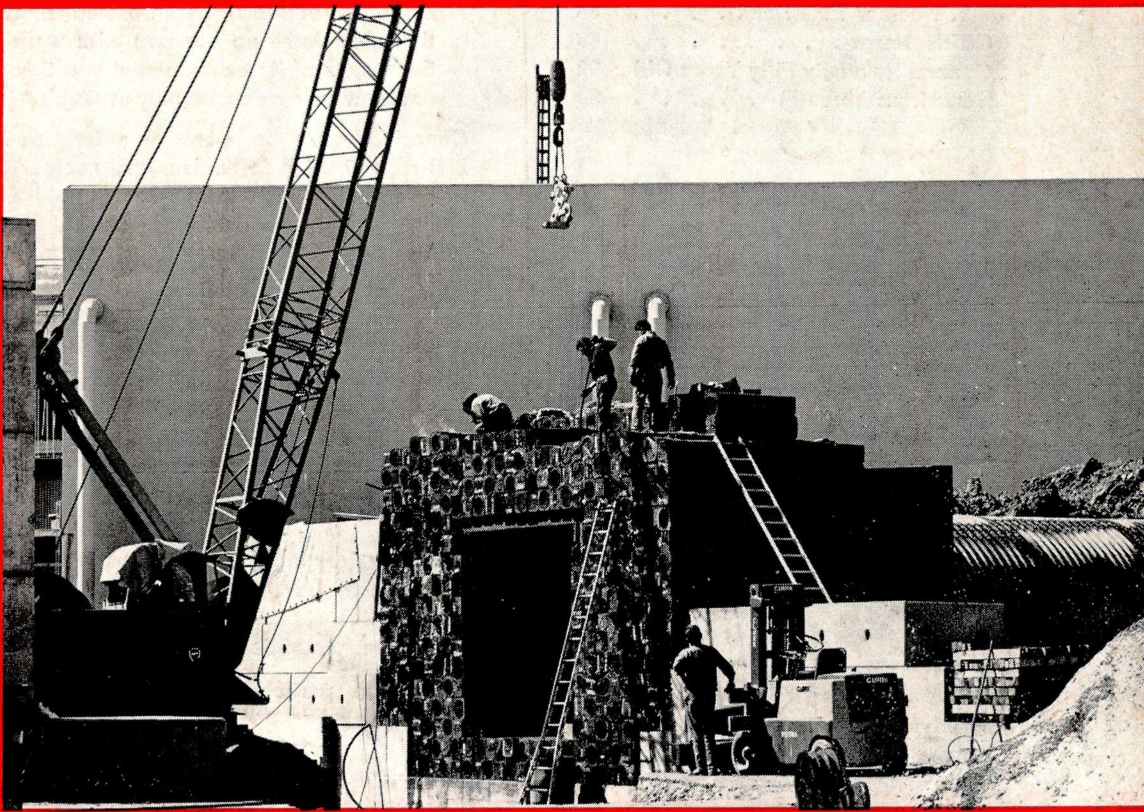
CERN COURIER



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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN COURIER

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Contents

The cover photograph, taken at the end of April, shows part of the installations being constructed near the proton synchrotron for the future neutrino experiments. On the right can be seen the meson decay tunnel (partially covered with earth) made of corrugated steel sheet and, in the centre, the last section of this tunnel is being constructed. This section is made of steel ingots in order to reduce neutron leakage out of the tunnel.

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The European Organization for Nuclear Research, more commonly known as **CERN** (from the initials of the French title of the original body, 'Le Conseil européen pour la Recherche nucléaire', formed by an Agreement dated 15 February 1952), was created when the Convention establishing the permanent Organization came into force on 29 September 1954.

In this Convention, the aims of the Organization are defined as follows

> **'The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available.'**

Conceived as a co-operative enterprise in order to regain for Europe a first-rank position in fundamental nuclear science, CERN is now one of the world's leading laboratories in this field. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of **high-energy physics,** often known as **sub-nuclear physics** or the **physics of fundamental particles.**

High-energy physics is that front of science which aims directly at the most fundamental questions of the basic laws governing the structure of matter and the universe. It is not directed towards specific applications — in particular, it plays no part in the development of the practical uses of nuclear energy — though it plays an important role in the education of the new generation of scientists. Only the future can show what use may be made of the knowledge now being gained.

The laboratory comprises an area of about 80 ha (200 acres), straddling an international frontier; 41 ha is on Swiss territory in Meyrin, Canton of Geneva (the seat of the Organization), and 39.5 ha on French territory, in the Communes of Prévessin and St.-Genis-Pouilly, Department of the Ain.

Two large particle accelerators form the basis of the experimental equipment:

— a 600 MeV synchro-cyclotron,
— a 28 GeV proton synchrotron,

the latter being one of the two most powerful in the world.

The CERN staff totals about 2300 people.

In addition to the scientists on the staff, there are over 360 Fellows and Visiting Scientists, who stay at CERN, either individually or as members of visiting teams, for periods ranging from two months to two years. Although these Fellows and Visitors come mainly from universities and research institutes in the CERN Member States, they also include scientists from other countries. Furthermore, much of the experimental data obtained with the accelerators is distributed among participating laboratories for evaluation.

Thirteen Member States contribute to the cost of the basic programme of CERN in proportion to their net national income:

Austria (1.90 %)	Italy (11.24 %)
Belgium (3.56 %)	Netherlands (3.88 %)
Denmark (2.05 %)	Norway (1.41 %)
Federal Republic of Germany (23.30 %)	Spain (3.43 %)
France (19.34 %)	Sweden (4.02 %)
Greece (0.60 %)	Switzerland (3.11 %)
	United Kingdom (22.16 %)

Poland, Turkey and Yugoslavia have the status of Observer.

The 1966 budget for the basic programme amounts to 149 670 000 Swiss francs, calling for contributions from Member States totalling 145 860 000 Swiss francs.

Supplementary programmes, financed by twelve states, cover construction of intersecting storage rings for the 28 GeV accelerator at Meyrin and studies for a proposed 300 GeV accelerator that would be built elsewhere.

The Particle Detectors

I. Nuclear Emulsions

by **A.J. Herz**
Nuclear Physics Division

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Personnel Division

Figure 1. An example of a 'jet' of secondary particles seen in nuclear emulsion following a collision involving a cosmic-ray particle of very high energy. In this case, observed by Daniel, Davies, Mulvey and Perkins in 1952, the particle had an estimated energy of 600 GeV. (The three emulsion photographs reproduced in this article are taken, with acknowledgement to Pergamon Press, from 'The Study of Elementary Particles by the Photographic Method' by Powell, Fowler and Perkins.)

This is the first of a series of articles which will describe the various types of particle detectors in use around high energy accelerators — how they work, something of their history, their present role and their possible future. The detectors have been divided into four groups: nuclear emulsions, counters, spark chambers and bubble chambers.

The nuclear-emulsion technique was very prominent about 20 years ago. The heyday is now over and the emphasis has moved to fewer, more specialized and complex experiments. This article follows the development of the technique and selects in particular one recent experiment at CERN to illustrate the use of nuclear emulsions in research.

History

The possibility of detecting *individual* charged particles by means of a photographic emulsion was first investigated as long ago as 1910 by Kinoshita, working at Manchester University. He was continuing some earlier work by Lord Rutherford in the same field. Kinoshita showed that a single α particle was capable of rendering a silver-halide grain developable. A year later, Reinganum showed that the passage of an α particle at glancing incidence to a photographic emulsion produced, when the emulsion was developed, a row of silver grains outlining the trajectory of the particle.

This early work was carried out with the type of emulsion used for conventional photography, which had a thickness of only a few microns. It was not until around 1930 that thick-layered emulsions (about 50 microns) were produced, first in research laboratories and later (1935-1937) on a commercial scale by Ilford Ltd in England. These emulsions were exposed for some months at mountain altitudes, for example by Blau and Wambacher, and on subsequent examination 'stars' were found which were ascribed to the disintegration of nuclei in the emulsion caused by cosmic rays.

By 1939, the technique was recognized as a useful tool for the investigation of nuclear and cosmic-ray phenomena, but it was considered to be only a qualitative method and of limited application. The systematic investigations of Powell from 1940 onwards showed, however, that the method was capable of giving accurate quantitative results. For example, Chadwick, May, Pickavance and Powell studied in great detail the scattering in various gases of particles accelerated in a cyclotron. At the end of the war, Ilford produced a concentrated 'nuclear-research' emulsion containing eight times the normal amount of silver bromide per unit volume. It was in emulsions of this type exposed to cosmic rays at mountain altitudes that the pion was discovered by Powell and his colleagues in 1947.

Finally, in 1947-48, first Kodak Ltd and then Ilford produced an emulsion capable of recording the tracks of particles moving with velocities such that they suffer the minimum possible energy loss (causing minimum ionization) in passing through the emulsion. Such emulsions are commonly known as 'electron-sensitive emulsions'; they can be purchased, if required, with thicknesses as great as 2 mm on glass or 1.2 mm as stripped emulsion, and in sizes up to 40 cm x 40 cm, or greater.

