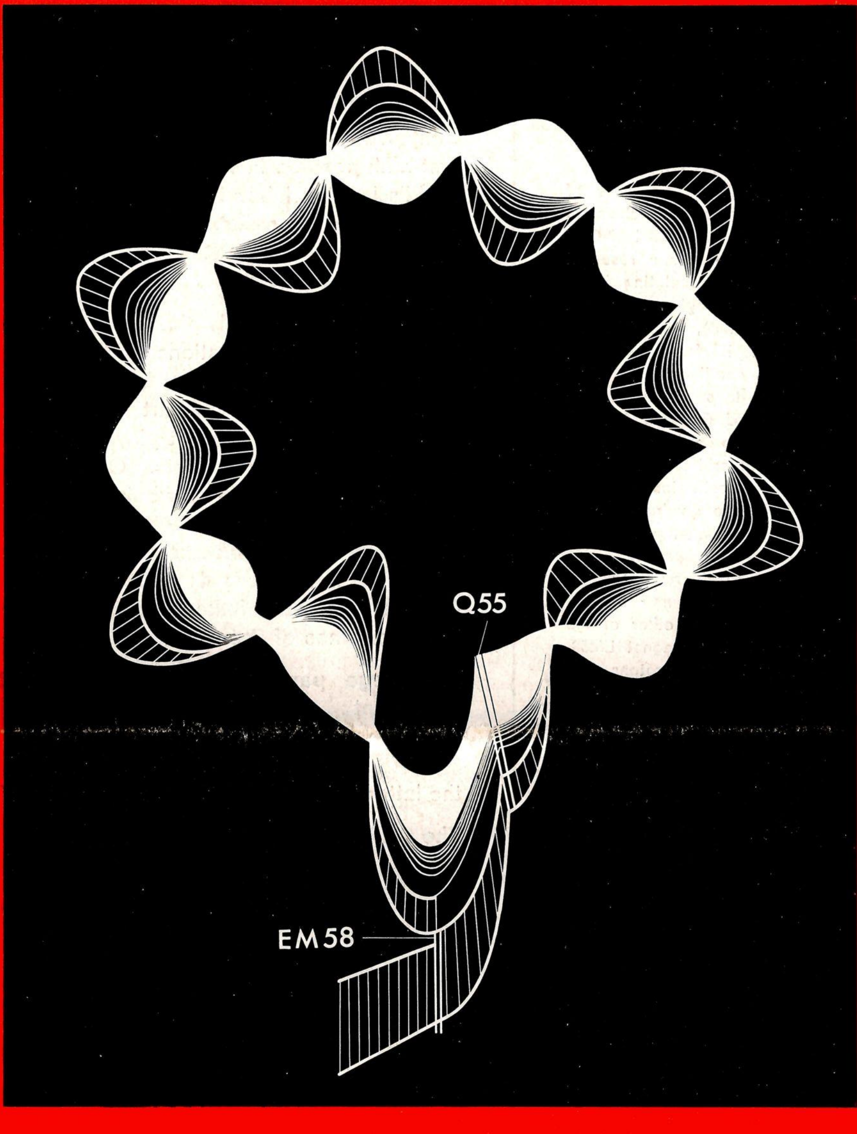
CERN COURIER



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Contents

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The cover design, a departure from our usual practice of using a photograph, shows one aspect of the important technical development that forms the main subject of this issue of CERN COURIER. It represents in a schematic way the proton orbits inside the CERN 28-GeV proton synchrotron during multiturn resonant ejection of the beam. The circulating beam (full band) is kept within a region where six sextupole lenses (not indicated), spaced around the accelerator, prevent it from becoming unstable, though betatron oscillations (with all possible phases) build up to some extent. As the mean orbit is expanded (by reducing the guiding magnet field), protons on the outer edge of the beam enter unstable orbits in which the amplitude of the betatron oscillations (exactly six per turn, produced by the quadrupole lens Q55) build up as shown. Eventually the horizontal separation between subsequent orbits becomes so large that a considerable fraction of the protons pass, in the course of one revolution, from one side to the other of the septum winding of the ejection magnet EM58. Once within the magnet, the protons are deflected completely out of the synchrotron. The 'bump' in the orbits near the ejection magnet is produced after the protons have been accelerated and allows the magnet to be fixed in position outside the (relatively large) volume required by the beam just after injection into the accelerator.

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.

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The European Organization for Nuclear Research, more commonly known as **CERN** (from the initials of the French title or 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 28 000-MeV (or 28-GeV) proton synchrotron,

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

The CERN staff totals nearly 2200 people.

In addition to the scientists on the staff, there are over 350 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 Organization, in proportion to their net national income:

Austria (1.95%)	Italy (10.78%)
Belgium (3.83%)	Netherlands (3.92%)
Denmark (2.07%)	Norway (1.47%)
Federal Republic of Germany (22.74%)	Spain (2.18%)
France (18.57%)	Sweden (4.23%)
Greece (0.60%)	Switzerland (3.19%)
	United Kingdom (24.47%)

Poland, Turkey and Yugoslavia have the status of Observer.

The budget for 1965 amounts to 128 760 000 Swiss francs (= $29 800 000), calling for contributions from Member States totalling 126 400 000 Swiss francs (= $29 300 000).

A supplementary programme, financed by twelve states, covers design work on two projects for the future of high-energy physics in Europe – intersecting storage rings for the 28-GeV accelerator at Meyrin and a possible 300-GeV accelerator that would be built elsewhere ●

Last month at CERN

CERN site crosses the frontier

Monday 13 September was another historic day in the life of CERN, marking the signing of the agreements giving the Organization an extension of its site across the Franco-Swiss border into French territory. CERN thus becomes the first international organization to have a single site implanted across an international frontier, half in one country, half in another.

Three agreements were signed on that day. In order of time, the first was the lease granting CERN the use of the land, the second an agreement between the French and Swiss Governments concerning administrative and legal questions, and finally the agreement between CERN and the Government of France, defining the legal status, on French territory, of the Organization and those who work for it.

The lease was signed at Gex by Mr. Georges Dupoizat, 'Préfet du Département de l'Ain', Mr. Raymond Rocher, 'Inspecteur principal des Impôts' of the 'Département', and Mr. Augustin Alline, representing the 'Ministre des Affaires Etrangères', and by Prof. Victor F. Weisskopf, Director-General of CERN.

The agreement between the French and Swiss Governments was signed in Geneva by Mr. Jacques Martin, for France, and Mr. Jakob Burckhardt, for Switzerland.

At CERN, a short ceremony, witnessed by a few specially invited guests, was held in the Council Chamber, with Mr. J.H. Bannier, President of the Council, presiding, supported by Sir Harry Melville, Vice-President. Mr. J. Martin signed the agreement for the French Government and Prof. V.F. Weisskopf for CERN.

This extension to the CERN site, acquired by the French Government especially for the purpose, covers an area of 39.5 hectares (97.5 acres) in the Department of the Ain, in the Communes of Prévessin and St.-Genis-Pouilly. It will bring the total area of the laboratory to just over 80 ha (nearly 200 acres). The lease is for 99 years (renewable), at a rent of 10 francs per annum.

The signature of these agreements represents a further step towards the construction of the intersecting storage rings, for which approval was given in principle by the Member States of CERN last June (see *CERN COURIER*, vol. 5, no. 7, June 1965) and for which the site was necessary.

The presence of part of the laboratory in France does not, however, change any of the provisions of the Convention for the establishment of the Organization, signed at Paris on 1st July 1953. In particular, the seat of the Organization and the registered address will continue to be Geneva, Switzerland.

PS experiments

In the last two weeks of August (34 and 35 in the PS schedule), the main experiments at the proton synchrotron were those using the two bubble chambers in the North hall. The **81-cm Saclay/Ecole Polytechnique chamber,** filled with liquid deuterium, provided 60 000 photographs of 5 GeV/c positive pions and 75 000 pictures of 3 GeV/c negative kaons. The **CERN 1.1 m³ heavy-liquid bubble chamber** was used to obtain 200 000 photographs of positive kaons. Each of these pictures shows the tracks of some 8 to 10 kaons which enter the chamber, stop, and decay into other particles, and it is planned to photograph and examine some 5 million events of this kind in a comprehensive study of the decay properties of the positive kaon.

During the same period, many of the counter groups mentioned in last month's issue of *CERN COURIER* continued to prepare their equipment or actually conduct data-taking runs. A start was made on 'tuning' the o_8 beam line, containing three 10-m electrostatic separators, which will supply particles to the CERN 2-m bubble chamber.

For six shifts during 26 to 28 August, the machine was devoted solely to a number of **emulsion exposures,** which nevertheless made full use of the beam in a rather interesting way. The main experiment, carried out in the k_5 beam normally used by the heavy-liquid bubble chamber, involved the stopping of negative kaons in an emulsion stack, in order to study the hyperfragments and sigma hyperons produced by the interaction of kaons with atomic nuclei in the emulsion. To ensure that the kaons stopped in the stack, they had to be passed through a 'degrader', to decrease their momentum, and by using a second emulsion stack for this purpose the tracks of 800-MeV/c kaons and their interactions were automatically obtained for future study. In addition, since target no. 6 serves as the origin of the m_5 beam as well as the k_5, it was possible to expose a third emulsion stack to the 3 GeV/c negative kaons of this beam.

An interesting technical point for which there was not space in the last report, is that a new, shorter, **fast ejection magnet** (EM 1) was installed by the NPA Division in the tank in straight-section 1 of the accelerator during August. This solved a problem of incompatibility that had arisen after the installation inside the tank of the first magnet of the m_4 beam line, and now enables both the fast-ejected beam, h_3, and the m_4 beam to be used at the same time. Although the equipment appeared to work well when the first tests were made in conjunction with the muon storage ring, at the beginning of September, the intensity of the external proton beam was not nearly as high as expected. This, however, was thought to be due only to slight misalignment of the magnet, or of some other piece of equipment in a beam line that stretches for some 110 metres between the accelerator and the storage ring.

During these tests, in each cycle one bunch (5 %) of the circulating protons was ejected at an energy of 12 GeV, and another 15 % was directed, at 17 GeV, by means of the rapid beam deflector on to target no. 6, for the m_5 beam in the North hall. The remainder, at 20 GeV during the 200-millisecond-long flat top, was shared between target no. 1 (40 %), for South-hall beams, and targets no. 60 (10 %) and 64 (30 %), for the East hall ●

We regret that the production of this special issue devoted to the PS external beams has meant that other items have had to be held over until the November issue.

