CERN COURIER

CERN/PI 54. 4. 63

6

VOL. 3

pp. 77-84

June 1963

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Fast ejection of protons from the CERN proton synchroton

In the May issue of CERN COURIER we published a first-hand account of the stress and excitement in the PS main control room on the day the primary proton beam was extracted from the accelerator for the first time.

The present article, compiled with the collaboration of C. A. Ramm and other members of the NPA Division, explains the principles of operation of the unique equipment that has made this feat possible. It includes also some introductory sections explaining the way in which protons are accelerated in the synchrotron and used for experiments with internal or external targets.

Since the middle of May 1963, CERN has become unique as the only place in the world where experiments can be carried out with a high-intensity beam of 25-GeV protons ejected from an accelerator and travelling in free air. Already this beam is being utilized to produce the most intense beam of muon neutrinos (or neutrettos) ever to be obtained by man, opening the way to a new step forward in our knowledge of the constitution of matter. This new development has been made possible by the so-called fast ejection system, designed and constructed at CERN during the last few years. In what follows, we shall try to explain, in fairly general terms, how this system works.

The proton synchrotron

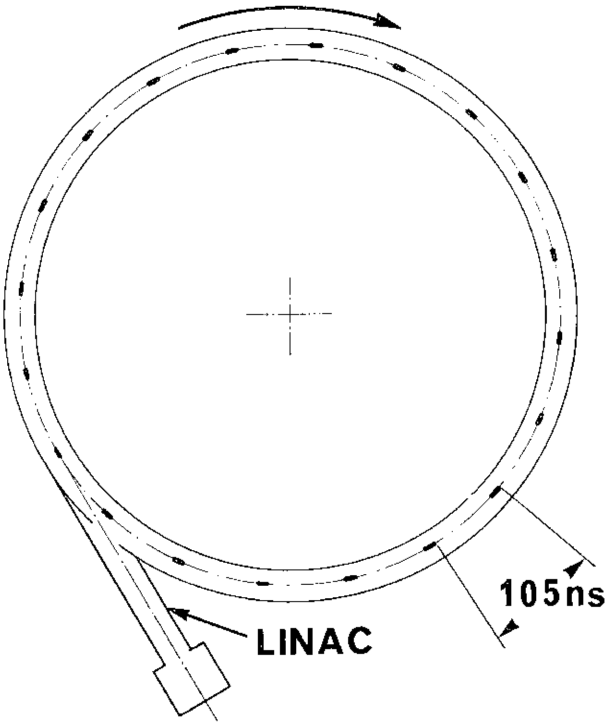
Before dealing with the fast ejection system itself, however, it is worth taking a quick look at some of the finer points of operation of the synchrotron (the PS), which accelerates the protons in the first place.

The protons come from an ionizing discharge in hydrogen gas, the gas being obtained from the electrolysis of water — no doubt some of the protons at some time formed part of the water in Lac Léman. They are injected into the linac, located in a building almost tangential to the PS magnet ring, where their energy is increased by means of radiofrequency oscillating electromagnetic fields between the 'drift tubes' (shown on p. 22 of the February issue of *CERN COURIER* this year). The lengths of these drift tubes are such that a proton being accelerated arrives at each gap just when the electric field there is of the correct polarity to give it energy. After reaching an energy of 50 MeV, the protons are injected into the synchrotron proper, a master timing system ensuring that they enter the ring just when the magnetic field has the right value to guide them precisely around the ring and back to their starting point.

The vacuum chamber thus becomes filled with a continuous beam of protons, circulating around the machine once every 6.7 microseconds. When the radiofrequency (r.f.) system of the synchrotron is switched on at this instant, about half the protons in the ring pass through the electric field between the electrodes in the r.f. cavities at the correct time to be accelerated. They thus gain more energy, and to maintain their orbits in the same position the magnetic field and the radiofrequency are increased in value together. Of course those protons which are unfavourably placed for acceleration when the r.f. is switched on are lost on the walls of the vacuum chamber.

Events happen so quickly in the acceleration and ejection of the protons that it is no longer convenient to measure time even in seconds. Two sub-units are used instead :
- **— 1 microsecond, equal to one millionth of a second**
- **— 1 nanosecond, equal to one thousandth of a microsecond.**

The process of acceleration gathers the protons into bunches, whose number depends on the particular relation between the frequency of revolution of the protons around the magnet ring and the radiofrequency itself. In the PS vacuum chamber the acceleration produces 20 discrete bunches of protons, equally spaced around the orbit (see fig. 1), which finally attain a velocity of up to 99.948% of that of light. At this stage of the cycle, each bunch passes any given point in the vacuum chamber once every 2.1 microseconds, and the protons acquire so much energy that their mass appears to increase by a factor of nearly 25. They can be held at this energy for a short time, and then the magnetic field falls to zero once more, the whole cycle being repeated normally once every three seconds.



Drawings by A. Dind (Engineering Division)

1. The proton beam inside the synchrotron is divided into 20 bunches. Each bunch takes about 6 nanoseconds to pass a given point, with about 100 nanoseconds between bunches.