Advantages and disadvantages

Nuclear emulsion possesses one most significant advantage over all other techniques. It is capable of extraordinarily high spatial resolution. Other techniques can resolve

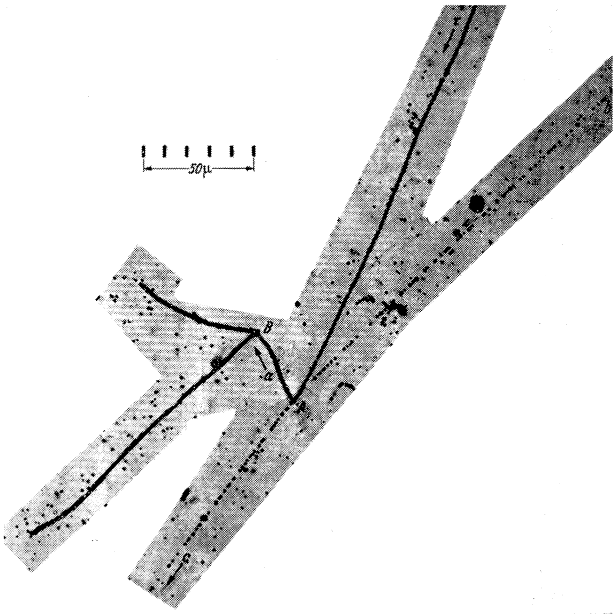


Figure 2. The famous observation of the τ meson in nuclear emulsion exposed to cosmic rays. This was the first clear indication of the existence of the many heavy mesons which have now been identified. The experiment used electron sensitive emulsion, which had just been produced, and was carried out by Brown, Camerini, Fowler, Muirhead, Powell and Ritson in 1948. The τ enters the emulsion from the top of the photograph; b and c are π^+ mesons; a is a π^- meson which gives rise to a star at B.

events separated by a few millimetres; using emulsion we can resolve events separated by a few microns. This has made possible the measurement of the lifetime of the π^0 meson (about 10^{-16} s) and is the basis of our confidence that there are no other commonly occurring unstable particles with lifetimes in the range 10^{-11} to 10^{-16} s.

There are some further advantages which are particulary significant in the case of complex experiments in which nuclear emulsion is used as a detector. First of all, it is an integrating device which can be exposed or irradiated until sufficient data have been stored in it; secondly, it can be used in very confined volumes, as will be illustrated later in this article in the discussion of the experiment to determine the magnetic moment of the Λ^0 hyperon.

Its chief disadvantage is that it consists of a mixture of complex nuclei — silver and bromine (as silver bromide) suspended in gelatine, which is largely carbon, nitrogen and oxygen. Further, the scanning of large volumes of emulsion, of necessity in three dimensions, is frequently very tedious. Thus, with the development of other powerful detectors such as the spark chamber and the bubble chamber (with its simple target material of hydrogen or deuterium for example) which are readily adaptable to automatic methods of analysis and data handling, nuclear-emulsion work has inevitably developed into a supplementary technique, except in certain special fields.

Use of the technique in research

There are two distinct ways in which nuclear emulsions can be used. Firstly, they may be placed in the path of particles (from an accelerator or in the cosmic radiation) and the interactions which these particles produce in the emulsion can be studied in detail. The charged pions and many of the 'strange particles' were first discovered, and their decay modes studied, in large stacks of emulsion exposed for considerable periods of time to the cosmic radiation (see Figure 2). The relatively small size and weight of emulsions enable them to be carried to great heights by means of free balloons. In this way, many studies have been carried out of

a) the interactions of very energetic particles — energies greater than 50 GeV (see Figure 1),
b) the composition of the primary cosmic radiation and
c) the development of the electron-photon cascade in the high atmosphere.

One well-known example is the work carried out by groups all over the world on emulsions which were exposed on a high-altitude balloon flight as a very large stack (60 x 45 x 30 cm) known as the 'Schein stack' after the American physicist who initiated the project.

The second way in which emulsion may be used is simply for particle detection, placed near to a target which is bombarded by a suitable particle beam. The target employed is often liquid hydrogen, although at cyclotron energies targets of many solids and gases have been used. In many cases the geometry of the experimental arrangement is so designed that the particles we wish to investigate stop in the emulsion, thus allowing their energy to be determined by measuring the distance they travel in the emulsion.

Experiments at CERN

The Emulsion Experiments Committee was first set up in January 1959 to plan and co-ordinate emulsion work at the PS and SC machines. During the first few years of operation of the PS (about 1960-1963), the majority of the experiments were of the first type described above — large blocks of emulsion were placed into particle beams of various types and energies. The stacks were subsequently divided and distributed to emulsion groups in the Member States and elsewhere. The number of groups involved during these years was of the order of 40, of which about 25 were in Member States.

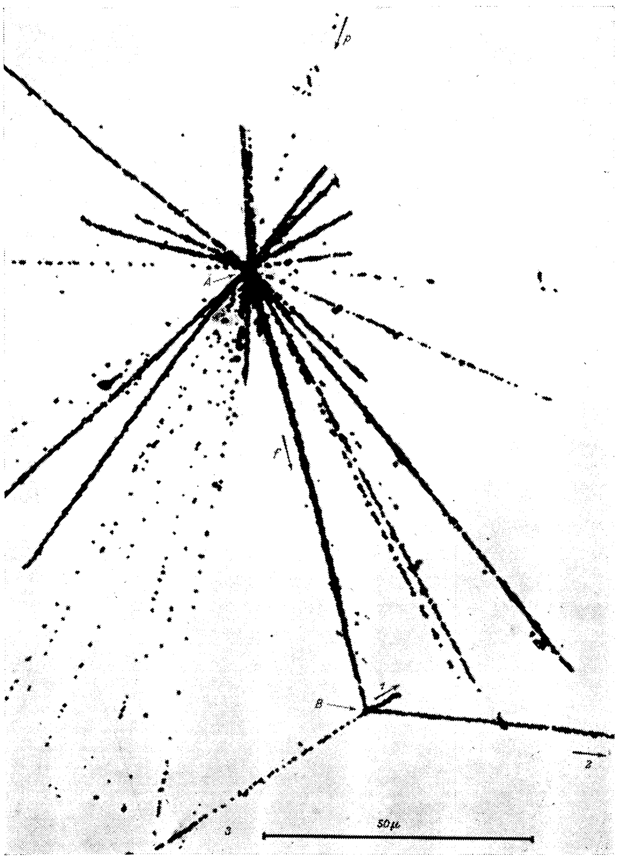
In Europe, two groups of collaborating Laboratories have been active for some years. One, called 'the European K-Collaboration', is composed of two emulsion groups in Dublin, two in London, one in Brussels, two in Prague and one in Warsaw, together with some members of the CERN group. As the name implies, these workers have used K^- mesons of various energies up to 6 GeV to study hyperfragments. (Hyperfragments are nuclear fragments which contain a trapped Λ^0 particle. Since this particle is unstable it eventually decays causing the break-up of the fragment.) Apart from the very large amount of detailed information which has been collected about hyperfragments, the most striking single observation was that of a double hyperfragment, that is, a nuclear fragment containing two trapped Λ^0 particles. This was found by the Warsaw group in 1963, ten years after the first discovery of a single hyperfragment, also by the Warsaw group (see Figure 3).

The second large collaboration is of six French Laboratories (Bordeaux, Caen, Clermont-Ferrand, Lyon, Paris and Strasbourg). They have concentrated their attention on studies of fragment and hyperfragment emission from nuclear disintegrations produced by antiprotons of momenta up to 6 GeV/c, in addition to work on K^- meson irradiated stacks.

A large volume of emulsion irradiated by pions and protons was sent to groups outside Europe. For example, material was sent in India to the Tata Institute, Bombay, the University of Chandigarh, Cotton College, Gauhati (Assam) and Osmania University in Hyderabad; in Pakistan to the Atomic Energy Centres in Lahore (West Pakistan) and Dacca (East Pakistan); in the United States to the Universities of Arizona, Athens (Ohio), Illinois and Nebraska; and in the Soviet-Union to the Lebedev and the Atomic Energy Institutes in Moscow and Erevan, and the Institutes of Physics in Alma-Ata (Kazakstan) and Tashkent (Uzbekistan). Most of these groups are far from large accelerators, and nuclear emulsions were for them the only way (apart from cosmic-ray studies) to work in the field of high-energy nuclear physics.

Work on the construction of pulsed magnets started in the emulsion group at CERN in 1958 because it was thought then that is would be possible to obtain a significant improvement in the accuracy of determinations of momentum and charge by observing the curvatures of the tracks in very high magnetic fields. These hopes were not fulfilled, but there are other applications in which the pulsed magnets have been successfully used. They were first employed in emulsion work at the PS in a series of experiments to search for Dirac magnetic monopoles in 1961 and 1962*.

Figure 3. The first observation of a 'hyperfragment'. The nuclear fragment, f, disintegrated at B, and measurements on the tracks 1, 2 and 3 indicated that the Λ^0 hyperon was a component of the nuclear fragment. The observation, using nuclear emulsion, was made by Danysz and Pniewski of the Warsaw Group in 1953.



These were the beginnings of the type of experiment in which emulsion is used as the detector in a complex experimental arrangement.

The Λ^0 magnetic moment experiment

It is thought by many that nuclear-emulsion work is somehow different from experimental research with other techniques, that it requires the application of special skills laboriously acquired during a long period of training, and that 'emulsion workers' spend their days looking down microscopes rather like classical botanists, making up descriptions of what they see. To judge how much truth there is in this view, we will describe one of the major experiments in which the CERN Emulsion Group has participated.

