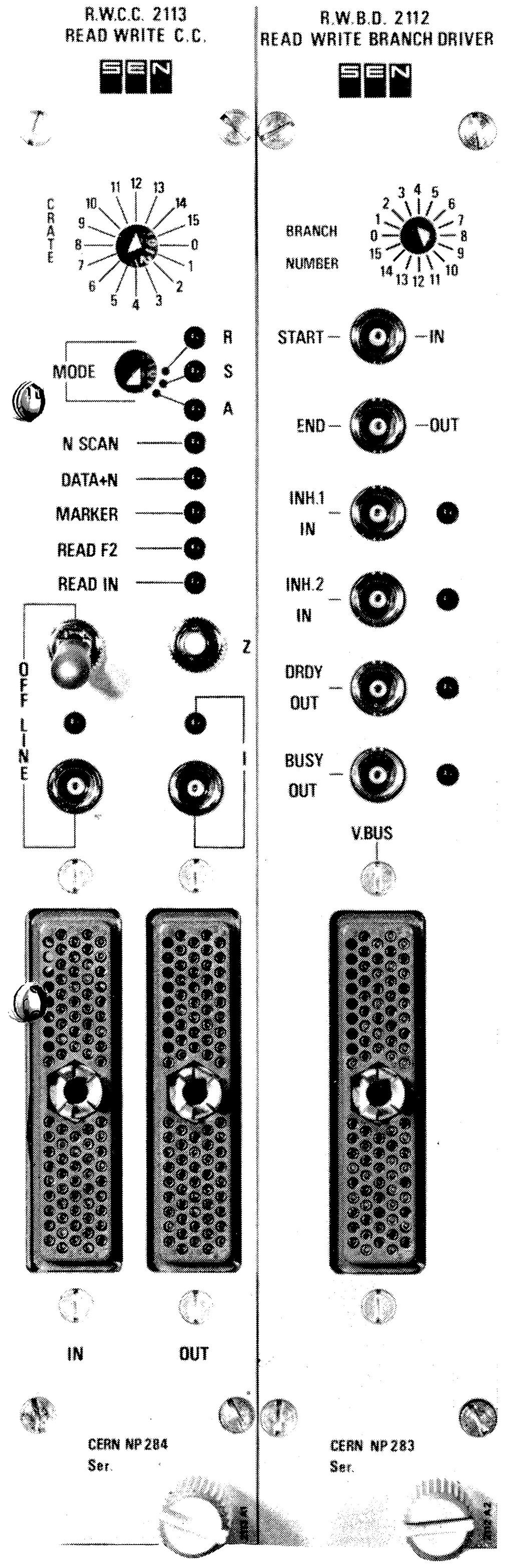






CAMAC

The Read/Write REMUS System
CERN NP 283/NP 284
by SEN Electronique



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- ★ compatible with ROMULUS system
- ★ high data acquisition rates with buffered DMA operations
- ★ versatile scan procedures

Description

These modules are intended for use in large systems where large numbers of similar type modules are to be read as a block and where a minimum amount of program control is required.

The controllers and branch drivers form a subsystem located within a normal CAMAC configuration.

The data structure is defined by pointers (word counts) generated by the branch drivers, minimising software overheads.

By using 40 word FiFos in controllers and branch drivers a high data acquisition rate is obtained and data acquisition can occur before and during the opening of the DMA channel. All branches are activated simultaneously, hence slow modules e.g. ADCs with long conversion times can be situated in the farmost branches. Ideally, the process resolves to one of sequentially reading out the FiFos.

Several read modes are available:
Repeat Mode, Stop Mode, Adress Scan Mode and LAM Scan Mode.

Some write facilities have been added to allow pedestal control in ADCs.

The system is organised as a tree with branches and subbranches and can thus process data of very large systems.