Inside each bunch, the protons move around in a rather complicated way, although the actual motion may be considered broadly as the resultant of two types of oscillation. The **betatron oscillations**, so called because they were first studied in that type of accelerator, are oscillations perpendicular to the general motion of the protons, and in the PS they are rather rapid. In both the horizontal and vertical senses a proton completes some $6^1/_4$ betatron oscillations per revolution. The betatron oscillations are really those of a freely circulating particle in a magnetic guiding field, and are induced by local perturbations to the particle motion, such as scattering from a residual gas molecule in the vacuum system or deviation by an irregularity in the magnetic field. Because of the latter it is very important that the circumference of the machine should not be a whole number of half wavelengths of the betatron oscillation, otherwise the oscillations could grow so rapidly that the machine would not work.

The **synchrotron oscillation** is a much slower phenomenon, a sort of to-and-fro motion of the protons in a bunch, taking many revolutions to complete. It arises from the fact that only a small proportion of the protons in a bunch receive exactly the right acceleration from the r.f. field to be always in the centre of the vacuum chamber as the magnetic field rises, and the remainder oscillate about this group. It is because the betatron and synchrotron oscillations are so different in frequency that we may consider their effects independently.

To eject the protons from the synchrotron, two types of system will eventually be used, both of which depend on the excitation of betatron oscillations. The first of these, the **fast ejection system**, for which the Nuclear Physics Apparatus Division was responsible, operates by suddenly initiating a betatron oscillation of such a magnitude that all the protons follow each other out of the accelerator in the time of one revolution. On the other hand, the **slow ejection system**, which is the responsibility of the Proton Synchrotron Machine Division, depends on a more gradual excitation of oscillations, so that the protons 'spill out' of the accelerator in a period of time spread over perhaps several tenths of a second. Both systems have very important experimental uses, but as their modes of operation are quite different only the fast system will be described in this article.

Producing beams from the PS

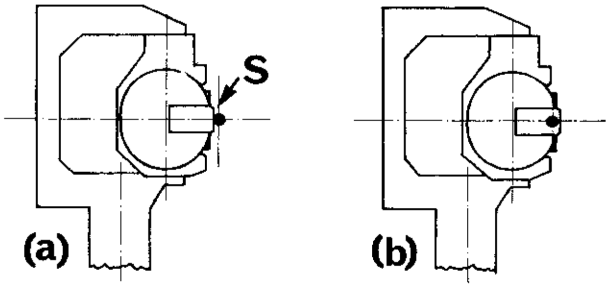
Until recently, the only method of using the primary accelerated beam of the PS for nuclear-physics experiments has been to introduce some material to scatter the protons out of the machine. For instance, a thin foil may be pushed into the circulating beam and those protons colliding with nuclei in the foil will be deviated. A few will then proceed in the right direction to arrive in some experimenter's apparatus. Some protons are scattered with nearly their original energy, but in most collisions secondary particles are produced and the energy of the protons is greatly diminished. By this means, though, beams of gamma rays, electrons, pions, kaons, neutrons, etc. have also been produced for the experimenters.

Because of the high energy of the incident protons, the greatest number of secondary particles is produced within a few degrees of the direction in which the protons are travelling, and of course it is just in this direction that most of the components of the accelerator are located. Thus, in the arrangement of a secondary beam there is always the difficulty of obtaining a good compromise between the obstruction to the particles presented by the PS itself and the fact that relatively few particles are produced at large angles. If the proton beam can be guided out of the machine to interact with an external target, many of the difficulties vanish, and for those experiments requiring intense secondary beams the advantages can be spectacular. With an internal target, it is possible to make the beam interact quickly or slowly, according to the experimental need. To have the greatest advantages from the extracted beam it is necessary to keep these facilities of fast and slow, and this is why two different ejection systems have been developed.

The successful achievement of an external beam does not mean that in future all internal targets in the PS will be abandoned ; they, too, have their advantages. A short, thin rod, just intercepting the circulating beam of the PS makes an excellent target, because those protons which fail to interact at first keep circulating around the machine and traversing the target until most of them finally encounter a nucleus of the target material. Thus the efficiency of an internal target is high, and the dimensions of the apparent source of secondary particles can be extremely small. The latter is a valuable feature in the design of 'optical' systems for secondary-particle beams, for the same reasons that make it easier in conventional optics to produce good images when the sources are small. With the extracted beam, protons which miss the target nuclei continue straight on, and there is no way of offering a second chance, except of course to have a second target. An internal target can be the tip of a rod a few centimetres long and 1 millimetre in diameter ; with the extracted beam, to give the protons the same chance of interacting, a cylinder of metal 10 to 20 cm long and two or three millimetres in diameter will be necessary. However, the extracted beam will make possible many experiments which previously could not be contemplated with internal targets because of the inefficiency of utilization of the secondary beams.

