CERN COURIER

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European Organization for Nuclear Research

CERN, the European Organization for Nuclear Research, was established in 1954 to '... provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto'. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of sub-nuclear physics. This branch of science is concerned with the fundamental questions of the basic laws governing the structure of matter. CERN is one of the world's leading Laboratories in this field.

The experimental programme is based on the use of two proton accelerators — a 600 MeV synchro-cyclotron (SC) and a 28 GeV synchrotron (PS). At the latter machine, large intersecting storage rings (ISR), for experiments with colliding proton beams, are under construction. Scientists from many European Universities, as well as from CERN itself, take part in the experiments and it is estimated that some 1200 physicists draw their research material from CERN.

The Laboratory is situated at Meyrin near Geneva in Switzerland. The site covers approximately 80 hectares equally divided on either side of the frontier between France and Switzerland. The staff totals about 2800 people and, in addition, there are over 400 Fellows and Visiting Scientists.

Twelve European countries participate in the work of CERN, contributing to the cost of the basic programme, 235.2 million Swiss francs in 1969, in proportion to their net national income. Supplementary programmes cover the construction of the ISR and studies for a proposed 300 GeV proton synchrotron.

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CERN News

Superconducting coil for Omega

Following a series of successful tests on a superconducting coil using a new cooling technique, it has been decided to adopt this new type of coil for the magnet of the Omega project. The new technique uses a hollow superconductor through which liquid helium is circulated to establish the necessary low temperature. The Omega coil will be the first of its type to be built apart from the test coils developed at CERN in the group led by M. Morpurgo.

The Omega project was described in CERN COURIER vol. 9 page 31. It is designed to provide for electronics experiments (those employing electronic counters and spark chambers as detectors) a 'universal' instrument (somewhat similar to a bubble chamber) capable of easy adaption to a variety of experimental set-ups. The detectors will be installed inside the aperture of a large magnet which will have removable pole pieces for camera access and modular sides which can be built up as dictated by the requirements of a particular experiment.

The main parameters of the magnet are:

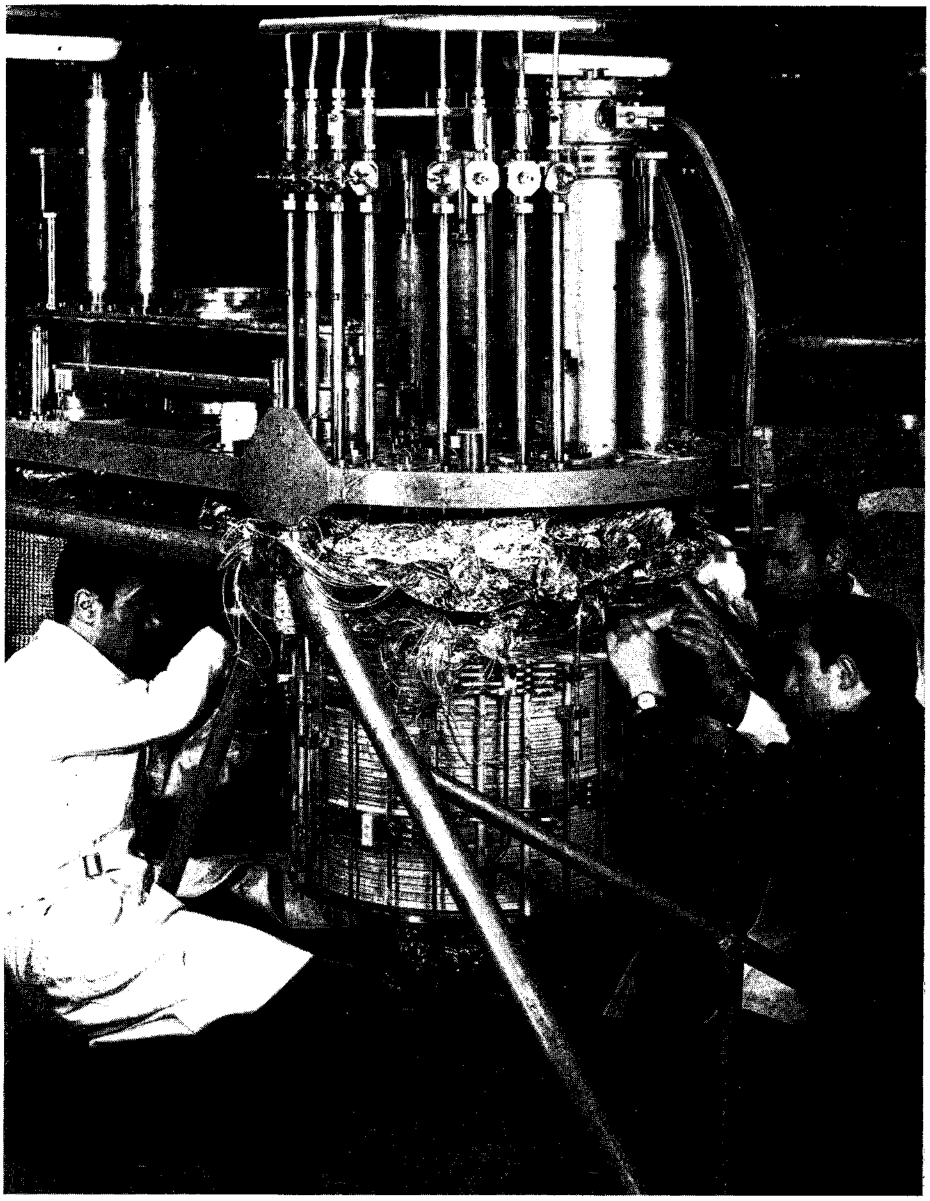
Maximum field at the centre	18 kG
Inner diameter of circular coils	3 m
Free gap between coils	1.5 m
Free gap between poles	2 m
Weight of magnet	1300 tons