External proton beams at the PS

by **K. H. REICH,** MPS Division

A new system for ejecting the high-energy proton beam from the accelerator has recently come into use for the East experimental area of CERN's proton synchrotron. In this article, K.H. Reich, who was responsible for co-ordinating all the many different aspects of the work involved in the realization of this addition to CERN's experimental equipment, describes first of all why external beams are desirable and then distinguishes between the two main systems used for providing then : single-turn ejection and multiturn ejection. The principles of the particular type of multiturn ejection known as resonant ejection, devised and developed at CERN and now put into operation, are then explained in some detail, followed by a description of the installation, illustrated by a diagram of the layout and photographs. Finally, indications are given of the developments to be expected at CERN both in the provision of more external beams and in the sharing of the accelerated protons between internal and external targets.

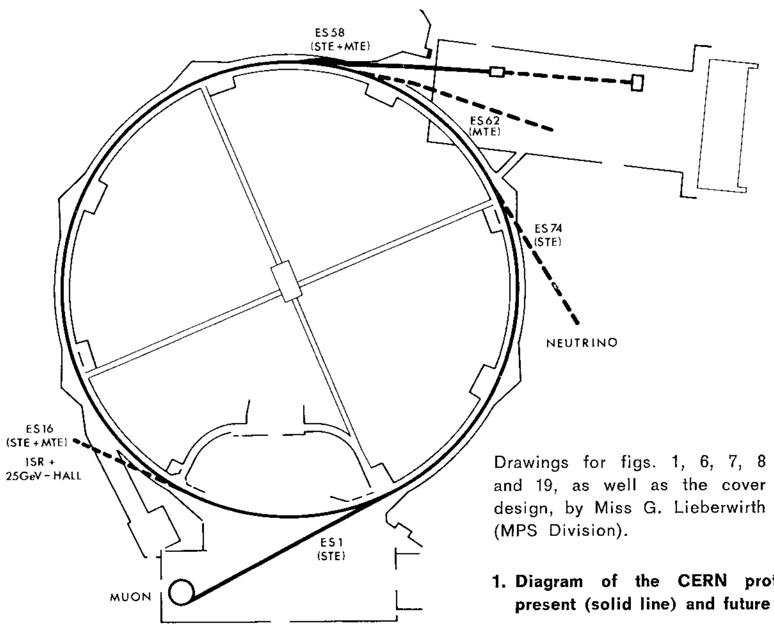
Ever since 1963* the use of external proton beams at the CERN proton synchrotron (CPS) has become increasingly popular. To provide these beams, two types of ejection system are used to expel some or all of the circulating protons from the accelerator. Both systems employ a septum type of ejection magnet (EM). The number of the straight section housing this EM is used to label the particular system. Thus, there is ejection system 1 (ES 1), which is the oldest, and ES 58, which has just been put into operation ; work is progressing on systems 62 and 74 and ES 16 is under serious study (fig. 1).

WHY EXTERNAL PROTON BEAMS ?

In view of the effort and expenditure required to provide each of these intricate and costly systems, not to mention the radiation shielding of the external beams, one obviously expects external proton beams to have important advantages when compared with the internal beam. Ideally, all the protons accelerated in the PS are eventually steered on to a target (which may in some cases take the form of the liquid in a bubble chamber). The comparison of beams can, therefore, be stated as follows : in what respect are external targets more advantageous than internal ones ?** The answer is a complex one which must take into account several seemingly unrelated aspects of the whole problem.

** For a discussion of internal targets, see CERN COURIER no. 9 (April 1960), pp. 8-9 ; all the developments mentioned there hav since been put into effect.

* See CERN COURIER, vol. 3, nos. 4-9 (April-September 1963).



Drawings for figs. 1, 6, 7, 8 and 19, as well as the cover design, by Miss G. Lieberwirth (MPS Division).

1. Diagram of the CERN proton synchrotron showing the present (solid line) and future (dotted line) ejection systems.

External targets

Firstly, an external target itself may be conceived almost without any restrictions as to location, size and material, other than those given by its intended use. This means that it can be placed at a convenient distance and angle with respect to a 'stationary' experimental set-up such as the large bubble chambers, the muon storage ring, or a heavy counter telescope, giving a new degree of freedom which may even decide whether an experiment is feasible or not. Then there is no machine vacuum to be preserved, so that the admissible target materials include gases and liquids, such as liquid hydrogen and deuterium. External targets can be aligned, exchanged and manipulated more easily than internal ones.

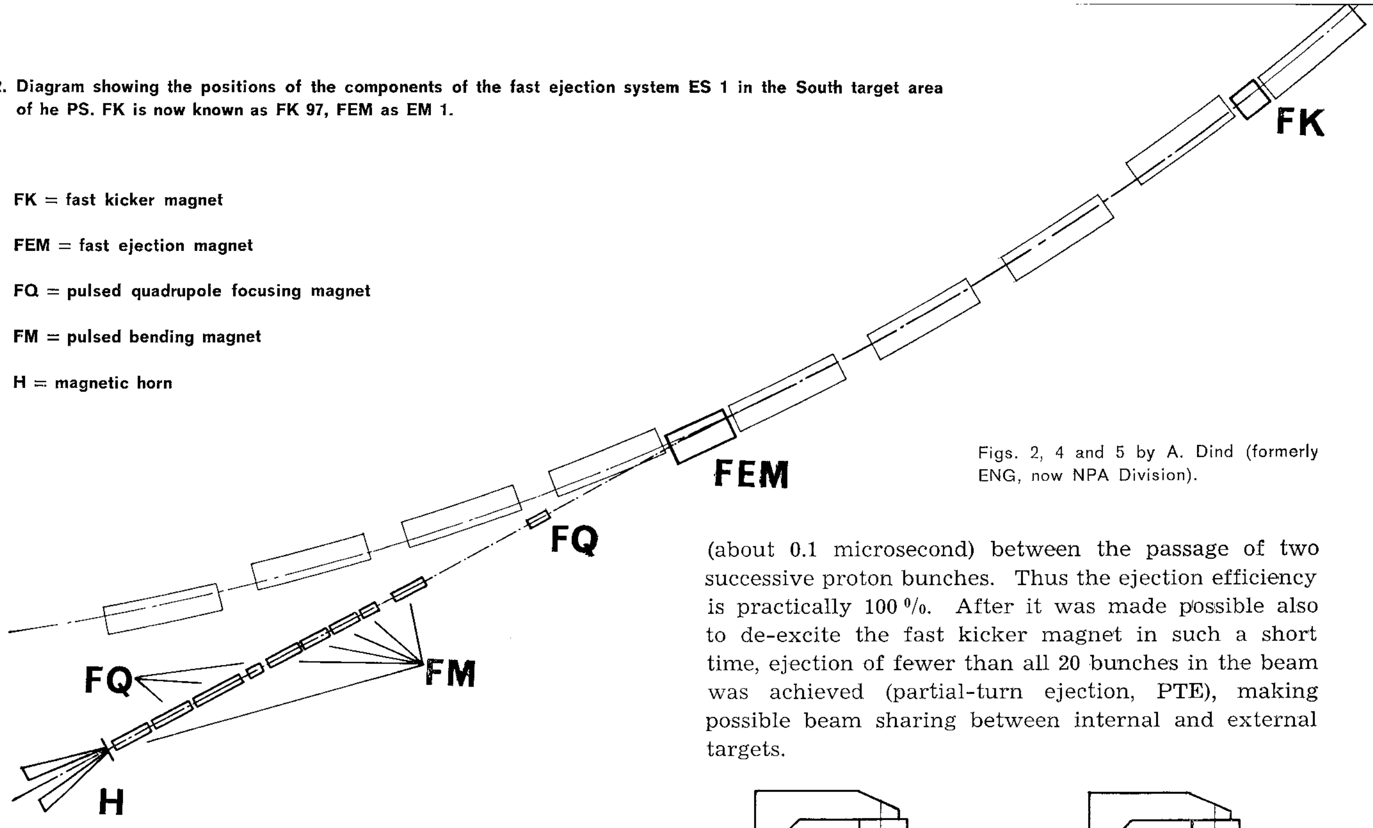
There is no need to worry about what happens to the circulating beam, and so the external target may be used in conjunction with electrical or magnetic fields, or both, of any characteristics. Such fields can be used either to act on the target nuclei, as in the polarized-proton target, or to influence the trajectories of the secondary particles produced, as in the case of the magnetic horn.

As a consequence of the absence of the PS magnetic field, positive, negative and neutral particles, at all energies, may be obtained from an external target with the same amount of effort. With no accelerator magnet unit in the way, the first lens of the secondary beam line can be closer, thereby capturing more secondary particles.

Again, because the primary beam before the target is freely accessible, it can be tailor-made for the use intended. In particular, the beam diameter and angular divergence may be chosen and adjusted at will, and the beam current hitting the target can be measured with precision.

Finally, in view of the high efficiency of modern ejection systems, the radioactivity induced in the

2. Diagram showing the positions of the components of the fast ejection system ES 1 in the South target area of he PS. FK is now known as FK 97, FEM as EM 1.



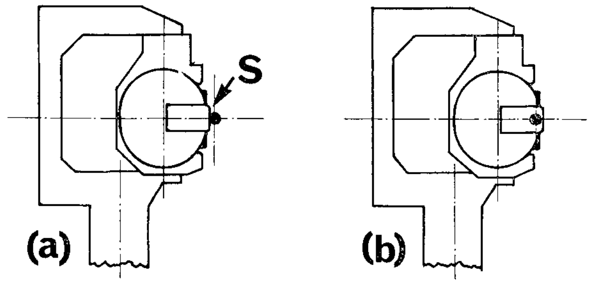
Figs. 2, 4 and 5 by A. Dind (formerly ENG, now NPA Division).

accelerator should eventually be an order of magnitude less than when working with an internal target.

On the other hand, internal multitraversal targets (through which a proton may pass many times before interacting) are said to be often more efficient in producing secondary particles and preferable as a (small) source of separated beams. Also, simultaneous use of several beams originating from the same internal target has long been an attractive feature. While the advantages of external targets seem considerable, there is, as yet, too little experience to forecast to what extent they will eventually replace internal ones. It is likely, however, that the trend will be for them to do so increasingly, particularly if the intensity of the CPS is increased by a factor like five.

SINGLE-TURN EJECTION

The first ejection system for the CPS (built by NPA Division) ejects the entire circulating beam during a single turn. Because of its short duration of 2.1 microseconds, this single-turn ejection (STE) is also called fast ejection. The system consists essentially of two special magnets inside the PS vacuum system, together with pulsed beam-transport elements (fig. 2)*. A fast kicker magnet (FK 97) (fig. 3) is rapidly brought into position round the beam at the end of the acceleration phase of the PS cycle and pulsed electrically so as to deflect the beam into a second magnet (fig. 4), the fast ejection magnet (FEM), which deflects it further clear of the ring vacuum tube and main magnetic field and along a separate evacuated tube into the external beam line. This arrangement enables the kicker magnet to be switched on in a time shorter than the interval (about 0.1 microsecond) between the passage of two successive proton bunches. Thus the ejection efficiency is practically 100 %. After it was made possible also to de-excite the fast kicker magnet in such a short time, ejection of fewer than all 20 bunches in the beam was achieved (partial-turn ejection, PTE), making possible beam sharing between internal and external targets.