The fast ejection system

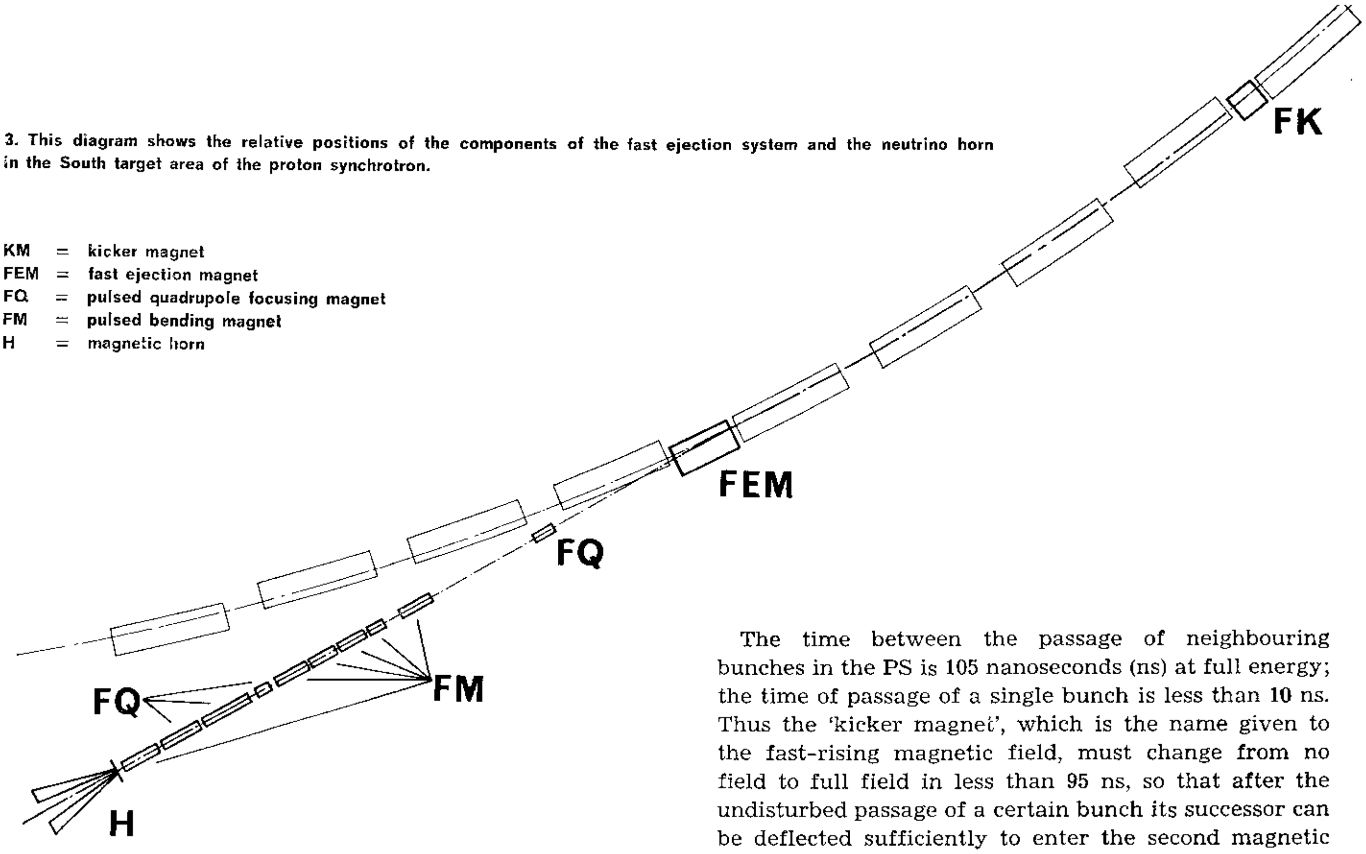
As with earth satellites, which we now regard as almost commonplace, the principle of the fast ejection system is elementary, but its achievement has required



2. When the bending magnet is brought into position inside the vacuum tank, the circulating beam passes just outside the septum, S, as shown at (a), looking along the beam direction. For the duration of the kicker-magnet pulse, the beam path is deviated so as to pass inside the septum, as at (b), and thus to come within the influence of the field of the bending magnet.

3. This diagram shows the relative positions of the components of the fast ejection system and the neutrino horn in the South target area of the proton synchrotron.

KM = kicker magnet
FEM = fast ejection magnet
FQ = pulsed quadrupole focusing magnet
FM = pulsed bending magnet
H = magnetic horn



a technological development and effort of no mean order. First, though, let us examine the principles.

Along a certain region of the orbit of the circulating protons, suppose a magnetic field can be made to appear in the time between the passage of two successive bunches. We could imagine this magnetic field sufficiently strong that it would deviate the bunches passing through it so much from their orbit that they left the machine completely. Thus we would have a sudden perturbation to the normal circulation of the bunches in the PS, with the result that they would all pass out of the machine exactly in the time that a single bunch normally takes to go around its orbit.