The idea that it would be possible to determine the magnetic moment of the Λ^0 hyperon using nuclear emulsions and a very-high-field pulsed magnet came first to V. Z. Peterson at the California Institute of Technology (CalTec), following a theoretical paper by M. Goldhaber. In 1957, Peterson proposed such an experiment, describing many of the essential features of the project finally carried out six years later. In the background of the proposal, there was the clear need to measure the magnetic moments of the hyperons. Peterson had started to develop pulsed magnets at CalTec and nuclear emulsion was suggested as the most suitable detector because of space limitations inside the magnet, coupled with a need for very high precision in the measurements on the decay products of the Λ^0. The idea was carried to CERN by Ph. Rosselet, then of the University of Lausanne, who worked with Peterson on the CalTec pulsed-magnet project during 1958. After his return to Lausanne in 1959, the group there (under Professor Haenny) took up the development of pulsed-magnet coils suitable for magnetic-moment experiments, and a proposal was submitted to CERN.

From 1959 to the end of 1961, a number of further proposals for the measurement of the Λ^0 magnetic moment were made by various combinations of members of the Lausanne, CERN and Bristol emulsion groups including, in one case, Peterson who visited CERN in 1960. However, progress was slow. As is often the case in experiments with nuclear emulsions, the problems were not chiefly associated with the adaptation of the emulsion technique to the requirements of the project, but were technical — engineering — difficulties which beset the development of the magnet and had to be solved by the usual methods of engineering, involving a fair proportion of progress through trial and error. Secondly, and most importantly perhaps, there was the need for the advocates of the experiment to generate enthusiasm for it, to obtain adequate support and priority and to ensure the collaboration of a sufficient number of physicists. Many other projects competed for attention and for the use of the available support facilities. Also, there was the tradition to be overcome that emulsion experiments do not require special beams, extensive facilities or large amounts of machine time.

Towards the end of 1961, it was clear that a pilot experiment — a test exposure with a π beam and a high-field pulsed magnet — would be needed to provide

* CERN COURIER, vol. 2, no. 4 (April 1962) p. 10

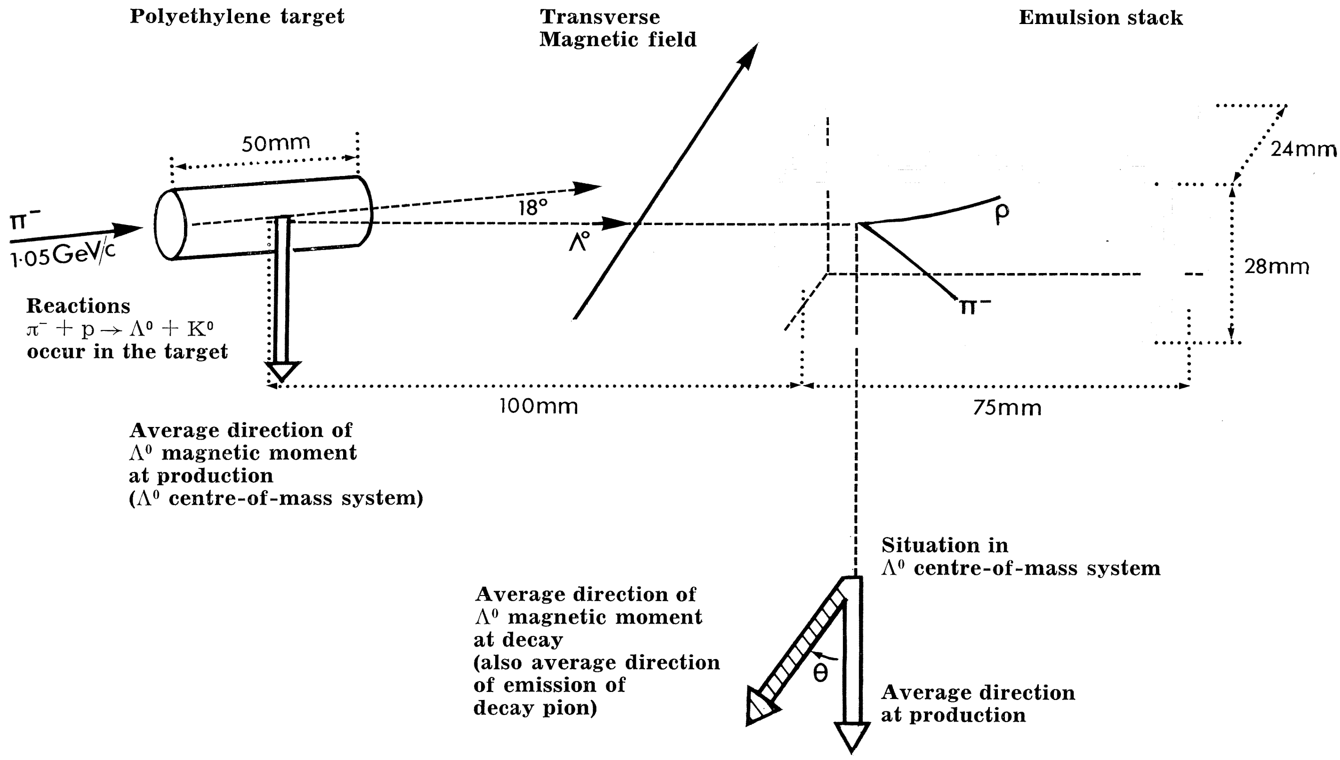


Figure 4. A schematic diagram of the Λ^0 magnetic moment experiment. The entire region shown here (target to emulsion stack) lies inside the pulsed magnetic field.

detailed data on which the design of the main experiment could be based. In particular, information was needed about the density and distribution of background tracks as a function of exposure, and about the exposure conditions (such as the intensity of the magnetic field). Also various methods of finding Λ^0 decays had to be tried to find out which was the best and what rate of detection could be expected.

It was found that an existing slow-K-meson beam could be modified to provide a flux of almost 10^5 π^- mesons per pulse, and test exposures took place in early February 1962. Most of the information needed was obtained, and it was possible to conclude that the experiment would be feasible with a magnetic field of 150 kG instead of the 75 kG used in the test runs.

At the time of the test exposures, the Lausanne/CERN collaboration also submitted a proposal for a measurement of the magnetic moment of the Σ^+ hyperon by a method similar to that for the Λ^0. This was a very attractive proposal, for whilst it was clearly possible to measure the Λ^0 moment by counter and spark-chamber nethods (and competing groups were working on this) t appeared to be very difficult to use any but the mulsion technique to find the Σ^+ magnetic moment. .ccordingly, the collaboration, which had grown to nclude the Munich emulsion group, gave priority uring the rest of 1962 to the development of the $^+$ experiment. Approval by the Nuclear Physics esearch Committee for the Λ^0 experiment was given in the Spring of 1963, and the exposures were scheduled for September.

The basic lay-out of the experiment is shown in Figure 4. Almost the whole of the region in the diagram is immersed in the magnetic field, so that the Λ^0 hyperons are in the field from production to decay. As shown, they are 'polarized' at production such that their magnetic moments are predominantly lined up perpendicular to the plane containing the incident π^- meson and the Λ^0 itself. The interaction between the magnetic moment and the applied field results in the rotation of this direction through an angle which is proportional to the magnetic moment and other, known, quantities such as the intensity of the field. The problem is to determine this angle Θ. It can be done because the most probable direction of emission of the pion in decay is the direction of the magnetic-moment vector. Thus if we measure the direction of emission of the pions from many Λ^0 decays, and transform them in each case from the laboratory system to the centre-of-mass system of the Λ^0 in question, we can find the average value of Θ. The precision depends on the number of Λ^0 decays collected, on the accuracy of measurement of direction and momentum in the emulsion, and on the errors in the determination of the value of the magnetic field and of other constants associated with the apparatus.

The main run took place, without major mishaps, in October 1963. Analysis began at the four collaborating Laboratories as soon as the processed plates had been distributed, and by Spring 1964 results were beginning to emerge. The character of the work had now changed, for the many technical tasks associated with the preparation of the experiment had been replaced by scanning, measurement and data analysis. Much comparison and discussion of data took place in meetings and by correspondence, and by June 1964 it was clear that the experiment would yield an improved estimate of the Λ^0 magnetic moment. A preliminary paper was read at the International Conference on High-Energy Physics held in Dubna in September. More complete results were published in Physics Letters in March 1965.

Figure 5. The Λ^0 magnetic moment experiment. The block in the centre is the pulsed magnet containing the emulsions. The beam comes out of the quadrupole magnet seen at the top right of the photograph.

This determination of the Λ^0 magnetic moment is an example of an experiment using nuclear emulsions in a complex arrangement in which the application of many of the techniques of experimental physics, and some of engineering, was involved. The handling and processing of the emulsions, the subsequent scanning and the measurements, whilst crucial to the success of the project, did not constitute the major part of the work, nor, we might add, were they the most difficult.

We have not given an example of the other type of nuclear-emulsion experiment: the irradiation of a large stack with particles of known type and momentum, followed by analysis of the interactions with the nuclei of the emulsion. In this, the more traditional kind of emulsion work, scanning and measurement constitute the major part of the practical activities which precede analysis and interpretation.