4. Schematic diagram of the way in which a septum magnet is used. At (a), the beam passes just outside the septum S where the effect of the magnet is almost nil, at (b) the beam has been deflected by the kicker magnet so that it passes inside the septum, comes under the full influence of the magnetic field, and is ejected from the accelerator.

There are three main reasons for wanting the ejection to be so fast, two fundamental ones and one technological. The fundamental reasons are, firstly, the desire to reduce the background from cosmic rays during the beam burst and, secondly, to separate in

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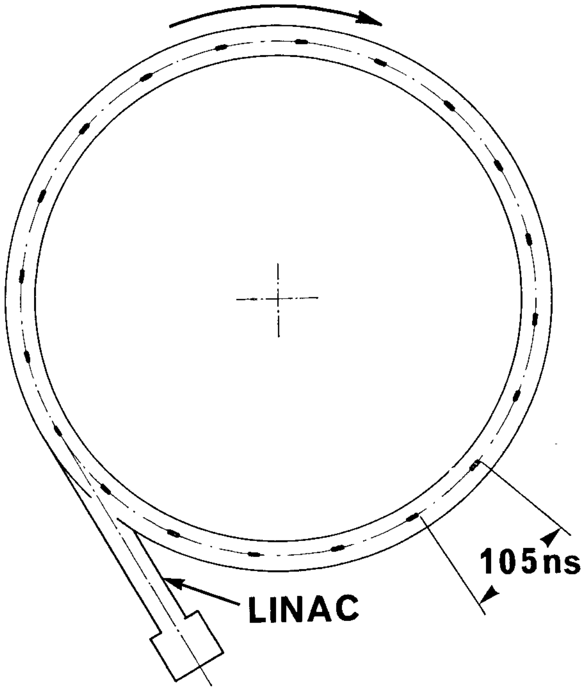
3. The kicker magnet FK 97 installed in its vacuum tank in straight-section 97 of the synchrotron. The tank cover is off and the magnet can be seen in its withdrawn position out of the beam path.

* Figs. 2, 3, 4 and 5 are taken from CERN COURIER, vol. 3, pp. 79-81 (June 1963), figs. 3, 4, 2 and 1 respectively.



5. Diagram indicating the circulation of the 20 discrete bunches of protons that constitute one pulse of the accelerator. Each bunch takes about 6 thousand-millionths of a second to pass a given point and the spacing between bunches is about 105 thousand-millionths of a second.

time the arrival of the burst and its effect. As cosmic rays are 'uniformly' spread in time, shortening of the CPS burst (keeping the same number of protons) reduces the number of rays arriving during the burst and hence their effect on the data ; the separation in time is required in experiments like that using the muon storage ring. The technological reason is that certain very highly powered supplementary pieces of apparatus, such as the magnetic horn, radiofrequency separators, and the very high-field magnets used with nuclear emulsions, can only be energized for very short periods of time. Not surprisingly, the first application of the fast ejection was in a field where almost all of the new possibilities could be used simultaneously : neutrino physics. Much higher neutrino and antineutrino fluxes could be provided by means of the magnetic horn, and the background from cosmic rays could be considerably reduced. Subsequent applications include nuclear emulsion work and the muon storage ring.

MULTITURN EJECTION

While very important for the experiments just enumerated, single-turn ejection is only exceptionally used for work with electronic counters and spark chambers, as in the neutrino experiment ; normally bursts about 100 000 times longer are desirable. The method of obtaining such bursts is multiturn ejection (MTE), a gradual peeling-off of the circulating beam over many revolutions.

In contrast to the conceptually simple STE (which, however, presents formidable technological problems), MTE is a much more tricky business. This can be seen intuitively from the following consideration : at the energies at which it is normally used, the internal beam has a diameter of about 1 cm ; if it is to be ejected over a period corresponding to 100 000 revolutions, then the individual 'layers' are some ten thousandth of a millimetre thick. In other words, at a certain stage a proton finds itself at a given radial position and begins to be ejected while its neighbour, which is a thousandth of a razor blade's thickness further to the inside, must be made to stay a little longer inside the CPS !

An early scheme to perform this feat, which has been and still is used at other proton synchrotrons, involves the use of a suitable internal target. A proton hitting this target loses so much energy that its new orbit is sufficiently separated from the old one to enable the thin winding of an ejection magnet to be placed in between the two.

While an individual proton is thus ejected rather quickly, the long burst comes about by steering the internal beam path very slowly into the target. This scheme was undoubtedly a large step forward when it was first used a decade ago ; to-day it is less attractive, mainly because the use of the internal target entails drawbacks such as beam loss, through nuclear interactions and scattering, and beam blow-up, through multiple scattering and increased energy spread. As a consequence of these defects the ejection efficiency is usually only about 30-50 %, and the beam diameter (strictly speaking, the beam emittance) as well as the energy spread of the external proton beam are larger than that of the internal beam.

EXPLANATIONS OF THE ABBREVIATIONS

EM — **Ejection magnet** (bending magnet) (EM 1, EM 58 etc.).

ES — **Ejection system;** labelled according to straight section housing EM (ES 1, ES 58 etc.).

FE — **Fast ejection.** Another name for STE or PTE.

FK — **Fast kicker** magnet (FK 66, FK 97 etc.).

MTE — **Multiturn ejection :** the beam is gradually ejected during a large number of turns (500-100 000). With the resonant ejection used at the CPS the burst can be long (slow ejection) or short (quick ejection).

PTE — **Partial-turn ejection :** basically the same as STE, but the FK is energized for a time shorter than a full CPS beam revolution period, causing the ejection of a preselected number of bunches.

QE — **Quick ejection :** short-burst (∼1 ms) mode of operation of the resonant (MT) ejection.

RBC — **Radial bump coils,** used for deforming the equilibrium orbit of the internal beam.

RE — **Resonant ejection :** MTE used at the CPS in which a controlled resonance is set up between the revolution of the protons along their orbit in the ring vacuum chamber and the betatron oscillations about this orbit.

SE — **Slow ejection :** long-burst (∼200 ms) mode of operation of the resonant (MT) ejection.

STE — **Single-turn ejection :** the entire beam is ejected during a single turn by means of an FK and an EM.

Resonant ejection

The modern method, used for the first time in a proton synchrotron at CERN*, is known as resonant ejection. Under normal operating conditions, if a proton is slightly deflected from its path because of, say, the existence of a stray magnetic field in a straight section, it 'oscillates' about its former orbit. However, because of the design of the magnetic field, the proton never comes back to exactly the same place after each complete revolution and so these betatron oscillations, as they are called, never build up to any great amplitude. This feature of the magnetic field is, of course, extremely important for the operation of the synchrotron, and for this reason a number of quadrupole and sextupole magnetic 'lenses' were included in the original construction so that the field could be corrected if necessary. In fact they were not needed, but these same lenses now form the basis of the resonant ejection system.

The system works by setting up a resonance, in a controlled way, between the revolution of the protons along their orbit in the ring vacuum chamber and the betatron oscillations about this orbit. From a number of possibilities (integer, half integer, one third) the integer resonance was chosen for the multiturn ejection at the CPS because it could most easily be achieved with the existing lenses. This means that the number of radial betatron oscillations per revolution, instead of being near 6.25 for all orbits inside the CPS vacuum chamber, is made to decrease as the orbit radius gets bigger, passing through the value 6.0 for the orbit running (very roughly) along the middle of the chamber. For this, one quadrupole and a number of sextupole lenses are used. Each time it passes through the quadrupole lens a resonant proton (see below) experiences, on successive turns, an increasing deflection to the outside, producing a growth in the amplitude of the betatron oscillations (see cover design). After 50-100 revolutions the amplitude growth per turn has reached about 20 mm under typical operating conditions.

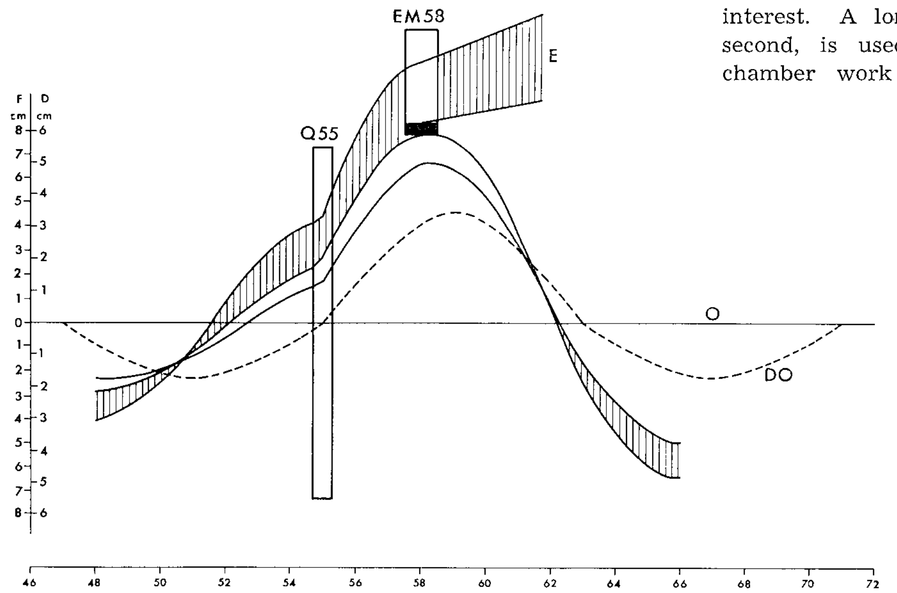
In the CPS, about a thousand million protons are building up such oscillations more or less simultaneously. Thus, at a given instant, some protons are found at practically all radii greater than the 'unstable' radius. This means that an ejection magnet of the septum type, placed at practically any radius, will necessarily cause the loss of some protons (those which fall on to the septum). However, it is reasonable to expect that with successive turns separated by, say, 20 mm and a septum thickness of a few millimeters a high proportion (like 70 %) of the protons will enter the opening of the EM and be ejected. This emphasizes, however, the need to keep the septum as thin as possible.