To achieve such a powerful magnetic field, capable of being switched on in such a short time, would be beyond the limit of present techniques. The same result, however, can be obtained by working in two stages. In the first stage, a magnetic field is created, with a time scale similar to that which we have just described and strong enough to cause the trajectory of the bunches to be deviated into a region where there is a second magnetic field. This second field is sufficiently powerful to direct the bunches completely out of the accelerator, and can be placed far enough from the normal orbit of the accelerating protons to be left on most of the time. Both high magnetic fields and very rapidly changing magnetic fields are difficult to achieve, but for different and conflicting technological reasons. By using two components in the ejection system the technical difficulties have been spread, so that the construction of each has become possible, although it still remains difficult. In a later article these two magnet systems, which are themselves of intrinsic technical interest, will be described more fully. For the present, let us just see what they do.

The time between the passage of neighbouring bunches in the PS is 105 nanoseconds (ns) at full energy; the time of passage of a single bunch is less than 10 ns. Thus the 'kicker magnet', which is the name given to the fast-rising magnetic field, must change from no field to full field in less than 95 ns, so that after the undisturbed passage of a certain bunch its successor can be deflected sufficiently to enter the second magnetic field, sometimes called the 'bending magnet', but more correctly the 'fast ejection magnet'. So that the latter field does not disturb the normally circulating protons, the ejection magnet is constructed with a 'septum' (fig. 2), that is it has a thin plate-like winding which produces a field exactly cancelling the stray field from the magnet gap outside the septum, where the protons normally circulate. In practice this septum is a few millimetres thick, and thus the kicker magnet has to induce a sudden sideways displacement of a few millimetres in the proton beam, assuming the beam itself is very thin, so as to cause the orbit of the bunches to 'jump' across the septum. The kicker magnet in fact causes just a change in direction of the protons, by starting a horizontal betatron oscillation. The oscillation first reaches its maximum amplitude after a quarter of a wavelength, or about 1/25 of the circumference of the PS, that is about four magnet units. This is therefore the most suitable position for the bending magnet, and we can thus understand the layout chosen in fig. 3.


CERN/PI 77. 4. 63

4. The kicker magnet installed in its vacuum tank (with cover removed) in straight-section 97 of the synchrotron. Here the magnet is in the withdrawn position ; each time before it is pulsed it is pushed further into the tank, so that the proton beam traverses the gap between its upper and lower pole pieces. Anton King and Pierre Pugin are seen making some adjustments to the actuating mechanism.

5. After their journey of hundreds of thousands of kilometres inside the synchrotron ring, the protons extracted from the accelerator are guided to their target at the magnetic horn by the beam-transport system, which focuses them into a fine beam whose cross-section is exactly the size of the spot shown here.

CERN/SIS 18219

The practical side, very briefly

The fast kicker magnet inside its vacuum tank is shown in fig. 4. It is about 1 metre long and U-shaped in section, and is seen in position out of the beam, which passes through the tank in the oval aperture in the end wall. At injection into the PS, the protons actually need the whole of the vacuum chamber for their betatron oscillations. It is only towards the end of the accelerating cycle that the circulating beam contracts sufficiently to pass easily through the kicker-magnet gap. Thus both the kicker magnet and the ejection magnet have to be clear of the normal limits of the vacuum chamber early in the accelerating cycle. Then, near the end of the cycle, each magnet is moved rapidly into place by means of a hydraulic mechanism. For the kicker magnet, this is partly visible to the right of the photograph. It is only when the magnets are in their correct places that the spark-gap and 'ignitron' switches can be fired to energize them. Thus in detail the whole system is quite complex, involving hydro-mechanical servo-mechanisms which position each magnet quickly and accurately, high-energy storage networks, pressurized spark gaps, delay lines and many other exciting developments of modern technology. Those of us who can remember that ten years ago an oscillograph with a sweep of a few nanoseconds per centimetre was a technical marvel, occupying about the space of a normal office, cannot help but pause in wonder occasionally at the development of technology. Such oscillographs have developed to be commonplace devices, to be installed unobstrusively in many places in the fast ejection system to monitor the timing cycles and wave forms. It has only been by using such available apparatus, and then hand-making the rest of the equipment in the CERN and other specialized workshops, that it has been possible to acquire all the components which are essential for the fast ejection system.

The enhanced neutrino beam

The ejection system was originally designed as a general facility for the PS because its constructors believed it would have many important uses. In fact, not very long after the project was first defined by B. Kuiper and G. Plass, it became clear that the equipment would be of fundamental importance for neutrino experiments. Theoretical physicists had previously pointed out that the large accelerators then about to come into operation at CERN and at Brookhaven should make it possible to observe interactions of neutrinos coming from the decay of beams of pions and kaons. The first successful neutrino experiment, at Brookhaven in 1962, used a target inside their synchrotron and depended on the decay of those relatively few pions which sent neutrinos towards the spark-chamber detectors. A greatly increased neutrino flux could have been obtained had it been possible to use pions travelling much nearer to the direction of the protons incident on the target. This is the theme of the enhanced neutrino beam at CERN.