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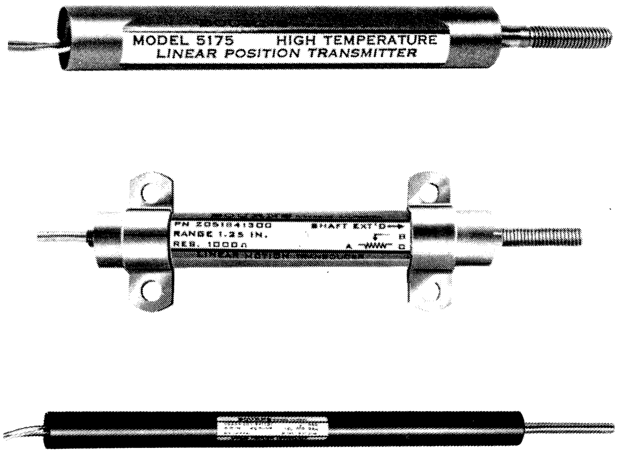

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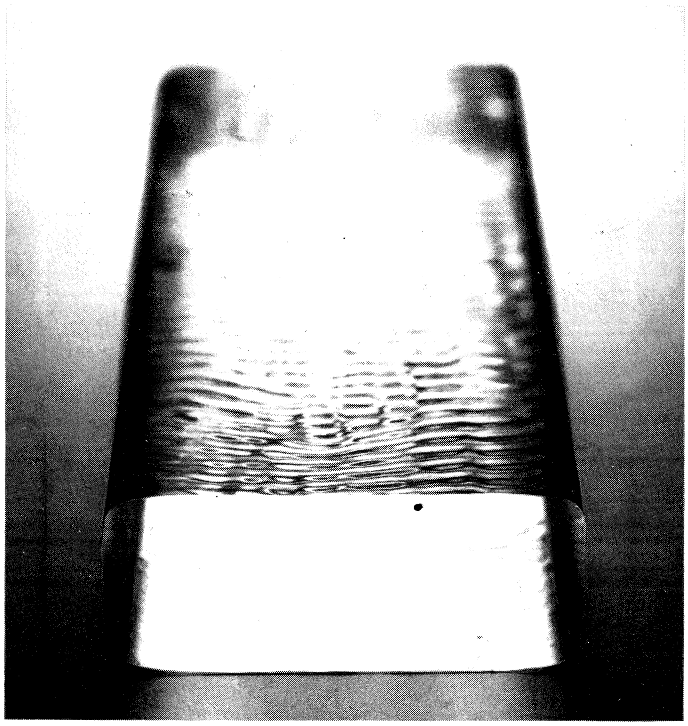