Besides giving a boost to the oscillations once they have started to build up, the sextupoles have the task of keeping the remaining protons out of resonance while they are awaiting their turn. In other words, referred to the position of the quadrupole, the sextupole action reinforces the quadrupole action at radii larger than the 'unstable' one and diminishes it at smaller radii. Thus the entire circulating beam can be kept in the CPS even with the lenses fully energized, so long as it is positioned at a radius sufficiently far to the inside of the 'unstable' radius.

This then is the sequence of events for achieving resonant ejection. The magnet cycle is chosen such that the protons in the ring reach the desired energy at the onset of the 'flat top'. The radiofrequency accelerating field is then switched off and the protons continue to circulate as a beam, 5 to 10 mm wide, under the influence of the guide field of the main magnet. At this stage the quadrupole and sextupole currents have also reached their correct values and the 'unstable' orbit is somewhat larger than that on which the beam is circulating. The guide field is than steadily reduced, causing the average proton orbit to expand ; when the orbit reaches the 'unstable' radius, growth of the oscillation amplitude starts (see fig. 6). By then the EM has been energized and deflects the protons that enter it out of the CPS and into the external beam line.

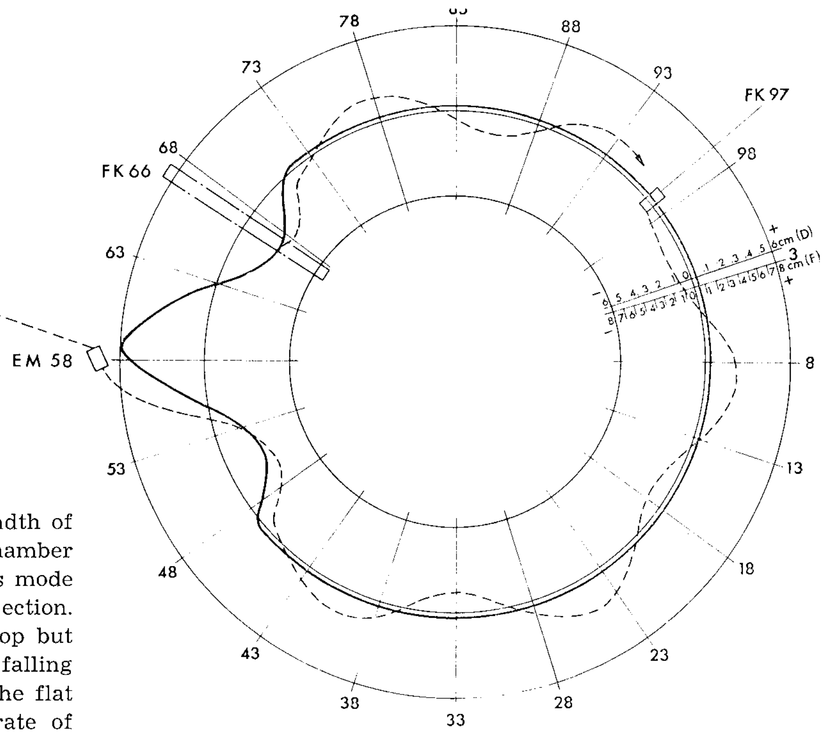
The burst duration thus depends on the rate of change of the synchrotron guide field, which directly controls the 'spill-out' rate. Two burst durations are of practical interest. A long burst, lasting about a fifth of a second, is used for electronic-counter and spark-chamber work ; this is also referred to as slow

* See CERN COURIER, vol. 3, pp. 110-111 (September 1963).



6. Schematic representation of the beam behaviour, on either side of the ejection magnet, during slow ejection from straight-section 58. The numbers on the lower scale are those of the straight sections between synchrotron magnet units ; the side scale shows distance horizontally from the mean orbit in the centre of a focusing section (F) or defocusing section (6-cm D displacement corresponding to 8-cm F displacement). O represents the undeformed orbit, DO the same orbit deformed by the action of the bump coils, E (shaded) the envelope of orbits followed by protons on their last turn before entering the ejection magnet (deflection by the EM is not shown). The septum of the ejection magnet is indicated in black.

7. Schematic representation of fast ejection using EM 58 and either FK 97 or FK 66. As in fig. 6, numbers round the circle represent straight sections whilst the displacement from the undisturbed orbit is given by the radial scales. The solid line shows the orbit disturbed by the bump coils but with the kicker switched off ; the dotted lines show the effect of energizing either of the kicker magnets.



ejection. A short burst, lasting about a thousandth of a second, is used (for example) for bubble chamber work other than with r.f.-separated beams ; this mode of operation goes also under the name of quick ejection. The short burst is obtained not with the flat top but by using a high rate of field change during the falling part of the magnet cycle. For the long burst the flat top must be inclined very slightly only, the rate of change being in fact only a small fraction of a per cent. of that normally used during rise and fall of the magnetic field. This presents a difficult technical problem because the ripple on the magnet power supply, intrinsically largest on the flat top, produces instantaneous rates of change many times larger. At the CPS this basic problem was solved by adding an electronic filter to the supply. Furthermore, the instantaneous rate of beam spill-out is controlled by means of a feedback system which moves the beam automatically further to the outside in the CPS quadrupole when the spill rate decreases, and vice versa, thereby accelerating or delaying the spill-out process. The result is a fairly good rectangular-shaped burst, as ideally wanted by the experimenters.

THE NEW EAST-AREA SYSTEM

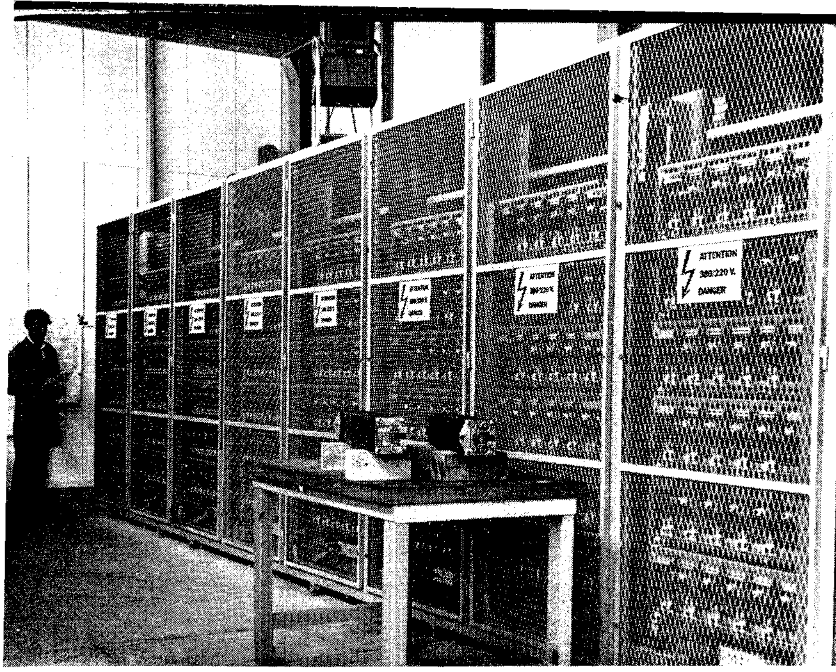
The detailed working of the resonant-ejection method was studied experimentally in 1963 after a long-pulse EM had been installed in straight-section 1 of the CPS. Its behaviour was essentially as expected from theory ; in particular it could be shown that the quality of the external proton beam was not much different from that of the internal beam and that the ejection efficiency was as high as calculated.

Unfortunately, the use for physics of this experimental beam turned out to be far from easy because of the closeness of the fast-ejected beam and secondary beams from target 1. For the new East-area ejection (designed and built by MPS Division) it was therefore decided to separate more widely in space the slow-ejected proton beam, the fast-ejected beam, and the secondary beams from internal targets. Besides the studies of possible ejection trajectories, the early work was aimed at finding out how far the septum for a long-burst EM with a high useful field (20 kilogauss) could be thinned down and to what extent the stray field could be reduced. After theoretical and experimental results had shown the feasibility of a satisfactory EM up to these field levels, the following solution was adopted : slow ejection (long-burst resonant ejection) from s.s. 62, secondary beams from s.s. 61, and fast and quick ejection from s.s. 58. While awaiting the completion of ES 62, ES 58 is also used to produce long bursts for electronic-counter and spark-chamber work. The new ES 58 is shown on the inside picture pages (153-156), and some of the highlights are discussed in the following paragraphs.

Ejection magnet

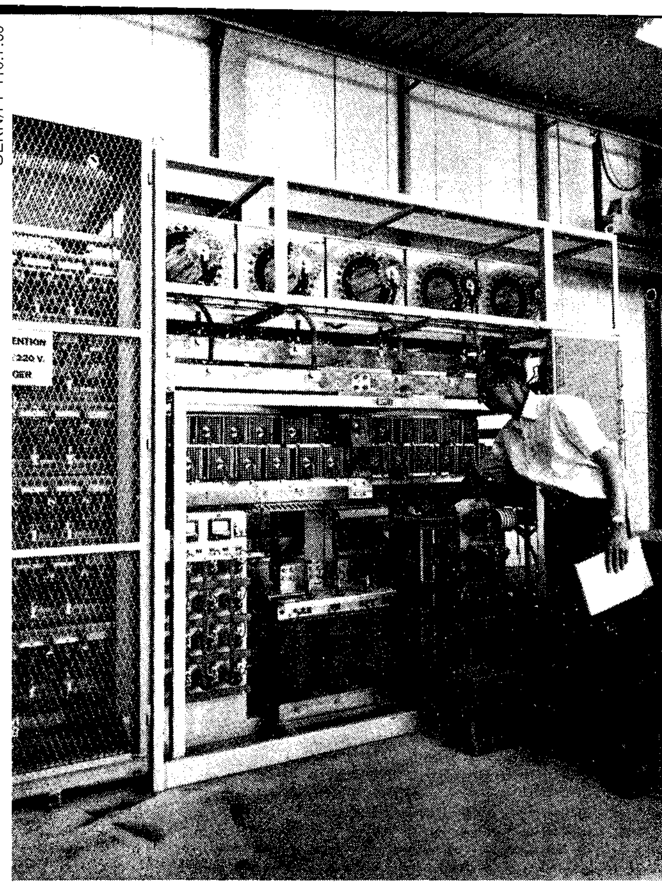
Unless one rearranged the positions of the long and short straight sections — an enterprise of non-negligible scope which might adversely effect the CPS performance —, this scheme necessitated ejection from a short straight section. It was also decided to use, if at all possible, a stationary EM, placed outside the space occupied by the beam orbits during injection and acceleration. A stationary magnet increases the beam-sharing possibilities and reduces the maintenance, since no moving parts can wear out. As the beam displacement by means of the FK could not be increased markedly, this meant deforming the equilibrium orbit locally to bring the circulating beam close enough to the septum of the EM before switching on the FK. This orbit deformation is achieved by means of 4 pairs of special windings (radial bump coils, RBC), placed on the yokes of 8 CPS magnet units. The maximum amplitude of the deformation obtained after installation of enlarged vacuum chambers is about 8 cm. For MTE about half this amplitude is used (fig. 6), and for STE 7 to 8 cm (fig. 7).