However, the importance of the results obtained depends on the quality of the interpretation. Even the most perfect stack, irradiated to give a convenient density of events, processed to have high uniformity and low distortion, scanned and expertly measured, is only raw material for the investigation. Those who use the emulsion technique must understand and interpret their results just as any other research workers. Skill in that field is more important and much more difficult to acquire than a working knowledge of the emulsion technique.

The Present Situation

With the steady rate of development of new methods and techniques in experimental sub-nuclear physics, the range of applications in which nuclear emulsions have an advantage over other detectors has been decreasing rapidly during the last few years. As a result, most of the groups who have used emulsions in the past have changed to other techniques, either because the change allowed them to pursue their special interests more effectively, or because in that way they hoped to have greater opportunities to take part in major developments.

Of the groups that remain active and continue to consume accelerator-produced particles, the majority are working in a clearly defined field: hyperfragment studies. A new experiment to obtain a more precise determination of the Λ^0 magnetic moment is under active preparation by a collaboration of five groups including CERN, and is scheduled at the PS for the end of 1966. Another collaboration is working on the fragmentation of nuclei of various elements by high-energy protons using a system in which energetic fragments pass through an analysing magnetic field before entering the nuclear emulsion. Both the high spatial resolving power of emulsion and the possibility of identifying nuclei coming to rest in it, are involved in this experiment.

Apart from these current applications to research, there continues to be a steady demand at CERN for beam-profile determinations and intensity surveys, where the simplicity and flexibility of the emulsion technique often makes it more convenient to use than other methods.

The future

It is always risky to predict the future in print, and especially so in the present case where there is already a long record of unfulfilled pessimistic prophecy. We do not think that the emulsion technique is dead, to be soon forgotten. It is simple, easy to adapt to new requirements, and a physicist does not need a long apprenticeship in order to use it.

As with the bubble-chamber technique, the analysis of the experimental material can be done at small university laboratories, far away from the accelerator. The investment in equipment for analysis can, moreover, be relatively modest, much less than for bubble-chamber work for which access to a large computer is always needed.

Except in special applications, such as hyperfragment studies, nuclear emulsion is basically unsuitable for the investigation of very rare events and for the detection of complex processes where neutral links travel more than a few hundred microns before giving rise to a visible secondary event. Accumulated background will swamp the rare events, unless they have very striking characteristics, whilst complex processes will usually escape detection because the background obscures the relationship between vertices connected by neutral links, and because only a very small region of the emulsion can be in view at any one time.

It is clear, therefore, that future applications will be of the kind in which one or other of the strong points of the technique is of paramount importance. Such applications have always existed since the time of Kinoshita, fifty-five years ago, and we can expect that they will continue to be found in the future. For that reason, it is important not to let the emulsion technique disappear from the arsenal available to experimental physics. It may be put into storage, perhaps, but if it remains at the disposal of those who want it, it will almost certainly continue to be used from time to time.

CERN News

Linac current over 100mA

On 3 May, a 100 mA proton beam was accelerated to 50 MeV in the proton synchrotron injector. This achievement followed the installation of a duoplasmatron ion source and exceeded the highest beam current previously obtained from the linac.

To begin at the beginning. The protons to be accelerated in the synchrotron are obtained from hydrogen gas in an ion source. The proton sits alone at the centre of the hydrogen atom and to obtain a proton beam it is necessary to strip off the orbiting electron, creating a 'plasma' of free electrons and protons, and to apply appropriate voltages to draw off the protons. But this simple picture hides a multitude of complications and the ability to produce a good ion source involves a dexterity which could appropriately be named ion sorcery. Nevertheless, a good source is a key feature in the ultimate performance of the whole machine and a great deal of the success of the CERN PS could be attributed to the excellent quality of this first unit.

Up to now the sources have been of the r.f. type, where pulses of radio-frequency power set up fields in the source which tear the electrons from the hydrogen atoms. (Work on these sources has been led by U. Tallgren.) Beam currents of 250 mA have been obtained from the r.f. sources giving, reliably, currents of around 70 mA accelerated in the linac. This was already a much better performance than is obtained on comparable linacs anywhere else in the world.

During the present PS shutdown the r.f. source has been replaced by a duoplasmatron type. With this source, the plasma is created by an arc discharge and concentrated by a special arrangement of electrodes. High proton currents can then be drawn off from the plasma. At the Dubna Conference in 1963, the Electrophysical Laboratory of Leningrad described their work on a duoplasmatron source incorporating a new feature, whereby the plasma is allowed to expand giving a larger plasma surface from which to extract the proton beam. This leads to a reduction of the space-charge effect inherent in an intense beam*. The effect can be further reduced by using a short accelerating gap immediately after the source.

Following the Conference, research on this type of source and accelerating gap was started at CERN. In recognition of its Soviet origins, the source was called the 'Vodkatron'**. (Work on the source was led by B. Vosicki and on the accelerating gap by J. Huguenin.)

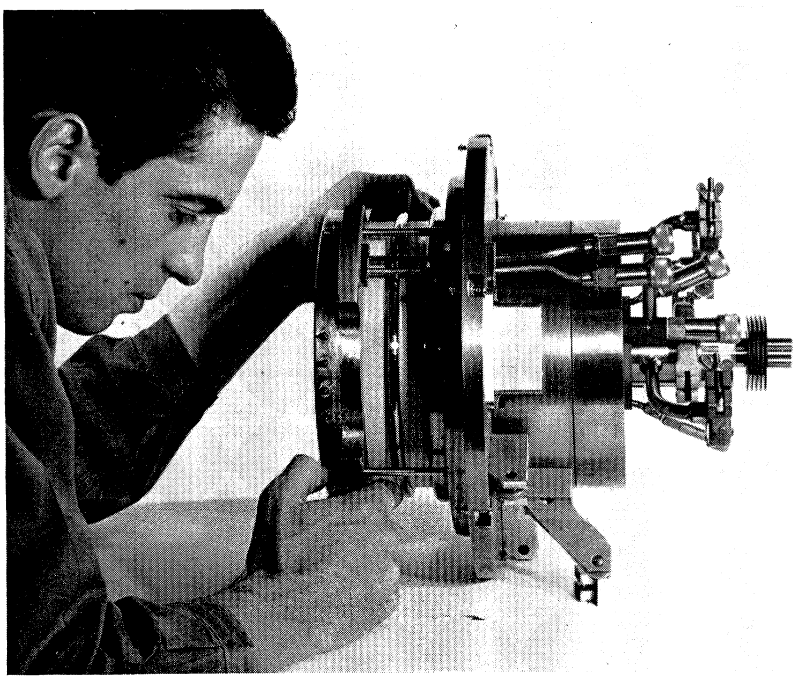
After installation of the duoplasmatron source on the PS, proton beams of up to 125 mA have been accelerated to 50 MeV. A current of 900 mA is drawn from the source; the useful pulse length is about 10 μs; in the short accelerating gap, 540 kV is applied across 12.6 cm between titanium electrodes. The 540 keV beam emerging from the new pre-injector has a very high density in phase space*, approximately an order of magnitude greater than with the r.f. source system. One would, of course, like this to result in a corresponding increase in density at 50 MeV, and eventually in a significant increase in PS intensity, the ultimate aim of pre-injector development.

However, with the new beam, severe beam loading*** occurs in the linac tanks (the gross effects of which will be dealt with by the compensation system due for completion in a few months' time), there is also an aggravation of space charge effects, both in the linac and in the PS. It is unlikely that there will be a dramatic increase in the PS intensity, but it should be possible to study the space charge limitations in the synchrotron more easily.

* CERN COURIER, vol. 6, no. 4 (April 1966) p. 63.
** It was found later that the plasma-expansion idea was in fact pre-dated by the Lamb and Lofgren source of 1956.
*** CERN COURIER, vol. 6, no. 2 (February 1966) p. 29.

Complex nuclei

On 18 and 19 April, an 'Informal seminar on the interaction of high energy protons with complex nuclei' was held at CERN. The seminar was arranged by the CERN Nuclear Chemistry Group. About 50 visitors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A duoplasmatron source being assembled. On the right can be seen the connections to the electrodes and to the filament, and the hydrogen feed. The proton beam is extracted at the opposite end of the source.

from outside Laboratories, in addition to a considerable number from various CERN groups, participated.

The reactions discussed included fission, spallation and emission of fragments. The research is directed towards understanding these three processes which can be loosely defined as follows: fission — where a complex nucleus breaks up into two (or maybe more, see below) heavy fragments of approximately equal mass; spallation — where a number of light particles break off from the nucleus leaving one heavy fragment; emission of fragments — where one medium weight fragment breaks off from the nucleus. CERN has been active in this field of research ever since the Theoretical Study Division, which was then located at Copenhagen, sponsored some high energy fission studies using the Uppsala synchro-cyclotron. The Nuclear Chemistry Group at CERN, which has to a large extent been recruited from the Uppsala workers, continued and extended these studies using both the SC and the PS (see CERN COURIER, vol. 3, no. 3 (March 1963) p. 31). The CERN Emulsion Group has also participated in similar studies and at present other experimental techniques are proposed for use at CERN by outside Laboratories.