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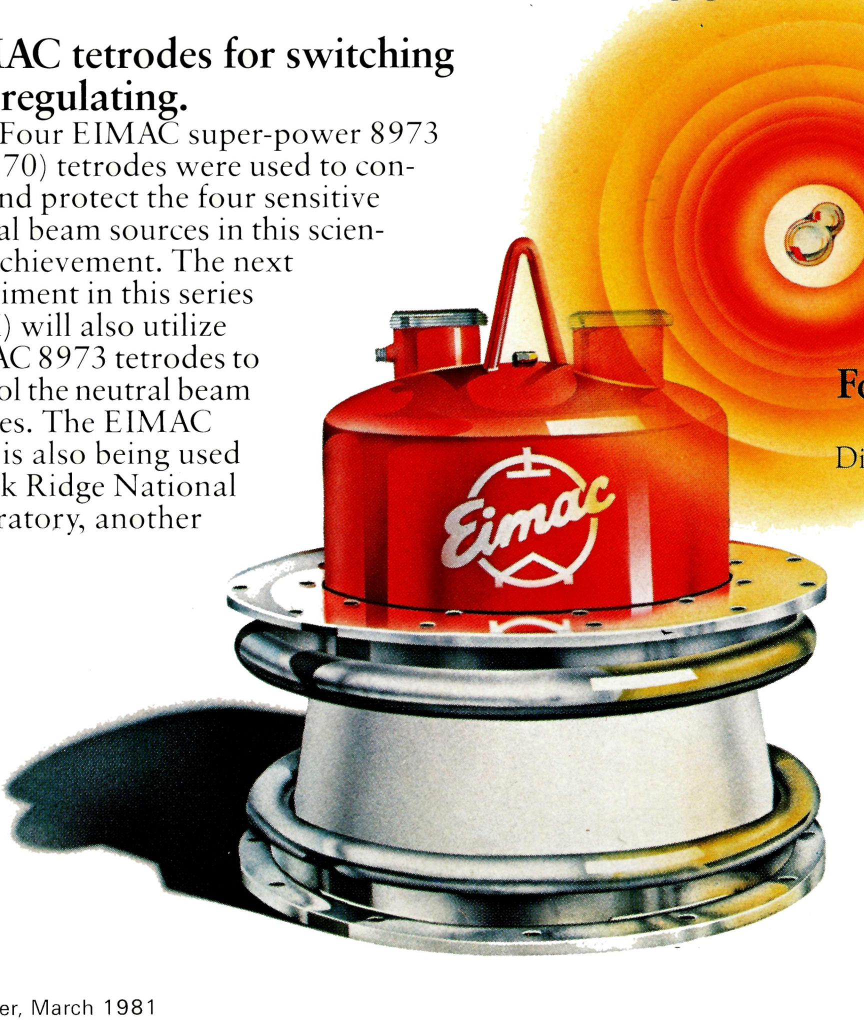

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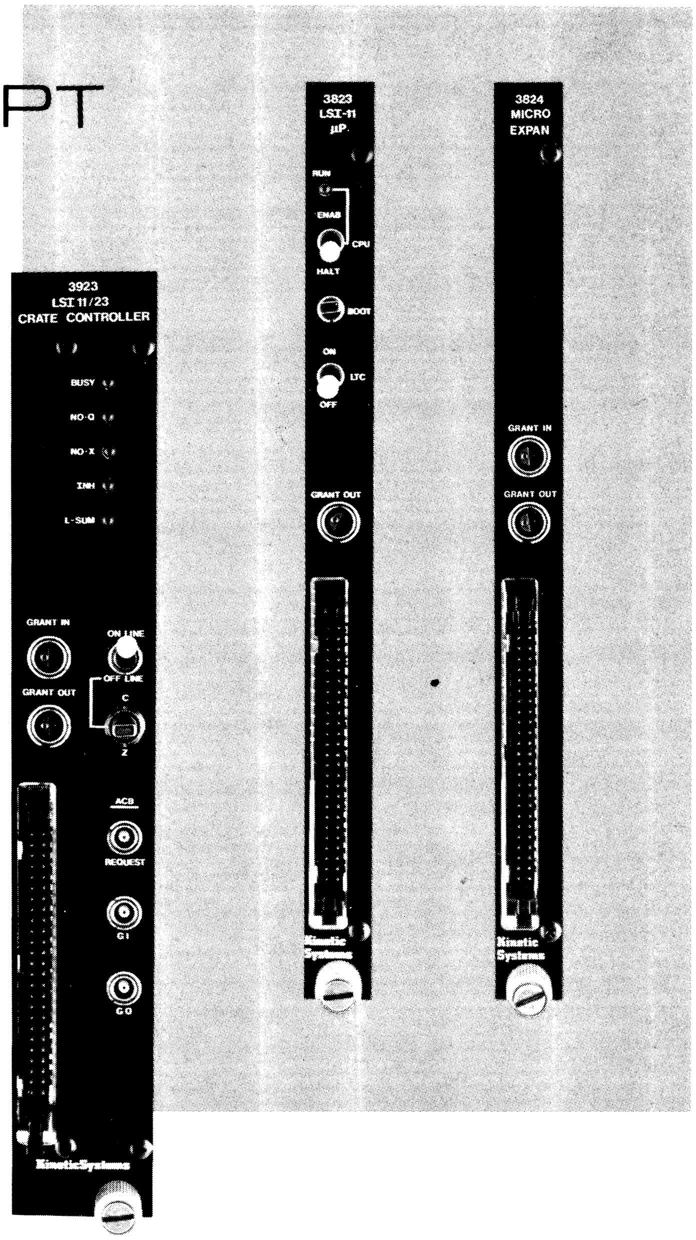