After it had been shown, contrary to some early apprehensions, that the beam survives this brute-force treatment, studies were concentrated on the problem of how exactly to get the beam out through the fringing magnetic field of the accelerator without worsening its properties. Contrary to the useful field in which the ring vacuum chamber is placed, the fringing field is not linear and it can therefore distort rather badly a particle beam passing through it. Such distortion leads to an increased spot size on the target, adversely affecting the usefulness of an external proton beam. One way to deal with this problem is to eject at such a large angle that the fringing field is traversed through a comparatively short length only and the most dangerous parts



CERN/PI 116.7.65

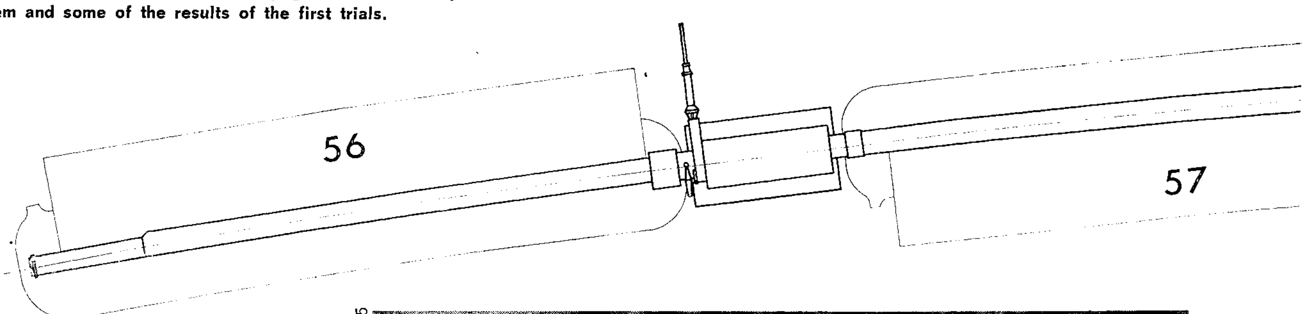
9. Power supply for septum magnet.
Supply : 60 V, 16 000 A pulsed, Pulse rise time : 30 ms,
Current ripple : $<$ 0.2 % (with filter), Load : 3.3 mohm, 40 μH.



CERN/PI 114.7.65

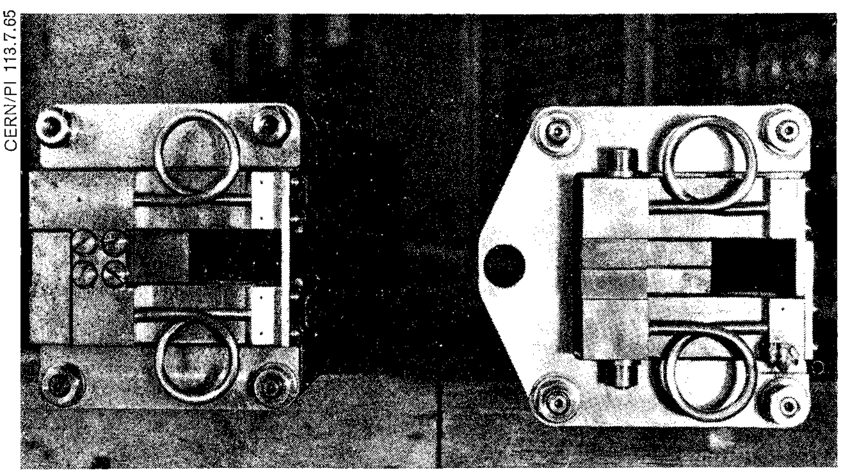
10. Electronic filter for septum-magnet power supply.

8. Simplified diagram of part of the synchrotron ring, showing the layout of ejection system 58 and the external proton beam line. The other photographs and diagrams on these pages show various parts of the system and some of the results of the first trials.



CERN/PI 64.6.64

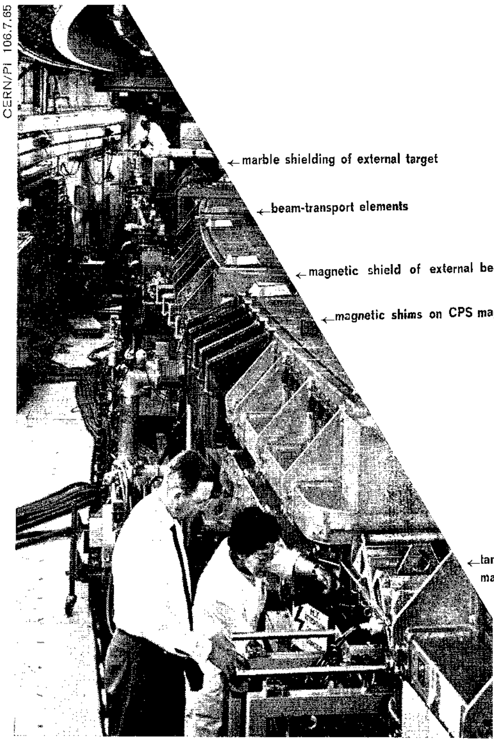
16. Lamination and septum winding for ejection magnet. The septum has been cut to show the cooling-water channels.



CERN/PI 113.7.65

17. The two sections of the ejection magnet (designed for thin septum and high fields).

	1st section (left)	2nd section (right)
Main magnetic field (kG) :	10	20
Mean stray field outside septum (G) :	6	50
Yoke length (mm) :	700	520
Air gap (mm) :	19 x 39	19 x 30
Septum thickness (mm) :	3	6.1
Pulse length at full current (ms) :	200	
Duty cycle :	1 : 10	



11. General view of external proton beam line from s.s. 58.

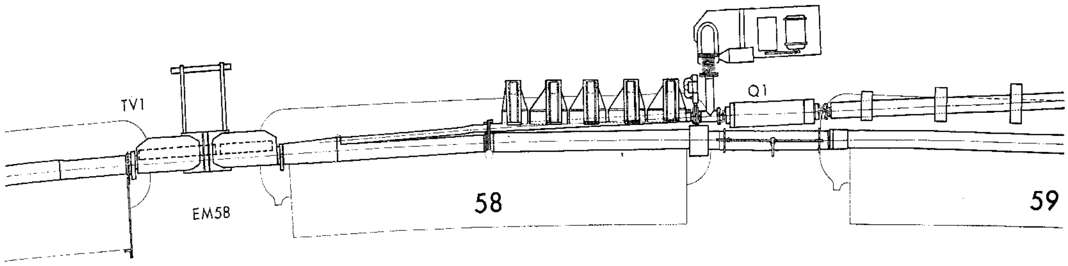
12. Shimming and shielding of CPS magnet.

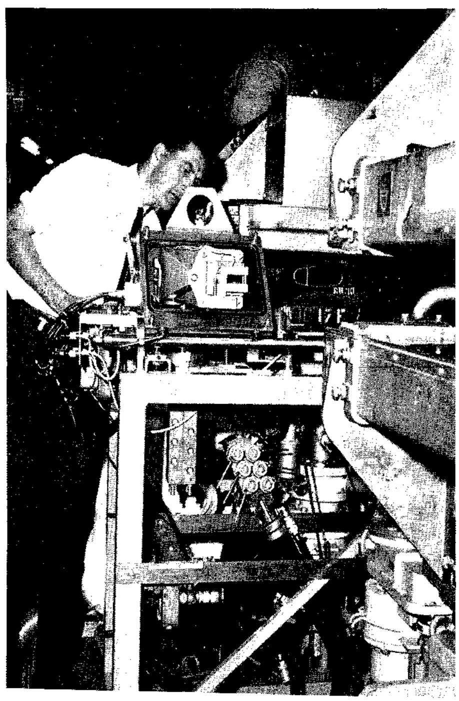
Right : 2 of the 5 shim supports (4 shims with hyperbolic pole pieces, including 2 with additional neutral pole, 1 shim with parallel poles).

Centre : arrangement in magnet 59 :

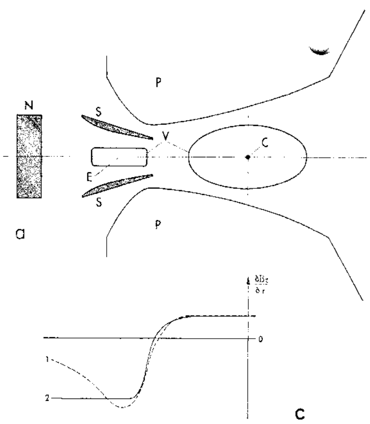
First part : bending section (aluminium spacers between parallel poles),

Second part : shielding section.





18. Ejection magnet installed in s.s. 58. 10 kG and 20 kG septum magnets mounted in series inside quick-disconnect vacuum tank ('Out' position, front part of tank removed).



19. One type of shimming of CPS magnet (the other type us

a) Principle : the two pieces marked S and the neutral

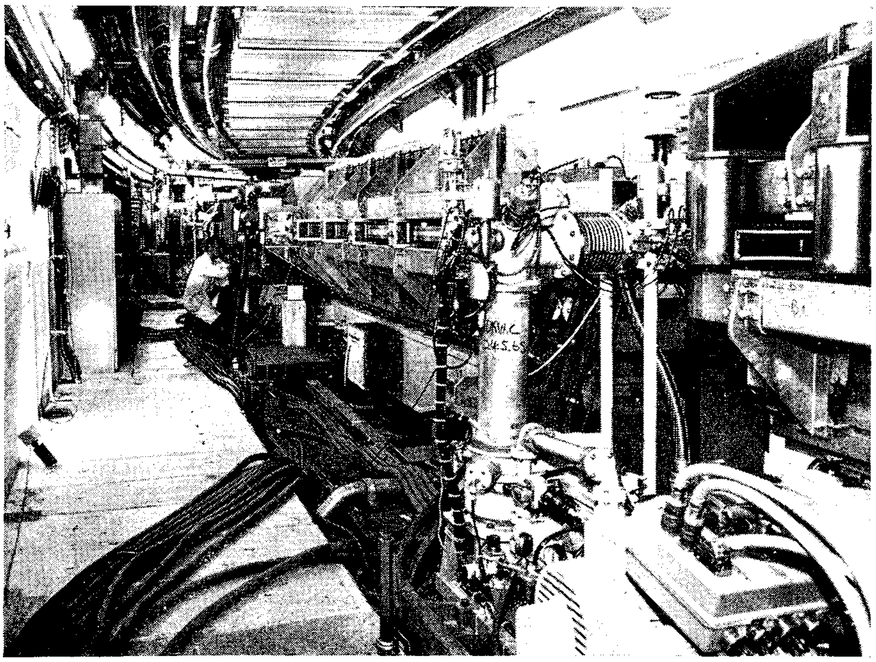
C = circulating beam, E = ejected beam, V = vacuum

b) Photograph of shim mounted on 101st magnet unit for

c) Result : in the region through which the beam passes,

remains constant (curve 2).