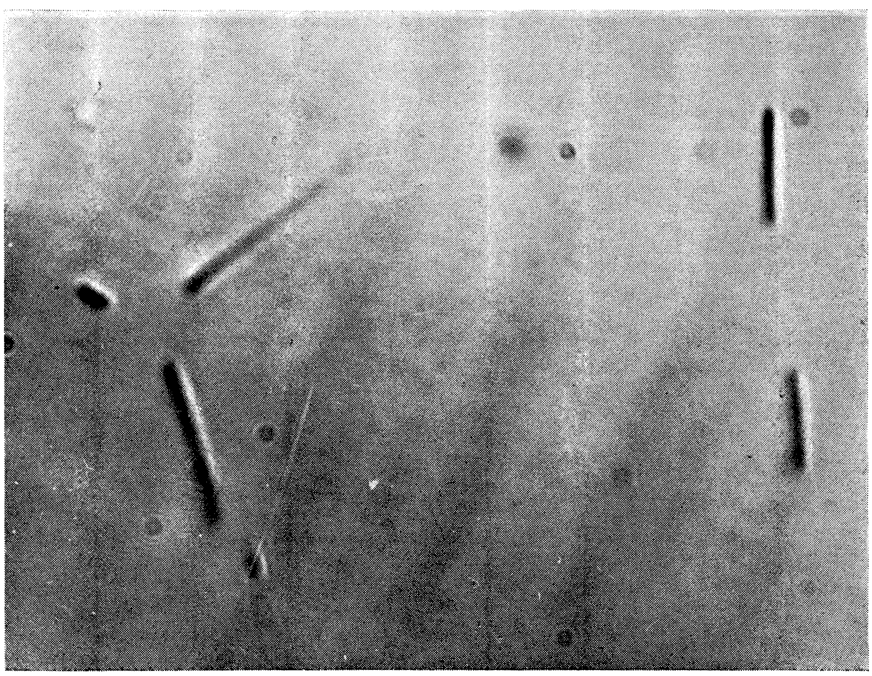
A considerable amount of experimental data has been gathered on these complex reactions but so far they have not been explained very well theoretically. However, systematics have been worked out and have become an important tool in various applications. For example, astrophysicists use these results in their work on cosmological phenomena and they are also used when calculating the shielding requirements for high energy accelerators. Quite recently a possible use of the spallation process as an intense neutron generator has been proposed in Canada. This project, which they have called ING for intense neutron generator, would involve a new type of accelerator (a separated orbit cyclotron, or SOC, first proposed by F. M. Russell of the Rutherford Laboratory) with an energy of 1 GeV and a proton beam of 65 mA.

Among the many interesting contributions at the seminar, some concerning particularly promising new experimental developments might be mentioned. B. Hahn from the University of Fribourg/CERN reported on preliminary results from experiments using a freon bubble chamber to identify light fragments emitted by various heavy nuclides bombarded by 21 GeV protons, and to determine their energies and angular distributions.

R. Klapisch described some experiments at Orsay using a mass separator on-line to study the formation cross-sections for isotopes of lithium produced in carbon, and of rubidium and cesium produced in uranium by 150 MeV protons.

Over the past two years the use of a new type of detector, such as mica sandwiches, for the observation of heavy particles has received considerable attention. The method involves a rather similar process to the nuclear emulsion technique. When mica laminates are exposed to irradiation by heavy particles, tracks of damaged material are left in the wake of the particles as they pass through the mica and they can be made visible by an etching process. Hydrofluoric acid preferentially attacks the damaged parts of the mica lattice leaving fine hollow tubes in the material so that they become visible in an optical microscope. One great advantage of this method is that the mica is only sensitive to heavy particles (atomic mass number of about 30 and above) and therefore there is much less confusing background due to the particle beam from the accelerator. (For further information on this technique, see 'Science', vol. 149, no. 3682, 23 July 1965, p. 383).

Mrs. J. Piekarz, from the University of Warsaw, on behalf of a CERN/Heidelberg/Naples/Warsaw collaboration, reported on the use of mica detectors in irradiations at CERN. Mrs. M. Debeauvais from the Centre de Recherches nucléaires at Strasbourg spoke of similar work using foils of plastic polycarbonate which is sensitive to particles down to atomic mass number about 15. The technique makes is possible to look for fission cross-sections which are very small. Both the above experiments reported the observation of 'three prong events', the tracks apparently coming from a common centre. This may be due to fission reactions where the complex nucleus breaks into three large particles instead of the usual two.



A microphotograph of fission fragment tracks registered in a mica sandwich. This photograph shows a three prong (left) and a two prong event which were recorded during the CERN/Heidelberg/Naples/Warsaw experiment at the PS. In the experiment, a 20 GeV proton beam was incident on a uranium target. Typical track lengths in the mica are about 10 μ long.

A possible future use for the new detectors is to measure the intensity of high energy beams, though the method is a slow one. Using a material for which the fission cross-section is known, with an array of the detectors, it may be possible by counting the number of fissions recorded in the detectors to estimate the flux of the particle beam.

SC Shutdown

The 600 MeV synchro-cyclotron began a long shutdown on 8 May which will extend to mid-July. During this time major modifications will be carried out as part of a programme to improve the capacity of the machine and its associated facilities for research (see CERN COURIER, vol. 6, no. 2 (February 1966) p. 30).

The main items of work planned for the shutdown are —

i) To reinforce the shielding on the roof of the SC building to keep radiation levels in neighbouring buildings and off the site down to acceptable limits, allowing a margin of safety for possible increases in beam intensity.

ii) Construction of a new underground tunnel to take the external proton beam line to the ISOLDE (Isotope Separator On-line Development) project. This tunnel has to be constructed underground again to keep external radiation levels down. It also frees the existing proton room for experiments involving less intense beams.

iii) Modification of the accelerating system of the synchro-cyclotron. The modification is designed to increase the frequency sweep of the system permitting operation at higher magnetic fields.

iv) Installation of new quadrupole lenses on the beam lines on the meson platform in the SC hall.

In addition new power supply and cooling installations will be brought into operation and many elements of the SC machine and its associated equipment will be overhauled.

Computer Programme

The long term planning of research facilities for high energy physics involves more than the provision of more efficient, or higher energy, accelerators. Application of the advances in particle detection techniques (such as bigger bubble chambers...) needs to keep in step with the forseeable research requirements and, also, data processing facilities to analyse the information coming from the experiments must be planned to keep pace with the output of data. In particular, this involves the provision of extensive computing capacity.

A major study of CERN's computing needs was made by a European Committee in 1963 and the ensuing report recommended a considerable increase in computing capacity over the period 1965-69. The volume of data to be processed was expected to grow from that corresponding to the capacity of an IBM 7090 computer at the end of 1964, to between 10 and 15 '7090s' by the end of 1968. The actual growth to date has been very close to that predicted and a more recent review (February 1966) was in general agreement with the analysis made in 1963. (The predictions for 1969 and beyond, considerably exceed the capabilities of any currently available computer but the next generation of computers can be expected to emerge about that time.)

The 1963 report recommended the purchase of the large CDC 6600 as the central computer together with a number of small peripheral computers (for special applications such as on-line counter experiments), and also the addition, at an appropriate time, of extra storage capacity to the main computer.

A 6600 was installed at CERN at the beginning of 1965. The problem of bringing the machine into reliable use has been much more difficult than was anticipated and the troubles came to a head towards the end of 1965 when the machine had to be taken out of use for four weeks to undergo engineering changes. The performance of the computer has in addition been restricted by the poor software delivered by CDC which necessitated CERN spending a considerable part of the computer's time on 'system development'. A CDC 3400 was installed at CERN while the 6600 was unavailable in order to provide some on-site capacity, and has been retained to help process the back-log of work.

For the past twelve months, CERN has been short of on-site computing

CERN/PI 56.5.66

Excavation of the hole for the underground laboratory of the ISOLDE (Isotope Separator On-line Development) project. The project will use extracted proton beams from the 600 MeV synchro-cyclotron and the underground beam line from the SC is to be constructed during the present machine shutdown. (The SC building can be seen on the right.)

capacity and has had to put considerable effort into system programming and into making provisional arrangements to get round the difficulties. The research programme has been badly affected. It seems possible that high energy physics Laboratories will have to live with this problem in one form or another from now on, since the demands on computer technology that the research makes, is pushing the technology to its limits. Computers capable of coping with the vast quantities of data and the large range of problems involved, may (for earlier models at least) not have reached a 'reliable' stage of production.

A major outcome of the experience of the past year has been a decision that the future CERN computing facilities should have a much better 'fail-safe' characteristic. This implies having a secondary computer permanently available on-site to take over the most urgent work in the event of the main computer being out of action. One requirement of this secondary computer, because of the nature of some of the CERN work, is that it should have a storage capacity of at least 64 K.

Thus, major items among CERN's computer needs involve the acquisition of an appropriate secondary computer and (in line with the 1963 report) the eventual purchase of more storage capacity for the 6600. Computer manufacturers were consulted about these requirements and, after replies had been received, discussion took place in the Scientific Policy Committee on 8 March and in the Finance Committee on 10 March and approval was given to continue negotiations on the proposals with CDC. Negotiations took place at the end of March and the financial aspects of the agreements which resulted were approved at the Finance Committee meeting on 17 May.