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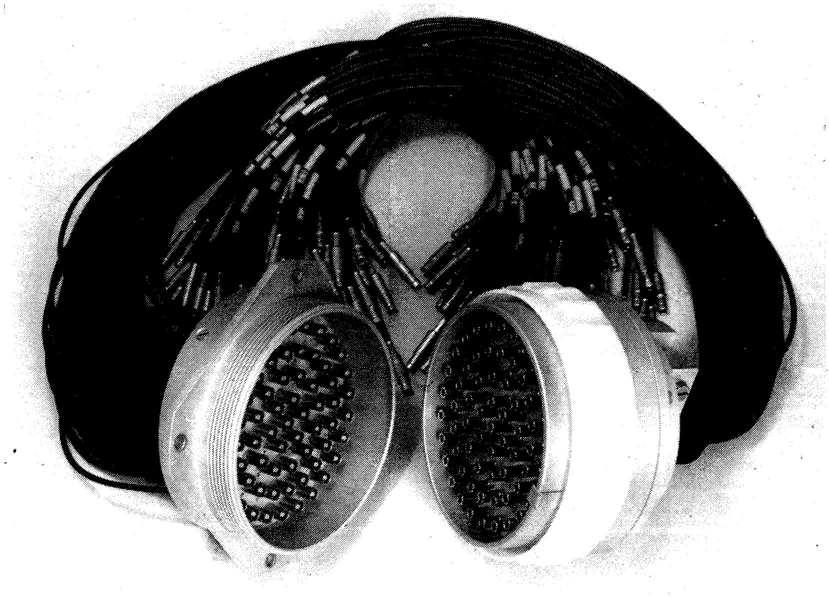

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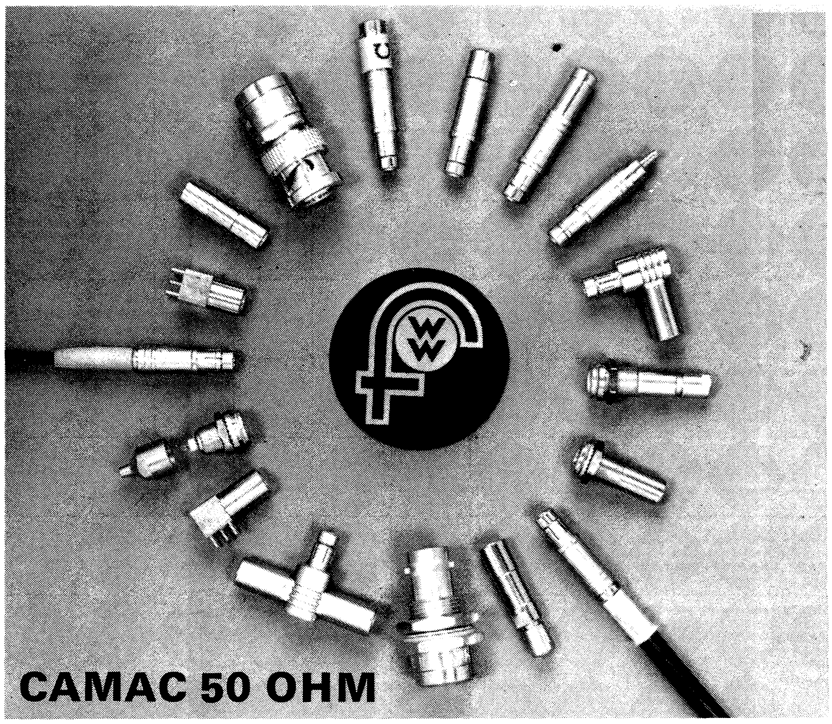