CERN/PI 103.7.65



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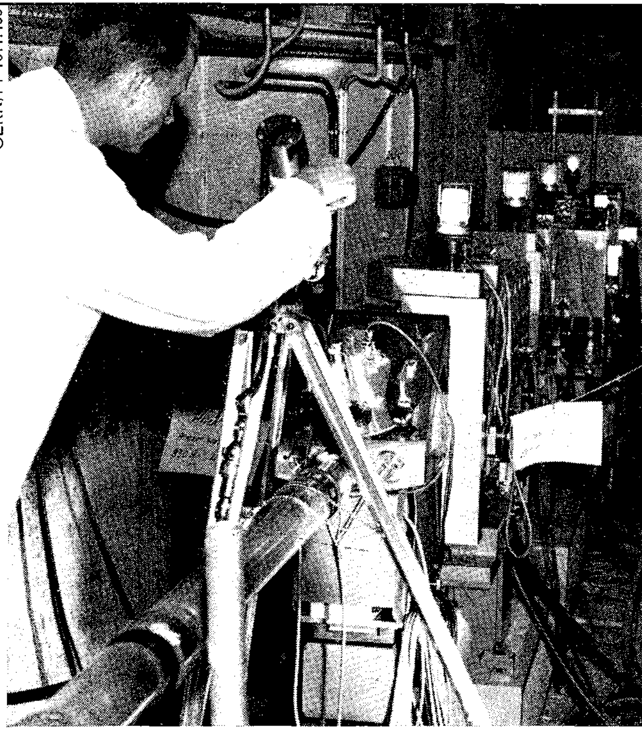
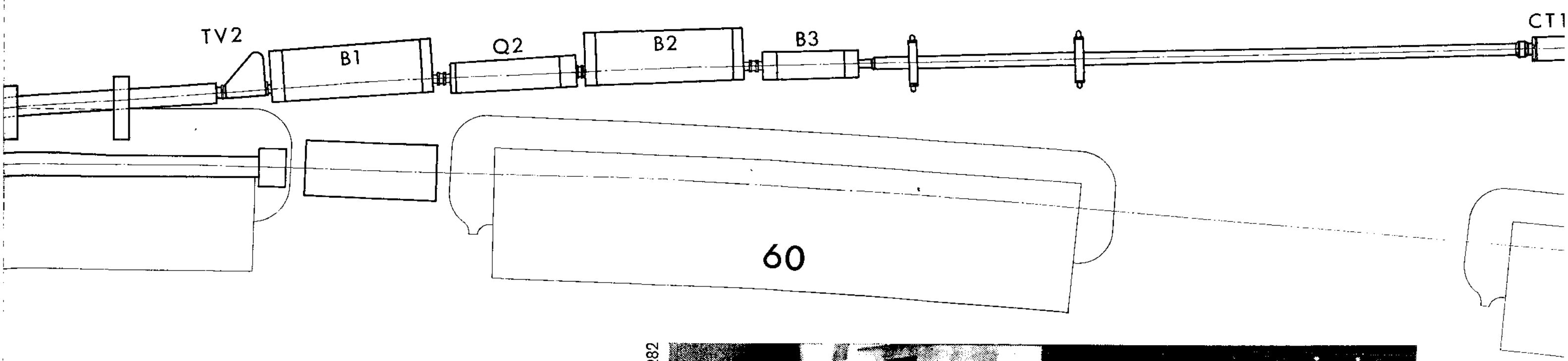
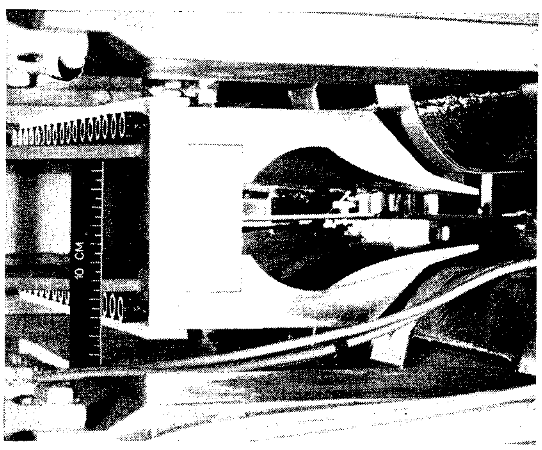


13. Partial view of external proton beam line, looking towards target.
Foreground : TV camera (TV3) and box housing up to 12 screens changed by remote control,
Centre : slim d.c. lenses (Q3 and Q4) and bending magnets (B4 and B5),
Background : marble shielding of external target.



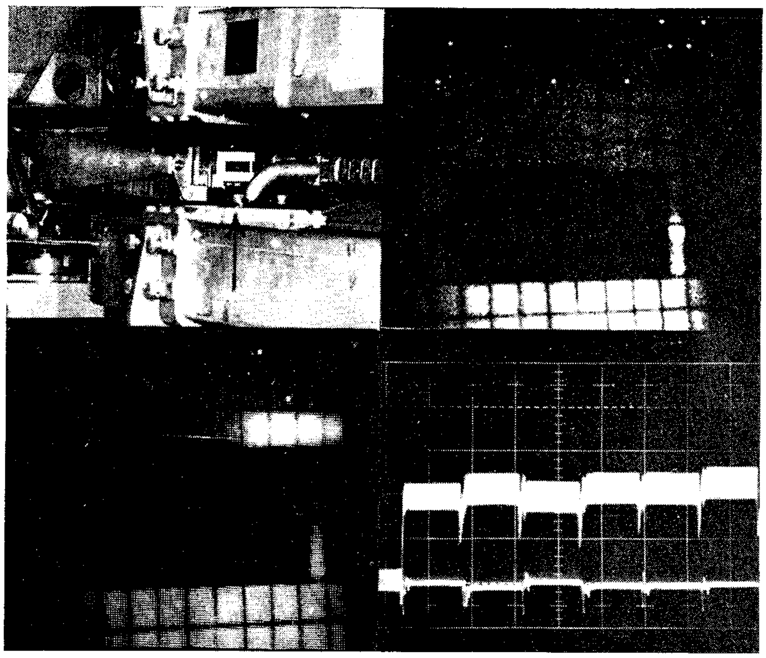


CERN/PI 187.1.65

b

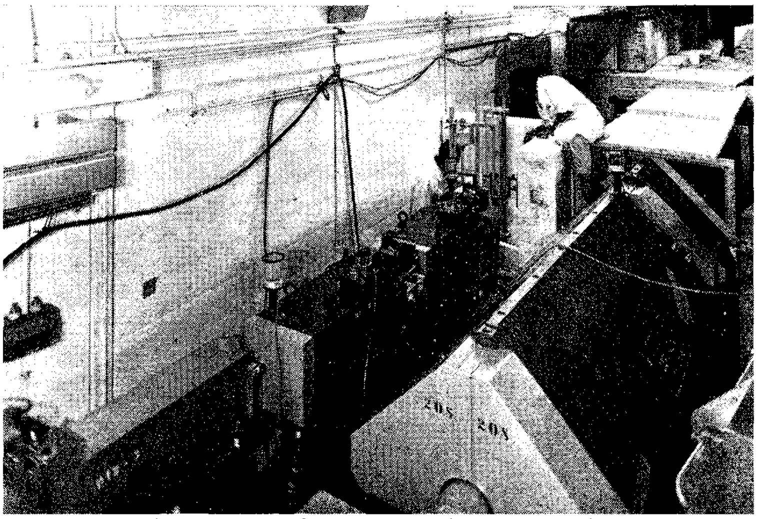
parallel pole pieces).
e N create a quadrupole field (P = pole pieces of magnet,
ıambers).
ɘasurements.
ɘ gradient no longer varies (curve 1, without shimming) but

CERN/SIS 24282



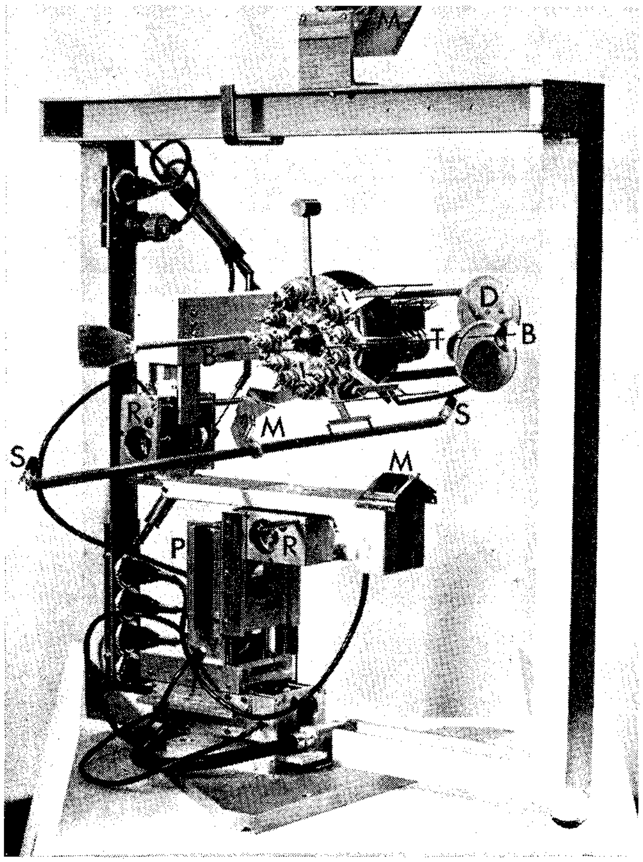
20. Slow internal-beam spill.
Upper left : TV screen no. 1 in front of ejection magnet ; aperture lined up with magnet aperture,
Lower left : internal beam shifted vertically by means of CPS dipoles to show full beam width,
Upper right : characteristic TV beam-spot image with spill in progress (5-mm gridon screen),
Lower right : horizontal beam profile as seen by selected solid-state diodes at exit of ejection magnet.