Among the agreements were the following:

The CDC 3400 will be replaced by a CDC 3800 (arriving in July of this year) on a rental contract. (There will be some overlap of the two machines at CERN.) This will enable production work now being done on a CDC 3600 in Paris to return to CERN and will provide a better standby machine on-site. It will have a storage capacity of 65 K and is very similar to the CDC 3600 which is regarded as a proven 'reliable' machine.

By September 1966, CERN will decide whether to replace the 3800 by a CDC 6400 which is being reserved for delivery in February 1967. This also has a 65 K memory but is faster than the 3800. It is compatible with the 6600 and would therefore make a most convenient standby machine and enable a computing service to be maintained round the clock, even though both machines require daily maintenance. Because of this close compatibility, the 6400 would also be suitable as part of a future computer complex in which the 6600, the 6400 and the extra storage capacity, mentioned above, could be linked together in a flexible, powerful time-sharing system. This could be organized so that either machine could operate independently to maintain the 'fail-safe' characteristic.

The hardware for the extra storage capacity will probably be a 512 K Extended Core Store also made by CDC, for which CERN has an option for delivery at the beginning of 1968.

Rencontres de midi

The aim of the 'Rencontres de Midi', organized jointly by the Staff Association and the Welfare Section is to provide information by direct contact. To this end, making use of the mid-day break once a month, the CERN Staff is invited to hear a prominent Swiss or French personality speaking on a subject of current and general interest.

The guest speaker at the last 'Rencontres de Midi' (on 25 April) was Mr. Herzig, Mayor of the Commune of Meyrin, conseiller municipal, conseiller administratif and a member of the Grand Conseil of Geneva, who spoke about the social problems of Meyrin. The Commune has grown from 1 915 inhabitants in 1939 to 11 500 at present, which gives Meyrin the status of a town. This figure includes about 40 % foreigners and members of international organizations.

Mr. Herzig said that while he was happy to see this growth at Meyrin, which was the first example in Switzerland of a satellite town, he regretted that the federal law did not allow communes, at present, to increase their income. The public authorities and private enterprise, he said, have already done a great deal to solve the problems set by the large increase in population. There remain, however, problems which the Commune is ill-equipped, financially and technically to solve quickly by itself: road maintenance, schools, theatre and concert hall, for example.

Beginning in the Autumn, the 'Rencontres de Midi' will invite in turn the leaders of the various political parties in Geneva.

Etc...

Professor Gregory, Director General of CERN, visited Spain from 25 to 29 April at the invitation of Professor Otero Navascues, President of the Junta de Energia Nuclear. The Director General spoke at the Institute of Civil Engineering, Madrid, on 'Engineering problems of large particle accelerators' and at the Science Faculty of the University of Valencia on 'Sub-nuclear physics'. He also visited the site near El Escorial, Madrid, put forward by Spain for the construction of the proposed 300 GeV accelerator.

The Society for Radiological Protection, U.K., held an international symposium in the third week of April. 240 delegates from 19 countries were present including some members of the Health Physics Group at CERN. The symposium was concerned with 'The radiological protection of the worker by the design and control of his environment' and A. Rindi, of the CERN Health Physics Group, spoke on the special problems connected with the use of high energy accelerators (see CERN COURIER, vol. 6, no. 3 (March 1966) p. 45).

A new proposal for the 300 GeV accelerator site has come from Greece. The site is near Athens. Germany has withdrawn its site at Reimsbach.

The Directorate has decided to set up a study group in the MPS Division to investigate the proposal to use slow-cycling synchrotrons in the injection system of the CERN PS as part of the machine improvement programme (see CERN COURIER, vol. 6, no. 4 (April 1966) p. 63).

At the time of writing (10 May) everything is going according to plan to bring the proton synchrotron back into operation. The repaired magnet power supply motor returned to CERN on 9 May. If the installation of the motor and initial tests are successful, operation of the PS will begin again on 25 May.

General Relativity 50 years old

by **A. Capella**

Theory Division

In May 1916, 'The Foundations of General Relativity Theory' by Albert Einstein was published in 'Annalen der Physik'. Fifty years later, this major contribution to scientific thought still has a rather isolated position with respect to the main-stream of scientific theory. (In contrast, the Special Theory of Relativity is one of the cornerstones of sub-nuclear physics.) To mark the anniversary of the publication of Einstein's paper a theoretician from CERN discusses the theory and its present status.

The great originality of general relativity theory rests in replacing the flat space-time of special relativity by a Riemannian space-time with non-zero curvature. Moreover, in this theory the idea of force is abandoned, the motion of mass being determined by the geometrical curvature of space-time. This curvature, in its turn, is determined by all the masses in the universe, by means of non-linear equations (Einstein's equations).

When the curvature of space-time is small (which corresponds to a weak gravitational field) and the velocities involved are also small in comparison with the velocity of light, Enstein's equations become equivalent, to a first approximation, to the Poisson equations of Newtonian mechanics.

Several months after the publication of Einstein's work on general relativity, Schwarzschild succeeded in rigorously solving Einstein's equations for the case in which the mass creating the field has spherical symmetry. This solution was applied to the study of the motions of the planets in the gravitational field of the sun and gave striking confirmation of general relativity theory. According to Einstein's theory, a planet does not describe a fixed ellipse (as is the case in Newtonian mechanics when the effects produced by the other planets are not considered), but an ellipse whose perihelion advances by a certain angle with each revolution. This angle was measured, and the result agreed very well with the predictions of the theory.

Shortly afterwards, two other effects predicted by the theory of general relativity, were confirmed by experiment: the bending of light-rays in the vicinity of a mass and the red-shift of spectral lines in the presence of a gravitational field. The latter prediction, moreover, received further confirmation following the discovery of the Mössbauer effect.

Since then, great progress has been made in the development of general relativity theory (Cauchy's problem for Einstein's equations, the study of the equations of motion, the discovery of new solutions, etc.), but it has not received any further confirmation by observation or experiment. Certain problems concerning the physical interpretation of the theory (the definition of energy and momentum, interpretation of co-ordinates, etc.) are still far from reaching a satisfactory solution. Furthermore, Einstein's attempts to develop, from the point of view of general relativity, a unified theory of gravitation and electromagnetism were not successful and general relativity occupied (and still occupies) a position which is rather cut off from other physical theories.

In the last decade, special attention has been paid to two problems: gravitational radiation and the quantization of the gravitational field. General relativity postulates the existence of gravitational waves, but it has not so far been possible to detect them. The reasons for this failure seem to be, on the one hand, the extremely low energy carried by the waves and, on the other, the difficulties inherent in the construction of an emitter of gravitational waves. At present, one can do no more than try to detect gravitational radiation coming from the interstellar regions. With regard to quantization of the gravitational field, although considerable progress has been made, it is still very limited and it can be said that no coherent quantization of general relativity theory exists at present.

The difficulties arise both from the curvature of space-time and from the identification of field and geometry which is the basis of Einstein's theory. These reasons, together with the weakness of the gravitational interactions, help to explain why gravitation has so far played almost no part in elementary particle physics.

It can therefore be said that, although general relativity is universally accepted as the macroscopic theory of gravitation, its validity as a microscopic theory (after quantization) has not yet been established. Consequently, the possibility that it will one day provide a bridge between physics on the macroscopic and the microscopic scale, remains no more than a hope.

News from Abroad

Dannie Heineman Prize

The 1966 Dannie Heineman Prize for Mathematical Physics has been awarded to Academician Nikolay Nikolayevich Bogolyubov of the Soviet Union. The award, endowed by the Heineman Foundation for 'Research, educational, charitable and scientific purposes', is presented annually under the auspices of the American Institute of Physics and the American Physical Society.

Dr. Bogolyubov was born in Gorki in 1908 and was educated at Kiev State University, receiving his doctorate of physico-mathematical science in 1930. Subsequently, he taught at Kiev and Moscow State University and in 1956 became head of the Laboratory of Theoretical Physics at the Joint Institute for Nuclear Research, Dubna, where he is now Director. He was cited 'for several outstanding achievements in bringing the resources of modern mathematics to bear upon fundamental problems in physics and, in particular, for the first rigorous proof of dispersion relations for the non-forward scattering of elementary particles'.

Professor L. van Hove, now Directorate Member for Research at CERN, received the prize in 1962 for 'his contributions to statistical mechanics and to field theory as examples of outstanding publication in the field of mathematical physics'.

200 GeV

Six sites have emerged from the second stage of the selection process for the American proposed 200 GeV accelerator. They are as follows: Ann Arbor, Michigan; Brookhaven; Denver, Colorado; Sierra foothills, California; Madison, Wisconsin; Weston, Chicago. A site at South Barrington, a suburb of Chicago, was also listed, as an alternative to the Weston site, but was withdrawn after local pressure. One of the contentions against having the accelerator at South Barrington was that the influx of scientists would 'disturb the moral fiber of the community'! Four commissioners of the US Atomic Energy Commission will make the final decision which is expected within a few months.

Villigen

The Swiss Parliament has approved the construction of a 500 MeV isochronous cyclotron at Villigen. The site of the new accelerator Laboratory is across the River Aare from the Federal Institute of Reactor Research at Würenlingen, north-west of Zürich.