The ejected beam is led by a transport system (cover photograph), which is physically small but of great focusing strength (fig. 5), on to a target in a device called the magnetic horn, which is designed to focus as many pions and kaons as possible towards the neutrino detectors. There is a region of free flight from the magnetic horn, and then a thick shielding impenetrable to all particles but the neutrinos which come from those pions and kaons, still relatively few, which decayed. Actually there are other neutrino-producing decays also, but so far the sensitivity of the detectors is too small for them to be of practical importance.

Thanks to the extracted beam, there will be an overall improvement in the rate of 'events', produced by interactions in the detectors, which will be between one and two orders of magnitude greater, according to the particular neutrino energy, than in the first experiments at CERN in 1961. It is unnecessary to stress the practical importance of such an increase in intensity in a long-term programme of experiments ; information which previously would have taken one year of machine time becomes obtainable in a matter of weeks ●

A.G.H.

◆ ◆ ◆

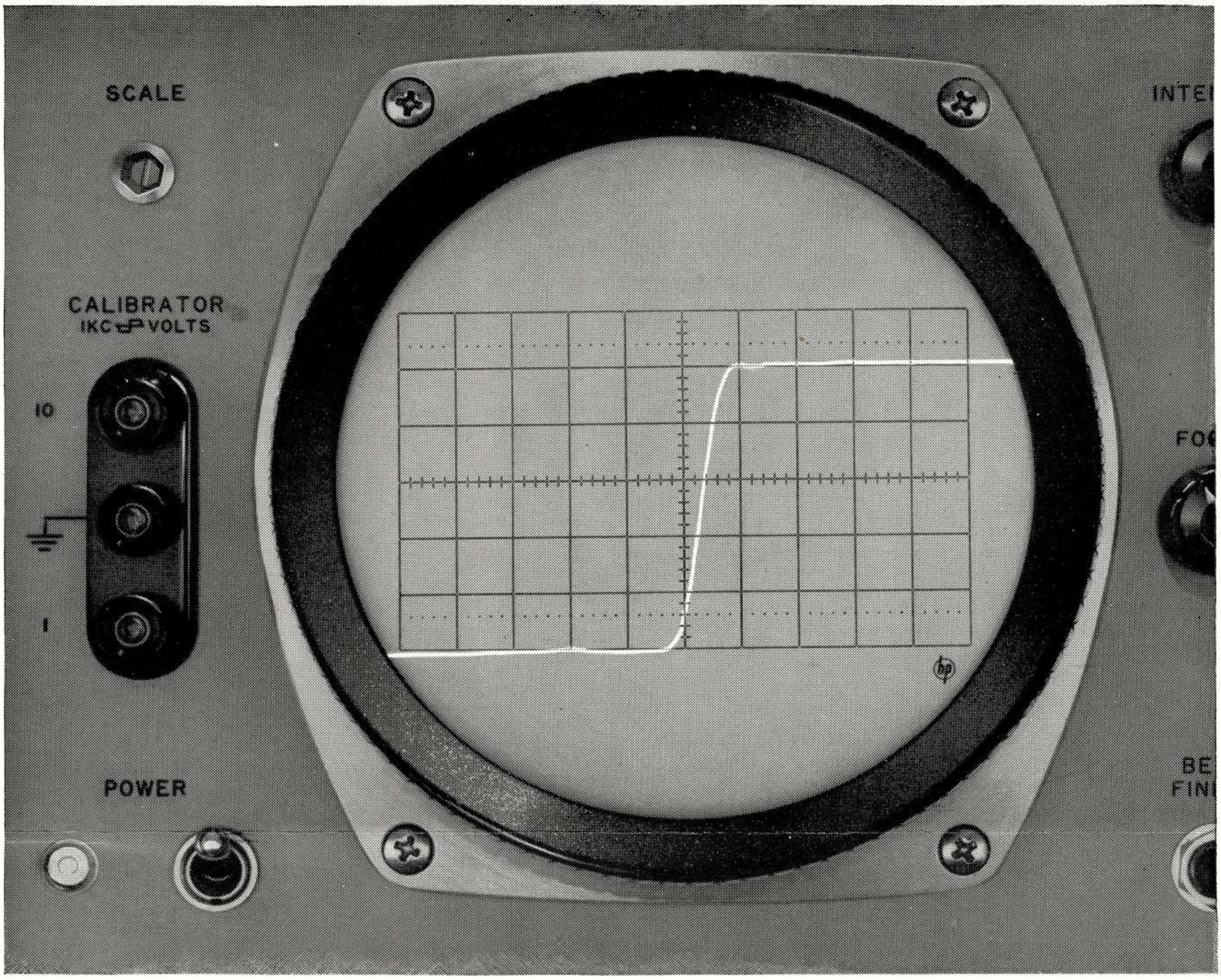
Last month at CERN (cont.)