The decision as to whether the magnet should be conventional or superconducting was left until quite recently in order to complete tests on the new cooling technique. The capital costs were anticipated to be about the same but the superconductor will be much more economical in operation (a conventional magnet would take about 7.5 MW of power).

Superconducting coils are normally operated immersed in a bath of liquid helium which is itself surrounded by a vacuum enclosure for heat insulation. The idea of having a hollow superconductor with forced cooling by circulating helium yields several advantages. The cooling is more uniform, the assembly is more compact (dispensing with the liquid helium en-

Contents

Cover photograph: An Aeroflot freight plane, Antonov 12, seen at Cointrin airport in Geneva for the first time on 23 July. The plane was chartered by CERN to carry equipment being used in the CERN-Serpukhov experiments to and from the Soviet Union. Another photograph and more details on the cargoes can be seen on page 231. (CERN/PI 226.7.69)



Assembly, in March of this year, of the rig where a superconducting coil, which was cooled by circulating helium within the hollow superconductor, was tested. Following the recent successful completion of these tests, it has been decided to adopt this new cooling technique for the large superconducting magnet of the Omega project.

CERN/PI 19.3.69

closure, the cryostat is simpler as the helium consumption is smaller).

Two trial coils have been built at CERN. The first used an extruded aluminium conductor in which niobium-zirconium (the superconductor) wires were embedded. The second, larger, coil was of copper with niobium-titanium wires. The dimensions of this coil were: length 45 cm, internal diameter 28 cm, external diameter 58 cm, conductor cross-section 5 x 6.5 mm^2, cooling channel cross-section 2.2 x 3.8 mm^2. Liquid helium from a 200 W refrigerator was forced through the coil at a pressure of 8 atmospheres, emerging at a pressure of 5 atmospheres. (The coil was tested at 200 atmospheres pressure difference without any trouble.) The current fed to the coil was taken up to 1400 A corresponding to a magnetic field of 50 kG. Beyond this level the superconducting property is lost.

The specification for the Omega coil is that it shall be a copper conductor with niobium-titanium as superconductor. The conductor cross-section is 18 x 18 mm with a cooling channel 9 x 9 mm. It will take a peak current of 5000 A which will establish a field of 20 kG in the magnet aperture. The helium will be provided from a 800 W refrigerator and will be circulated in the coil with an input pressure of 8 atmospheres.

One of the special problems concerns the mounting of the coil in the magnet. The coil supports need to be strong enough to withstand a force of 2000 tons when the coil is powered, must not conduct heat significantly between the coil at 4.5°K and the magnet yoke at room temperature, and must allow horizontal displacement of the coil as the coil contracts under cooling. A system of long thin struts cooled by liquid nitrogen will be used in a geometric pattern such that movement in the horizontal plane is possible.

Another problem was the possibility of induced currents in closed loops in the superconducting wires and the copper when the magnet power was switched off (the superconducting temperature being retained). It was calculated that these could result in a magnetic field around 10 % of the peak field which could take months to die down. The solution found was to have the superconducting wires twisted around one another in the form of a spiral which will reduce the decay time of induced currents to a few hours.

To produce the superconducting coil in this form is not easy. But the coil for Omega is an interesting technological development in the field of superconductivity which will probably be taken up elsewhere.