The project has been under consideration since 1961. It involves a two stage acceleration process — a 70 MeV cyclotron injecting into the 500 MeV machine which uses eight spiral ridge magnets and four accelerating cavities. External proton beams of from 50 to 100 μA, will be available. The total cost of the accelerator is estimated at about 90 million Swiss francs.

Construction is scheduled to begin this year and the first beams are planned for 1971 or 1972. Research will cover nucleon-nucleon interactions with emphasis on the use of polarized beams; meson studies with π and μ meson beams; nuclear structure research; radiation damage studies, and also research into the biological use of meson beams.

Cambridge (Mass.)

The Director of the CEA Laboratory, USA, has presented a 'Summary of Research Operations at the Cambridge Electron Accelerator' (CEAL - 1026) covering operations up to the end of 1965.

The Laboratory suffered major set backs during 1965, in particular, the bubble chamber explosion on 5 July, and the number of hours machine time available to 'main users' was reduced to just under 2000. The 1966 schedule hopes to double this figure. The experimental programme included the following topics — electron-proton scattering; photoproduction of electron pairs; photoproduction of mesons; electron-deuteron scattering; photoproduction using a 12 inch hydrogen bubble chamber; photoproduction of mu-pairs; photoproduction of charged pions and K mesons; production of pions by tagged photons; production of polarized photons with a laser; wide gap spark chamber studies; bremsstrahlung studies with a pair spectrometer; positron scattering in hydrogen, and the proton Compton effect.

Among the topics covered by apparatus development, the CEA scientists are considering the possibility of using the existing accelerator ring to store beams for electron-positron colliding beam experiments. They have already successfully tested the ability of the magnet ring to store the electron beam by switching the magnets to d.c. operation. A proposal from Stanford for electron-positron storage rings was recommended by the US Atomic Energy Commission in preference to a CEA proposal to build separate rings at Cambridge.

Argonne

It was announced on 18 April that a team of physicists, mainly from the University of Michigan, have found a new 'resonance', N* 3245, which is the most massive particle to be identified so far. The resonance is one of the excited states of the nucleon and is three and a half times as massive as the proton. It has a lifetime longer than 10^{-22}s which makes the particle unusually stable for a nucleon resonance; this may be due to its high spin value. The N* 3245 has not yet been assigned a position in one of the symmetry groups of elementary particles.

The experiment took place at the 12.5 GeV Zero Gradient Synchrotron (ZGS) at Argonne. It was an experiment using scintillation counters with a π meson beam from the accelerator incident on a liquid hydrogen target.

Brookhaven

A large scale experiment, planned by scientists from the Brookhaven Laboratory, to investigate the solar neutrino flux, is expected to be in operation very soon. The experiment uses as its detector a tank containing 3.8×10^5 litres of perchloroethylene in which the radio-isotope argon 37 is produced from chlorine 37 by neutrino interactions. It is located in a mine in South Dakota 1470 m deep. About 5 solar neutrino events per day are expected to be recorded in the detector.

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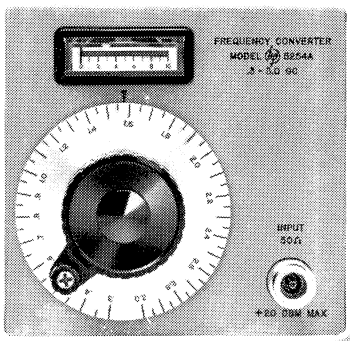

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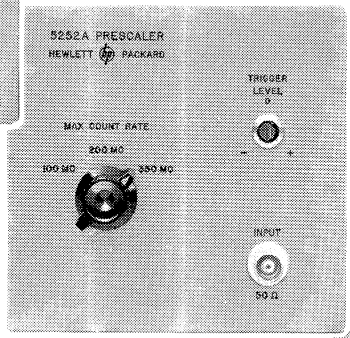

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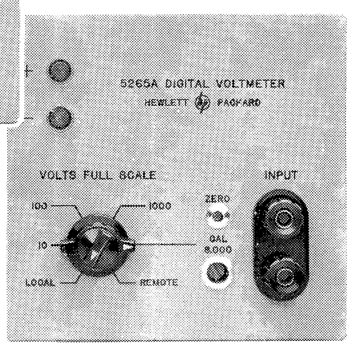

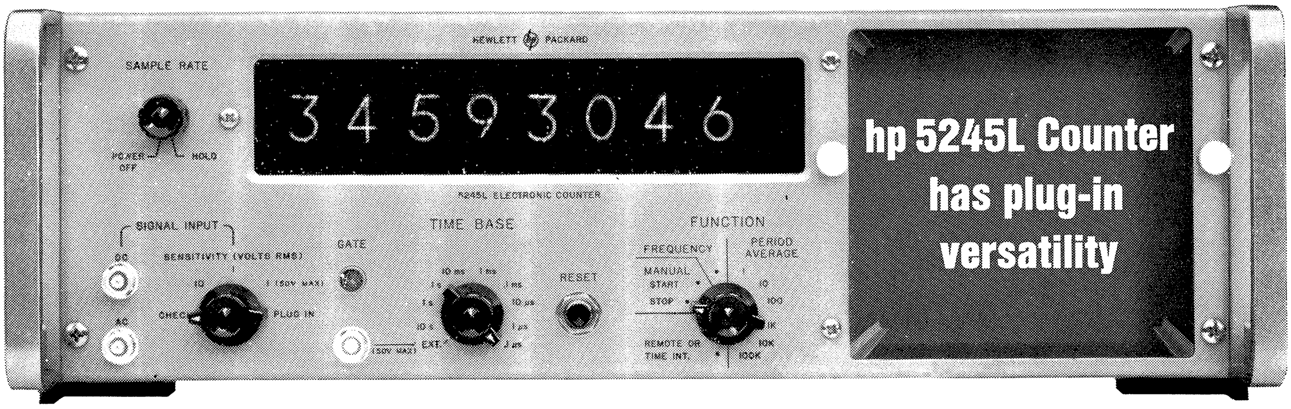

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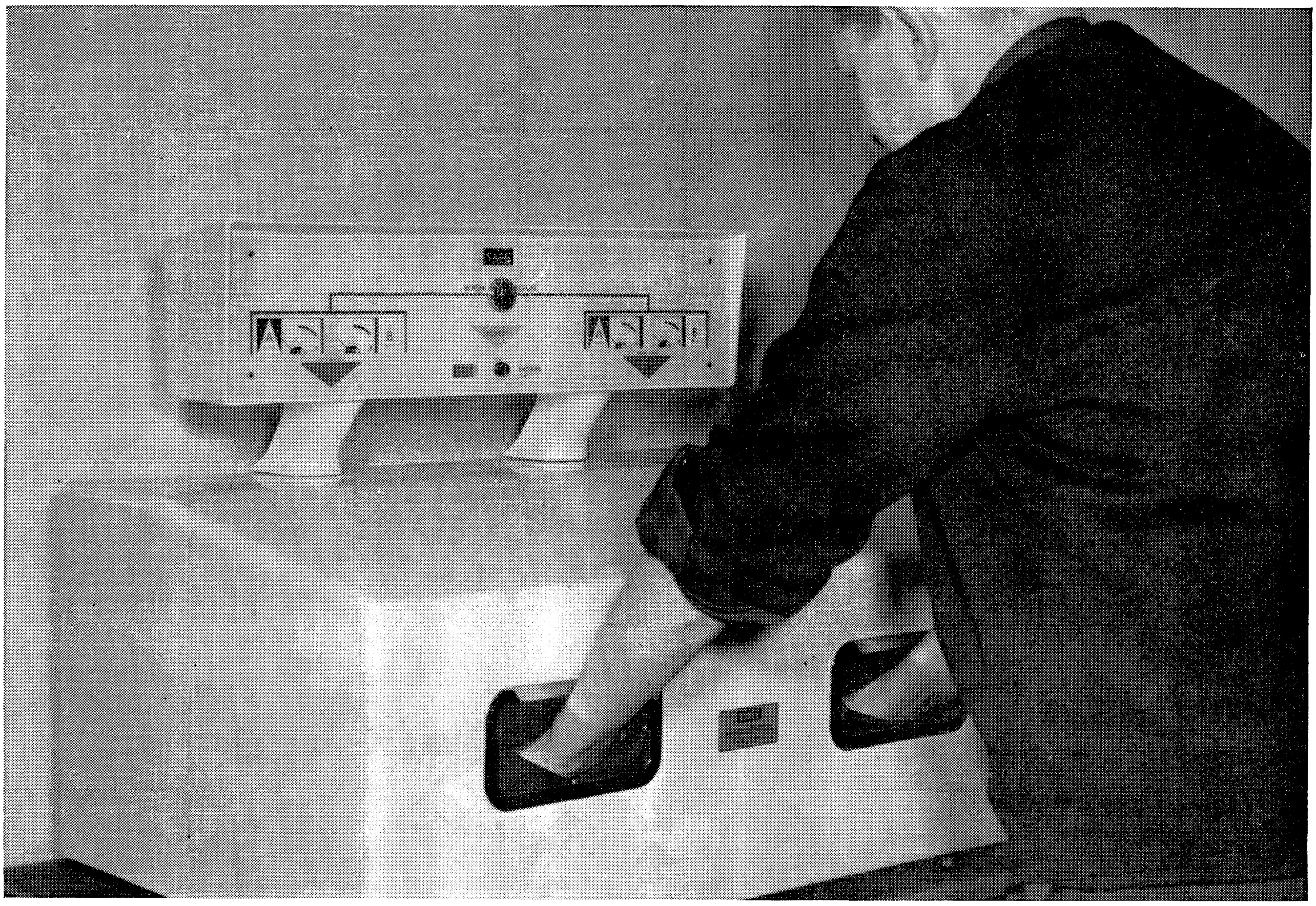