Letters on 1 May. They concern the **relative 'parity'** of two of the particles, **the sigma and the lambda.** Parity is a concept of the wave nature of all 'elementary particles'; it is said to be 'even' (plus) if the 'wave function' calculated for the mirror image of a particle is identical to that of the particle itself, and 'odd' (minus) if one wave function has a positive value and the other an equal negative one. Parity is one of the characteristics used to specify a particular particle or particle state.

Naturally parity is involved in any theory of sub-nuclear particles, and in some cases different theories predict different values. Thus in this case, according to the 'global symmetry' model, the sigma and the lambda should have the same parity, whilst some other models predicted that one should be opposite to the other. By combining the results of several different experiments carried out at the Lawrence Radiation Laboratory, Berkeley, it seemed more likely that the former prediction was correct, but the CERN experiment is the first to prove this by direct comparison of the two particles.

The experiment was carried out as a co-operative venture between European and American physicists. About a million negative K mesons in the k_3 beam of the CERN proton synchrotron were brought to rest in the interior of the Saclay/École Polytechnique 81-cm liquid-hydrogen bubble chamber, where they reacted with protons to produce neutral sigma hyperons. Many of these decayed into a lambda hyperon and a pair of electrons (one positive, one negative), and from measurements on the tracks of the electrons it was possible to deduce that the lambda had the same parity as the sigma rather than the opposite one. The measurements and calculations on the bubble-chamber pictures were carried out at CERN, the University of Maryland and the U.S. Naval Research Laboratory, Washington, D.C. ●

hp 175A . . . No parallax 6 by 10 cm display and 7ns rise time.



Actual photo shows 175A rise time of 7 ns. Sweep time is 10 ns/cm. Note absence of overshoot and reflections. Input is 0,1 ns pulse from hp 213B Pulse Generator.

The specifications tell why the hp 175A is ideal for accurate analysis of slow and fast waveforms.

Specifications – with 1751A Fast Rise Plug-In

RISE TIME: 7ns at all sensitivities
BANDWIDTH: 50 mc at all sensitivities
SENSITIVITY: 50 mv/cm to 20 v/cm ± 3%, 9 Ranges
CALIBRATOR: 1V, 10V ± 1% at 15°C to 35°C; ± 3% at 0°C to 55°C
SWEEP TIME: 100 ns/cm to 5 sec/cm ± 3%, 24 Ranges, 10 ns/cm with magnifier ± 5%
TRIGGERING: Internal, approx. 2 mm at 1 mc, 2 cm at 50 mc; External, approx. 0.25 V at 1 mc, 0.5 V at 50 mc, Power Line
INPUT IMPEDANCE: 1 Megohm nominal, 22 pf
HORIZONTAL AMPLIFIER: DC to 500 KC, 0.1, 1 v/cm
GRATICULE: Internal, Parallax free, 6 x 10 cm linear
CATHODE RAY TUBE: hp 12 KV Post Accelerator with internal metal shield, aluminized phosphor, safety glass faceplate
PRICE: 175A, Fr. 6052.–; 1751A, Fr. 760.–; 1780A Time Unit, Fr. 122.–

Other Plug-In Units:

1750A	40 mc Dual Trace 50 mv/cm, Fr. 1343.–
1752A	18 mc 5 mv/cm, Fr. 1086.–
1754A	40 mc 50 mv/cm four channels, Fr. 2637.–
1781B	Sweep Delay Generator, Fr. 1795.–
1782A	Display Scanner for X-Y Records, Fr. 1953.–
1783A	Time Mark Generator, Fr. 632.–

Easy to maintain Main Vertical Amplifier:

TYPE: Triode, eight 6DJ8 Tubes
RISE TIME: Less than 7 ns
ADJUSTMENTS: 1 Gain, 3 Pulse Response
SIGNAL DELAY: hp Fixed cable, approx. 0.2 μs, 330 ohms, no adjustments
CIRCUIT BOARDS: Etched, epoxy glass, plated through, solderless connections

HEWLETT-PACKARD

Headquarters in USA: Palo Alto (Calif.); European Headquarters: Geneva (Switzerland); European Plants: Bedford (England), Böblingen (Germany)