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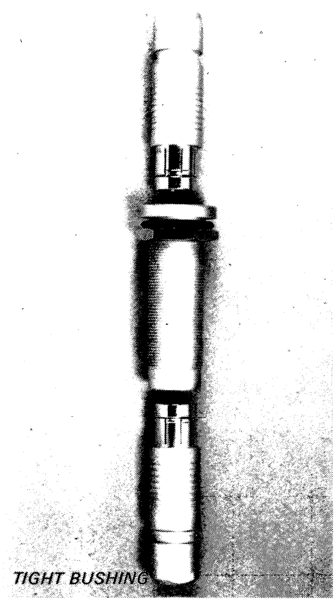

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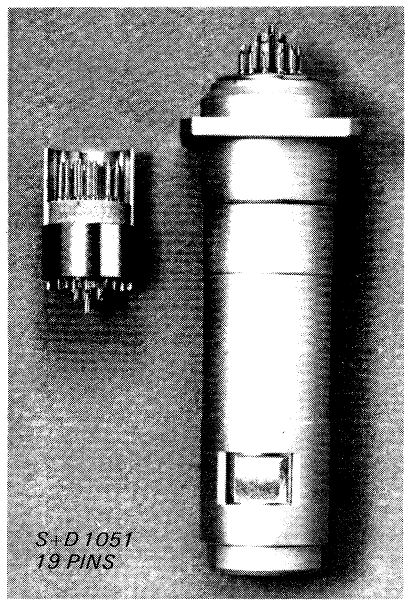

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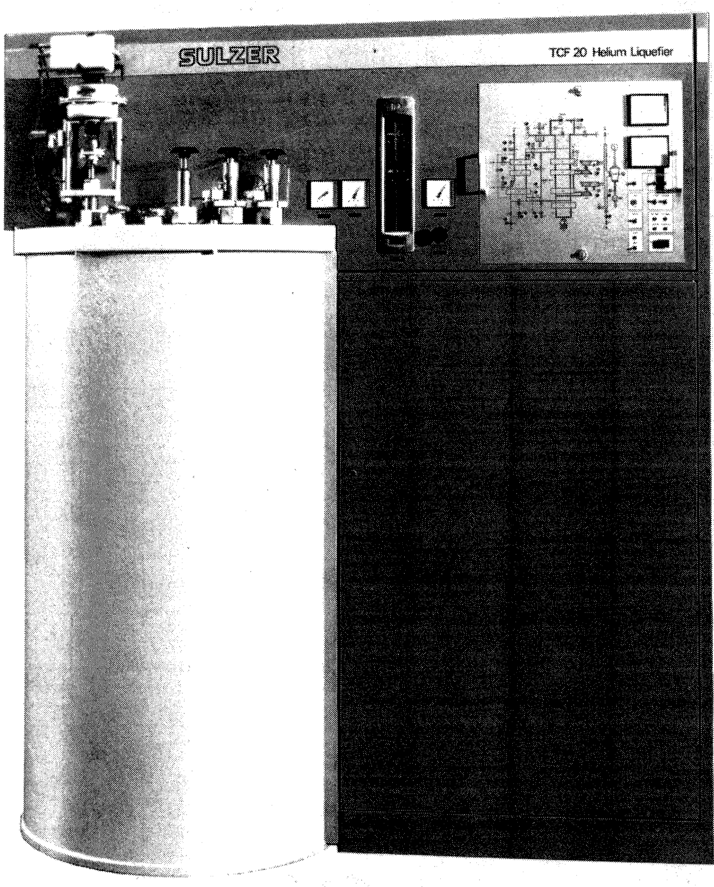

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