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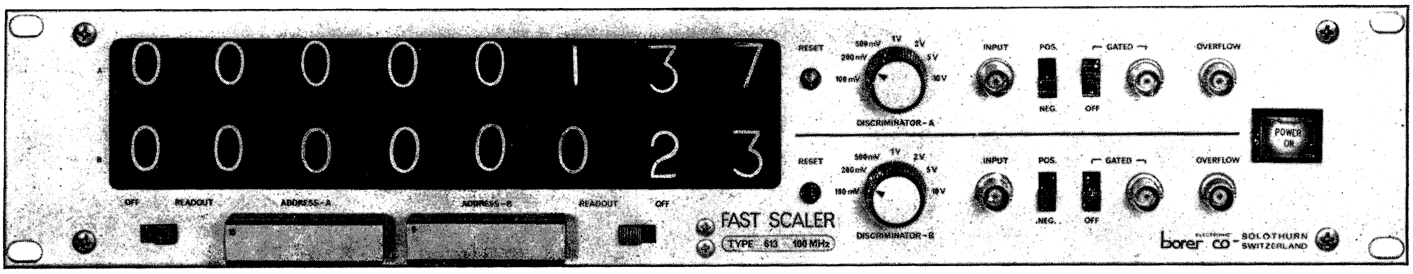

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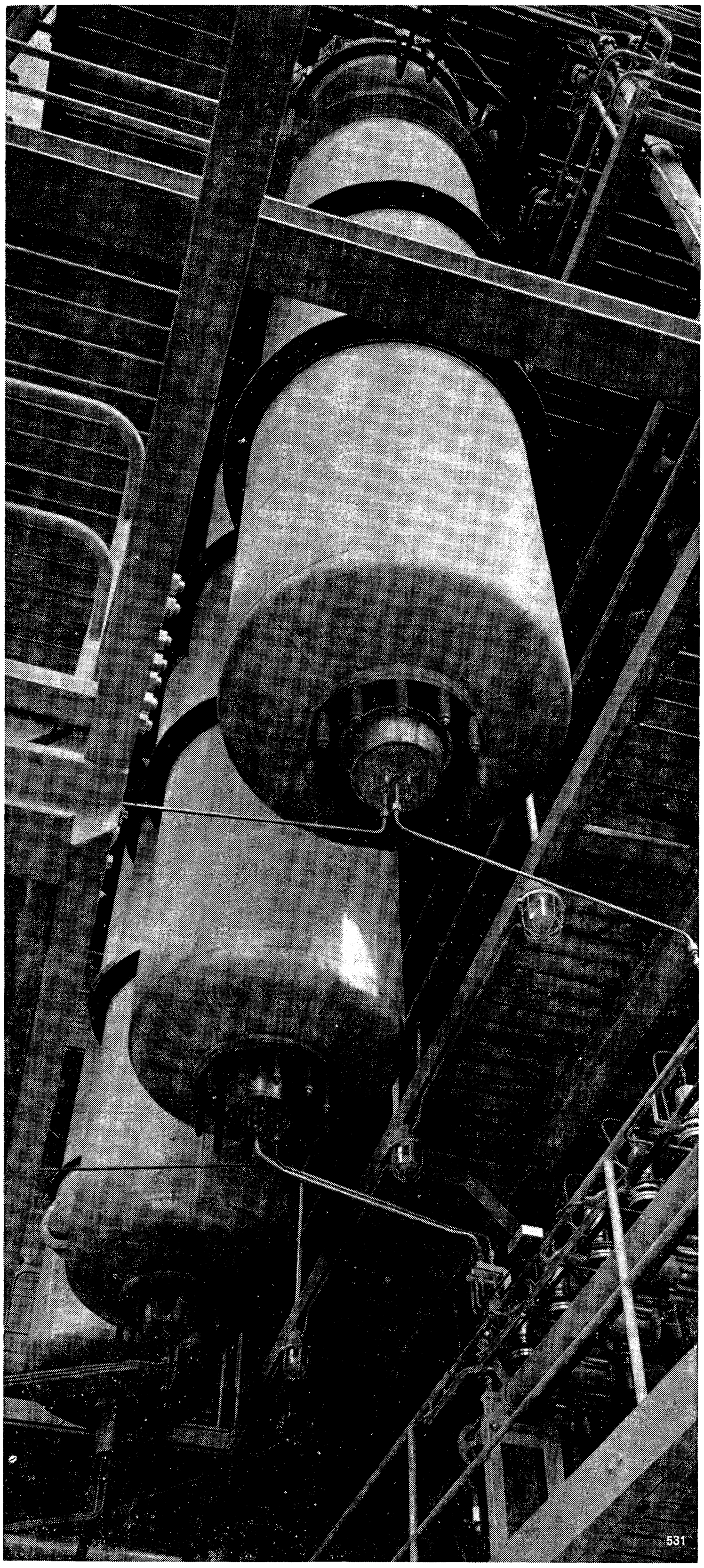

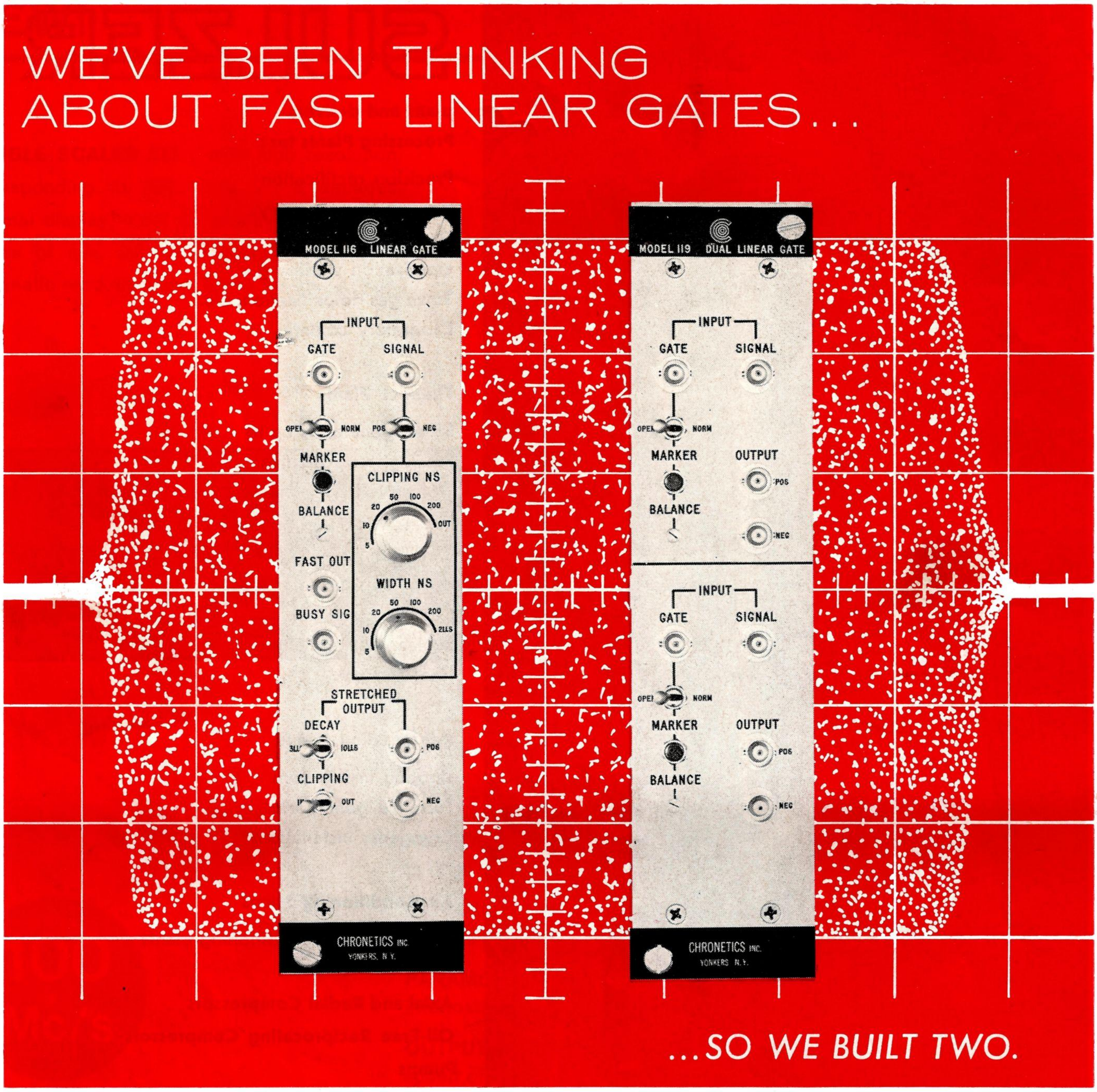

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