For information, contact your hp distributor

INGENIEURBÜRO M. P. FREY
WANKDORFFELDSTRASSE 66, BERNE
TELEPHONE (031) 42 00 78

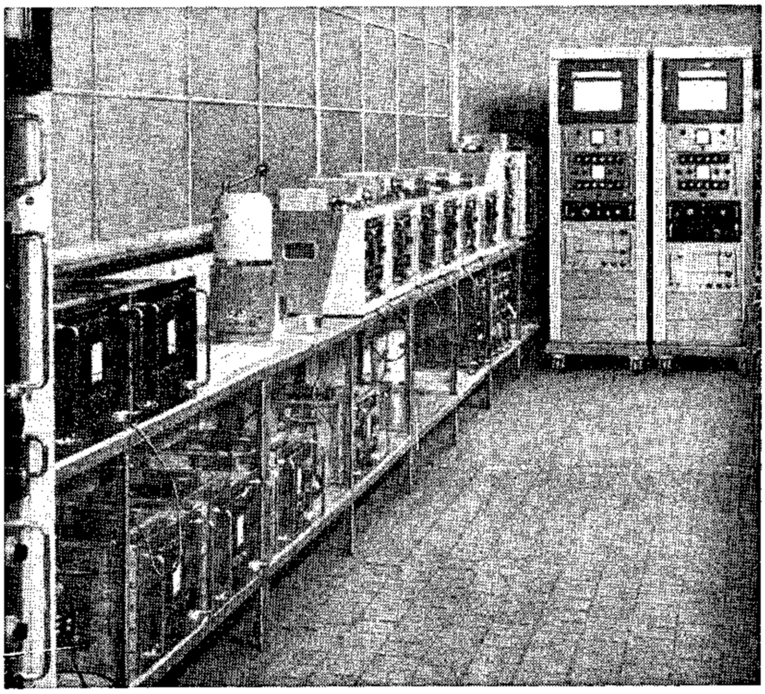
ACEC

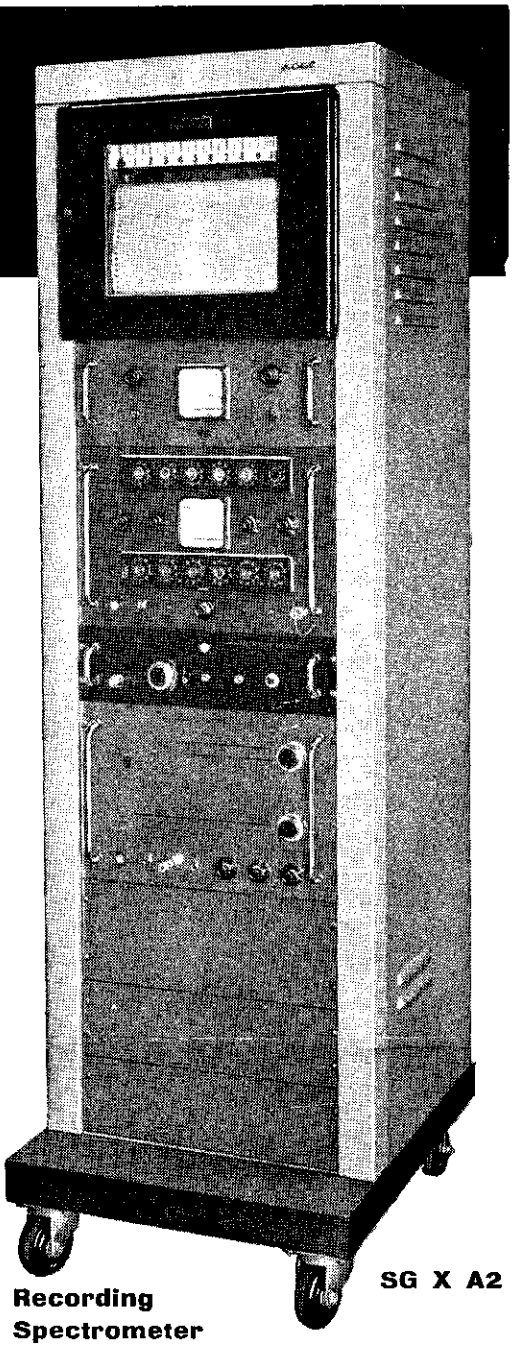
NUCLEAR EQUIPMENT

A complete range of nuclear instrumentation
from control reactor equipment

to high precision standard
laboratory instruments

200 hours testing before delivery assure
the perfect reliability of ACEC instruments





Recording
Spectrometer

SG X A2

- Input resolution time lower than 0,6 Microsecond makes possible spectrum recording at counting rate up to 100.000 counts/sec.
- Gain of 1.000.000 with PAL 300 preamplifier and ALA 100 linear amplifier pulse analyser, allows the use of semi-conductor nuclear detectors and X-ray proportional counter in the range of 1-10kV energy.
- Gain stability better than 0,1 % a day.
- Automatic scaler DM 160 for accurate quantitative analysis by counting ; high voltage supply incorporated and stabilized at ± 0,1‰
- Precision large range linear ratemeter for counting rate measurements up to 100.000 counts/sec.
- Motorized helipot potentiometers with three speeds selected by means of a gear drive accessible from the front panel.

and also :

- Automatic counting systems including a " unique universal " sample changer for ordinary and well crystals, printing timer.
- Linear, logarithmic recording gamma and X-ray spectrometer, stepwise scanning spectrometer.
- Typical instrumentation for each radioisotope application in clinical medecine.
- Explosion proof gamma density gauge and other equipment for industrial applications.
- Complete monitoring installations for reactor and radiochemical laboratories.
- Nuclear control systems for reactors.