CERN/PI 105.7.65

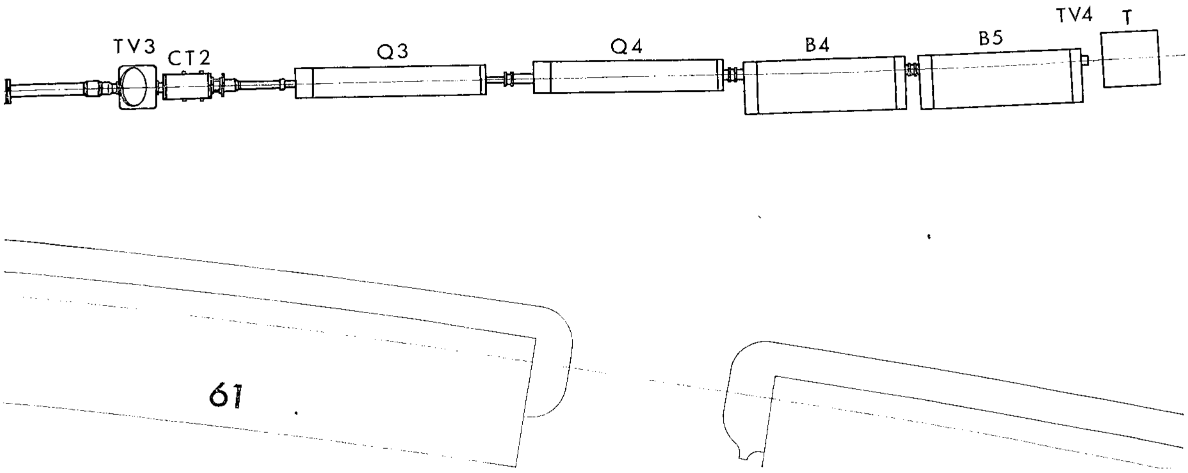


14. Partial view of external proton beam line, seen from top of synchrotron magnet.
From left to right : slim d.c. lens (Q4), 2 C-type d.c. bending magnets (B4 and B5), 2 exchangers for nuclear emulsions used during measurements, marble radiation shielding of external target,
In right foreground : standard beam-transport lens, for secondary beam o_8.

Photo : B. Sagnell (MPS Division)



15. View of the complex target mechanism, mounted in its support frame. The beam enters from the right and traverses the target head T along the line BB, as indicated. The head in use, two spares, and various luminescent screens, S can be seen mounted on the disk which can be rotated by remote control in order to bring the required one into position. Observation of the screens, either for target alignment or for beam alignment and focusing is made by means of mirrors, M, and a TV camera. On the beam-entry side, the diaphragm D (shown here fully open) can be adjusted by remote control so that the aperture is just large enough to let the beam pass through ; any beam jitter can then be detected by the light produced in the luminescent material at the rim. The target is positioned horizontally and vertically by beams of the unit P and rotated about a horizontal or vertical axis by the unit R.



21. External-beam current transformer for 1.5-ms burst.
Left : casing with fourfold magnetic shielding,
Centre : electronics in ring,
Right : transformer cores and external-beam vacuum chamber.

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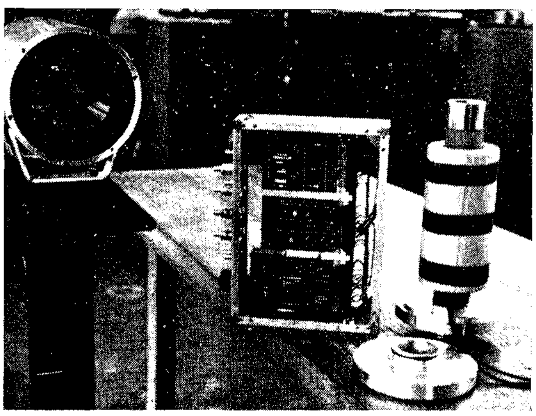

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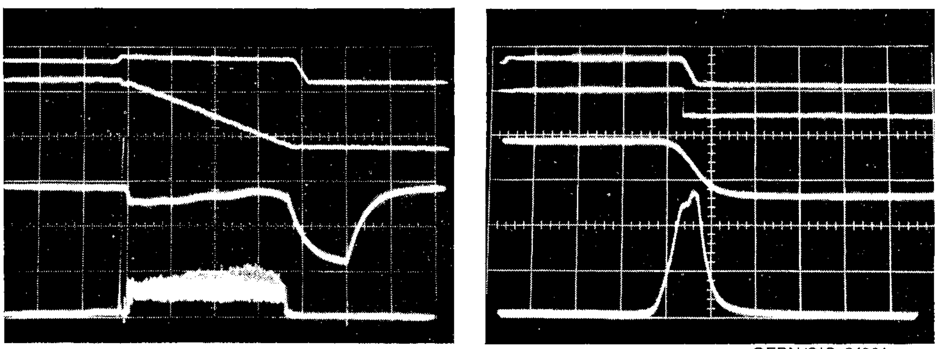

CERN/SIS 24364

22. Oscillograms of beam burst produced by resonant ejection.

Left : long burst (180 ms duration);
Sweep : 50 ms/division,
Top trace : flat top of magnet cycle,
Second trace : circulating proton current,
Third trace : current in positioning CPS dipole, controlled by spill-out rate,
Bottom trace : signal from counter looking at external target.

Right : short burst (1 ms duration);
Sweep : two upper traces, 50 ms/division, two lower traces, 0.5 ms/div.,
Top trace : flat top of magnet cycle,
Second and third trace : circulating proton current,
Bottom trace : signal from counter looking at external target.

are avoided. This is the solution adopted for ES 1. In principle, it would also been possible for ES 58 and ES 62. However, this would have meant a very powerful ejection magnet (20-kilogauss field throughout) which would necessarily have had a thick septum. This in turn would have led to a reduced ejection efficiency. Therefore a compromise solution was adopted,which nonetheless resulted in a practically undistorted beam as well as a good ejection efficiency.

For this the fringing field was corrected as far as possible towards the equilibrium (non-ejected) orbit by means of two types of high-quality magnetic shims (see figs. 12 and 19). The external beam trajectory was chosen to have the smallest ejection angle that would still just bring it into the corrected region. A two-section ejection magnet (fig. 17) was then provided to produce this angle (about 1°) with a minimum thickness of septum. The first section, 70 cm long, produces a field of 10 kG using a septum 3 mm thick. At the end of this section the beam has been deflected about 3.2 mm away from the line of the septum so that the second section, which is 52 cm long and set at an angle, can have a septum twice as thick as the first one without causing extra beam loss. This made it possible to use two windings and to obtain a field of 20 kG, using a special cobalt steel. The most difficult problems arising with these high-grade magnets were the cooling of the septum and the reduction of the outside stray field. The instantaneous current density in the septum reaches values as high as 300 A/mm², posing a considerable problem of water cooling to carry the heat away between pulses. The solution adopted was to incorporate the cooling-water channels into the septum itself (fig. 16), after the CERN Technology Workshop had succeeded in producing such an arrangement by electroforming and a long life test under shock conditions had shown its mechanical robustness. The stray magnetic field on the circulating-beam side of the septum must be small, because otherwise it disturbs this beam in an intolerable way. Through detailed studies and very careful design this field was brought down to 6 gauss (from 10 000 gauss) in the first section, and to 50 gauss in the second section (which is further away from the circulating beam), values which are no longer harmful. Another technological feat is the power supply for this magnet (fig. 9), which provides the required long-current pulses of up to 16 000 A with a precision better than ± 0.2 %. It uses silicon controlled rectifiers and electronic ripple filter (fig. 10).

Beam transport

The beam-transport elements (see figs. 13 and 14) are not pulsed, but are d.c. powered in the normal way, in view of the long MTE bursts. However, by adopting a 'figure-of-eight' design for the lenses and C-type design for the bending magnets, their radial dimensions could be reduced to such an extent that only 12-cm clearance is required at any point between the axis of the external beam and any boundary object (CPS magnet, tunnel wall, etc.). This, in fact, is the same as for the pulsed bending magnets used with ES 1 (the pulsed *lenses* are slimmer, but their bore diameter is 20% smaller). One of the 'slim' d.c. lenses is even installed in a CPS straight section, right against the synchrotron vacuum chamber. Thanks to adequate magnetic shielding, it does not disturb the injected beam noticeably.

Monitoring arrangements

Another important category of apparatus for the ES 58 includes the beam detectors and monitors. For the beam setting-up and stability control, light-emitting screens and closed-circuit television (fig. 13) proved invaluable. As the cross-sectional area of the beam and hence the proton density on the screen varies by a factor of about 1000 in going from, say, a focusing lens to the strongly focused spot on the target, screens of widely different sensitivity are needed for meaningful observation. This is, of course, all the more true if one wants also to work with very different beam intensities, for example by changing from MTE to PTE. The problem was solved by adopting a mechanism which changes up to 12 screens (in vacuum) by remote control and by using 4 different screen materials. In order of increasing sensitivity the materials are fluoroscopy screens as used in x-ray fluoroscopy, zinc sulphide (ZnS) on aluminium sheet, plastic scintillator 1 mm thick, and cadmium tungstate ($CdWO_4$), again on an aluminium sheet. An arrangement of 20 semiconductor-diode strips permits at one point simultaneous observation of the spatial and time distributions of the external beam (see fig. 20). The beam intensity of the fast-ejected and quick-ejected beams is measured by means of current transformers (fig. 21), developed from the earlier version employed in the fast-ejected beam of ES 1. A secondary-emission chamber was built for the measurement of the intensity of the slow-ejected beam. Various Cherenkov counters monitor the radiation from strategic places such as the EM septum and the target.

Many items of importance

A project of this size to which more than 100 people contributed at CERN in one way or another includes of course many more items, all of them important for the final success but for whose description the space is lacking. Mention should at least be made of the vacuum system, namely the enlarged CPS vacuum chambers and the vacuum pipe for the external beam, which is directly connected (without any window). The EM is housed in a tank especially designed as a quick-disconnect plug-in unit (fig. 18). If the need should arise, an EM can be exchanged with a spare unit in about 15 minutes. In the Main Control Room the new controls and means of observation take up about 6 additional racks, arranged to permit independent, self-contained operation of beam spill-out and of the external proton beam proper. A new building (the East-ejection building) had to be erected to house the power supply for the EM and the supplies for the orbit bump coils and the CPS ejection quadrupole (no. 55).

First trials

The results of the running-in of the system have already been reported in *CERN COURIER* (vol. 5, p. 115, August 1965). Broadly speaking, everything worked as expected on first trial. The ejection efficiency of the MTE is about 70%. The strongly focused fast-ejected beam passes continually through a hole 2 mm in diameter in a ZnS screen without visibly illuminating the rim. Under the same condition the multiturn ejected beam just touches this rim. Besides testifying to the beam stability this demonstrates the success of the magnetic shimming — after taking away the shims the spot size was roughly doubled and the edge was no longer sharp and regular. The spot sizes obtained are fully adequate for the beam uses intended, and with further operational experience it may even be possible to reduce them somewhat. Similarly, the characteristics of both the long burst and the short burst from the MTE (fig. 22) come up to the physicist's expectations. The characteristics of the STE, achieved by means of FK 97. are unchanged from those already known from ES 1.