ATELIERS DE CONSTRUCTIONS ELECTRIQUES DE CHARLEROI

Société Anonyme - CHARLEROI Tel. 36.20.20
Telex : 7.227
ACEC/Charleroi
Telegr. : VENTACEC Charleroi

ACEC
CHARLEROI

The European Organization for Nuclear Research (CERN) came into being in 1954 as a co-operative enterprise among European governments in order to regain a first-rank position in nuclear science. At present it is supported by 13 Member States, with contributions according to their national revenues : Austria (1.92 %), Belgium (3.78), Denmark (2.05), Federal Republic of Germany (22.47), France (18.34), Greece (0.60), Italy (10.65), Netherlands (3.87), Norway (1.46), Spain (3.36), Sweden (4.18), Switzerland (3.15), United Kingdom (24.17).
Contributions for 1963 total 92.5 million Swiss francs.

The character and aims of the Organization are defined in its Convention 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.'

Last month at CERN

As already recorded in the previous issue of *CERN COURIER*, May 1963 will be remembered in the history of CERN as the month in which, for the first time ever, protons with energies as high as 25 GeV were extracted as a focused beam from an accelerator. This, generally recognized to be a remarkable technical achievement, highlights the fact that scientists and engineers in Europe are once again among the leaders in the field of high-energy physics and its associated technology.

Contents

The cover photograph shows the pulsed beam-transport units which guide the external proton beam of the CERN proton synchrotron from the point where it leaves the accelerator until it interacts with a target. The proton beam, which is now the basis of the most intense neutrino beam in the world, travels inside the evacuated tube seen near Roger Gerst, who is making some adjustments to a position monitor. A description of the fast-ejection system begins on p. 79.

CERN COURIER

is published monthly in English and in French. It is distributed free of charge to CERN employees, and others interested in the construction and use of particle accelerators or in the progress of nuclear physics in general.
The text of any article may be reprinted if credit is given to CERN COURIER. Copies of most illustrations are available to editors, without charge.
Advertisements are published on the sole responsibility of the advertisers.

Published by the
European Organization for
Nuclear Research (CERN)

PUBLIC INFORMATION
Roger Anthoine

Editor :
Alec G. Hester

CERN, Geneva 23, Switzerland
Tel. 34 20 50

Printed in Switzerland

The foresight of those who planned CERN rather over ten years ago is now being confirmed.

During the first three weeks of the month, the proton synchrotron operated on a similar timetable to that of April, each night being given to physics experiments and most of each day to the final installation and testing of the fast ejection system. **The beam was ejected for the first time on Sunday 12 May.** Towards the end of the month, failure of one of the hydraulic components for the kicker magnet interrupted tests for about a week, allowing more time for nuclear physics.

Experiments were mostly those using particle counters, although a final run was made with the **École Polytechnique heavy-liquid bubble chamber** in the kaon beam (k_3) in the North hall. For much of the time, the intensity of the accelerated proton beam was deliberately kept below its maximum, to limit the induced radioactivity in the target area, but towards the end of the month values of around 6×10^{11} protons per pulse were being obtained. Unusually low energies were also demanded by the continuation of the experiment on proton-proton scattering, one run being with protons of momentum 4.9 GeV/c.

In its heavily shielded blockhouse in the path of the **neutrino** beam, the 20-ton brass and aluminium spark chamber was completed and tested with cosmic-ray particles.

During tests for some experiments on inelastic interactions of pions, using the m_3 beam in the South hall, the **Saclay/École Polytechnique 81-cm bubble chamber** was successfully operated for the first time with liquid deuterium instead of liquid hydrogen.

On 21 May a **one-day informal meeting** was held at CERN to discuss **'geometry programmes'** for the reconstruction of events in heavy-liquid bubble chambers. These programmes are the 'instructions' which are fed into a computor, together with measurements of the track positions on two or more stereoscopic photographs, in order to obtain the curvature and direction in space of each track and the positions of any interactions. At the meeting, which was organized by the Track Chambers Division, various programmes already in use at CERN and in other laboratories were described and discussed, and some suggestions were put forward for further improvements.

The last major part of the **1.5-m British national hydrogen bubble chamber** arrived at CERN on 11 May. Weighing 30 tons, and with a width of 4 metres, it consisted of the vacuum tank, with the chamber inside complete with its glass windows.

The journey was made by road from the Rutherford Laboratory, Chilton, which was left on 20 April. In order to prevent the windows, which have a thickness of 16 cm, from moving during transport it was essential that the inflatable window gaskets should be kept pressurized throughout the journey. A vessel filled with compressed nitrogen was used to supply the gaskets, and in the event of leakage this could be topped up by means of a bicycle pump. Because of the fragility of the chamber and especially of the windows, the speed of the transporter was limited to 15 km/hour.

The sea-crossing from Tilbury to Antwerp was made on 22 April, and there was then a delay of about two weeks at Antwerp, which was finally left on 6 May. Members of the British team travelled with the tank during all stages of its journey.

As soon as CERN was reached, the tank was mounted on its supporting bridge and placed in its final position in the East bubble-chamber building.

The results of an important experiment carried out at CERN on the properties of the so-called strange particles were published in *Physical Review*

Continued on p. 82