THE FUTURE

ES 62 and ES 74 (planned for the new neutrino area) are scheduled to come into use in 1966. ES 16 should be ready in time for the Intersecting Storage Rings and their 25-GeV experimental hall.

On paper a scheme has been worked out to increase the MTE efficiency above 95%, thereby considerably reducing the radioactivity induced in the CPS and providing a cleaner beam for physics. It involves focusing of the internal beam during its last turn before ejection by means of a lens with a septum about 0.2 mm thick. This scheme will be put into operation as a second stage of ES 62.

Another beneficial line of development should be the furtherance of beam-sharing techniques. The rise times of most pulsed elements have already been specified at as low a value as 1/50 second (ten times less than usual). The remaining elements will be modified in the months to come, and a comprehensive programming system is under development. Thus a rapid succession of bursts on internal and external targets during the same CPS pulse will soon become possible.

Beam sharing between internal and external targets will be further improved when the fast kicker FK 66 comes into operation. This new magnet will have an aperture sufficiently large for it to be left permanently in position inside the vacuum chamber, instead of having to be moved into place at the correct instant in each acceleration cycle. As the vacuum-chamber aperture has to be free for internal target operation, the interval between the two types of operation (external and internal) in any cycle will be shortened by a significant amount, since one will no longer have to await the withdrawal of the FK. Another, probably even more important, feature of the new kicker will be the possibility of energizing it repeatedly during the same CPS pulse for beam sharing between several ejection systems.

As a further step, multiple beams from the same external target should come into existence in the somewhat more distant future. While already being served well, high energy physicists may thus expect an ever increasing range of facilities at the CPS in the months and years to come ●

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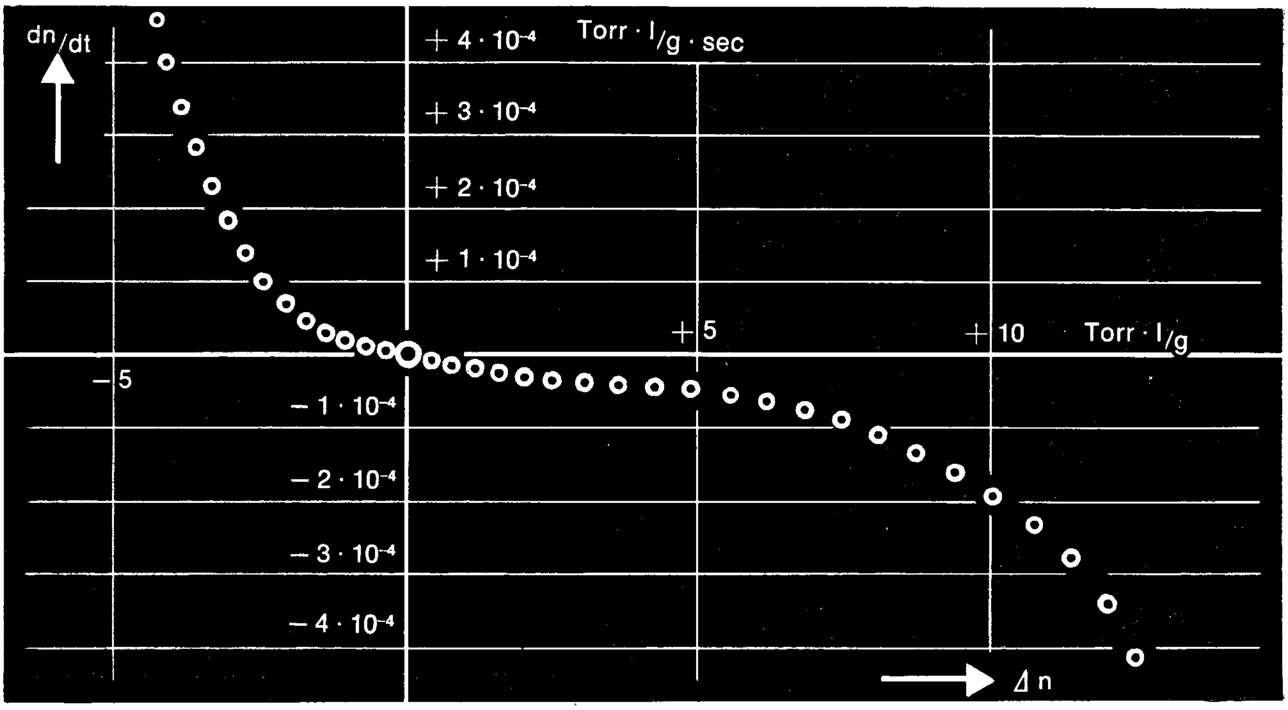

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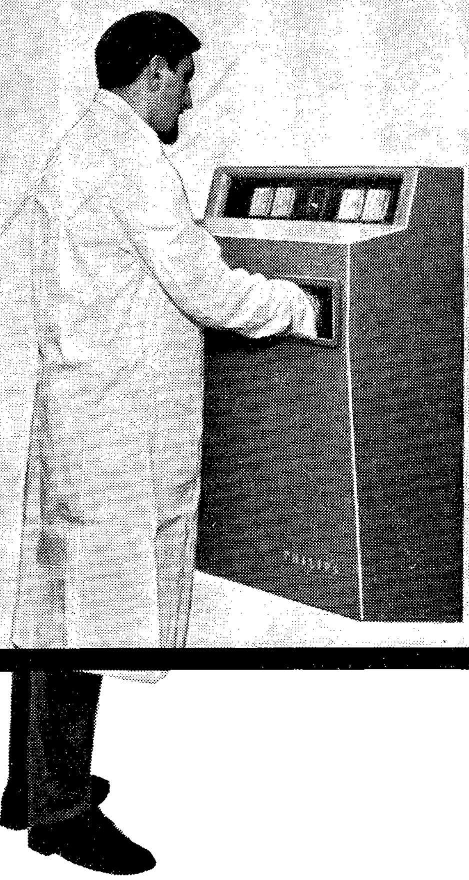

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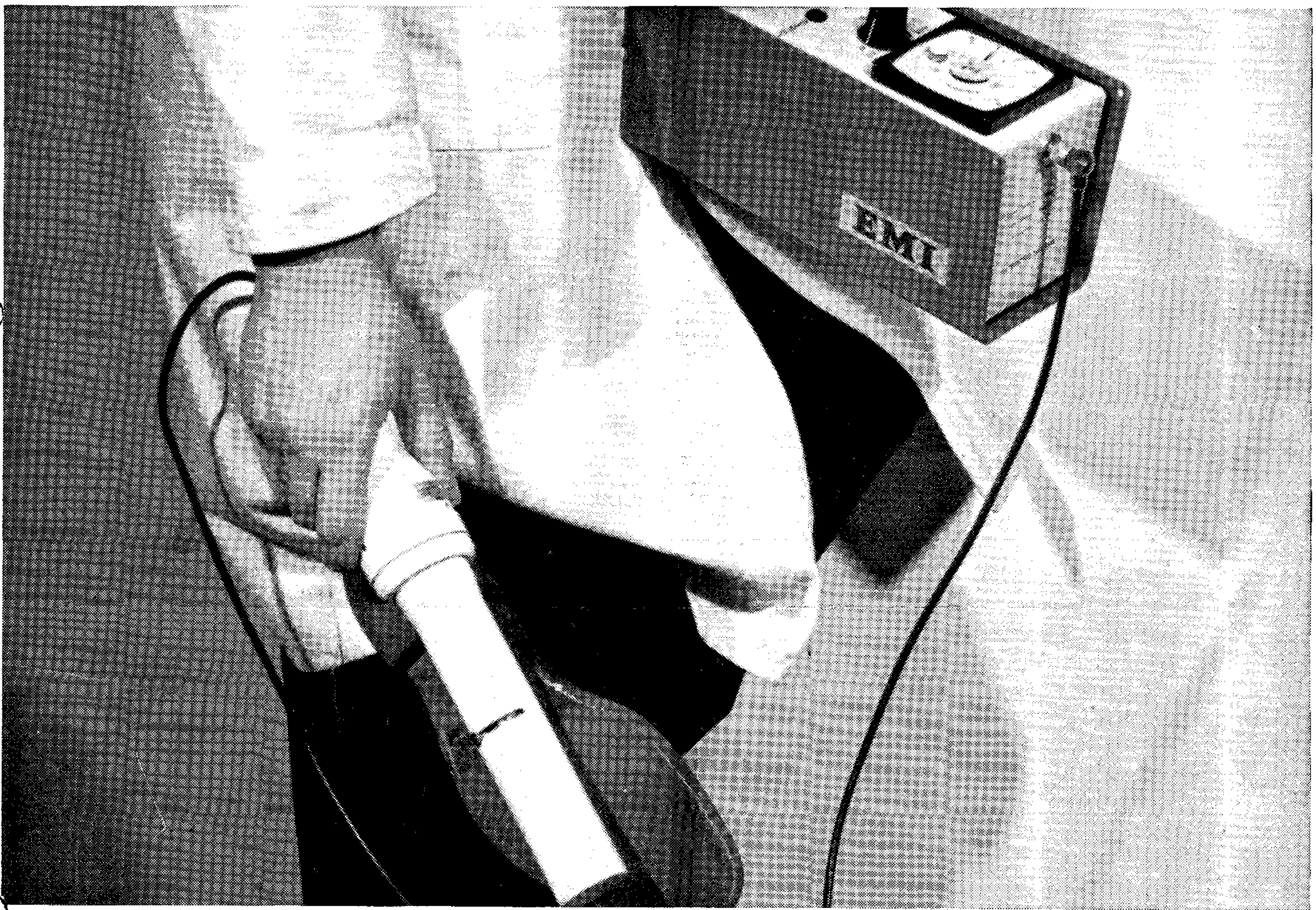

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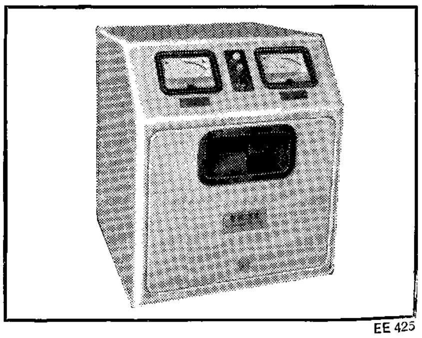

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