Topping 2 x 10^{12}

The intensity of the accelerated beam in the proton synchrotron had been increasing almost daily. In mid-July, it climbed over 2 × 10^{12} protons per pulse — reaching a record of 2.03 × 10^{12} protons per pulse. When pulses were recorded over 10^{12} some experimenters called for mercy. The flood of particles was so much more than they had designed for that counters were saturating. Most of the people concerned were, however, more than pleased. To have been able to improve the performance of the synchrotron by more than 100% over recent months is a considerable achievement.

The reasons for the success remain di-

General view of the LSD. In the foreground is the operator's desk with the mirror, attached to the ceiling, which projects views onto the table. On the right is the film transport system with its six vacuum boxes at the front. In the background on the left is the PDP 9 computer, the monitoring oscilloscope and the two magnetic tape units. On the right is the electronic equipment which monitors and controls the operation of the machine.

The photograph below shows the operator's desk. On the left are the control buttons for measuring the various parts of the photograph (fiducial marks, vertices, 'crutch' points, stopping points, etc.). On the right are the 'speed-ball' for controlling the X-Y movement (manual) of the stage, the television screen (by means of which the vertex can be accurately positioned on the optical axis) and the typewriter which provides communication with the PDP 9 computer.

verse as they were when the upward climb started some months ago (see CERN COURIER, vol. 9, page 105). Some of them are as follows:

— the excellent operation of the linac, which remains a necessary, but not in itself sufficient condition;
— the steady improvement of the vacuum in the synchrotron ring;
— the machine tuning, which is a difficult reason to pin down because it is a matter of flair and accumulated experience on the part of the operators, who have under their hands a vast range of controls some of which were not even thought of a few years ago.

Previously, attempts were made in particular to correct the position of the 'closed orbit' at injection, but now problems such as the beam size and non-linear effects, which influence the beam in a complex manner, can be tackled. The close cooperation between the machine operators and the machine study group, which has undertaken the study of non-linear phenomena, has been very important in attacking these problems.

One of the most fruitful manoeuvres was to vary the mean radial position of the beam during the first few milliseconds of each machine cycle in order to prevent instabilities developing. Another manœuvre aims to reduce the longitudinal oscillations of the beam by playing tricks with the r.f. accelerating field. This also avoids the particle bunches contracting too much in the longitudinal direction which causes major space charge effects.

Finally mention should be made of multi-turn injection which has been in operation during July and which has taken the maximum accelerated beam from 1.93×10^{12} to 2.03×10^{12}.

The PS and the linac were originally designed for single-turn injection. Attempts at multi-turn injection made in 1966 (see CERN COURIER vol. 6 page 29) were not satisfactory. However, now that the linac can provide very stable pulses for 20 μs, things are different. Injection for $2^1/_2$ turns was used very promisingly. The technique has not been used to its full potential.

Before the Booster synchrotron injector comes into operation, the linac will be able to provide pulses 100 μs long which will make possible multi-turn injection for ten turns.

LSD Progress

A description of the spiral reader (known at CERN as LSD after the initials of the French title 'Lecteur à Spirale Digitisée') appeared in CERN COURIER vol. 8 page 246. It is one of the instruments for the automated measurement of bubble chamber photographs, this particular type originating in Berkeley. The CERN spiral reader was built in collaboration with the Collège de France, in Paris.

The LSD automatically measures an event by scanning it through a slit which travels around a spiral centred on the point of interaction. Whenever the slit with its associated electronics detects a track, the polar coordinates of its position are recorded on a magnetic tape by means of an on-line computer (PDP 9). The tape is then fed to one of the CERN central computers (CDC 6600 or 6400), where spurious tracks are filtered out, and only the event is retained for further analysis by the physicist.

It was originally intended to operate the machine from 1 April 1969. Actually, on this date, several events were successfully fed through the entire analysis programme chain. It was then decided to begin production measurements while continuing to develop those parts of the machine which are not absolutely essential for measurement, but which simply serve to increase the speed. It was also decided to take steps to turn what was still a prototype into a piece of production equipment, improving its reliability and accuracy. Finally, the main emphasis was put on training staff involved in operation and use of the machine, supervision and assistance during measurement.

In practice, this development programme was planned in three stages:

1) The initial period, during which the machine was used for measurement for two days a fortnight, the rest of the time being employed in modifying those components found to be the least reliable, such as the film transport system and the mechanical cone-periscope assembly. During this period, the measurement analysis programmes showed up a systematic error in the measurement of fiducial marks. Investigating this problem revealed three main sources of trouble:

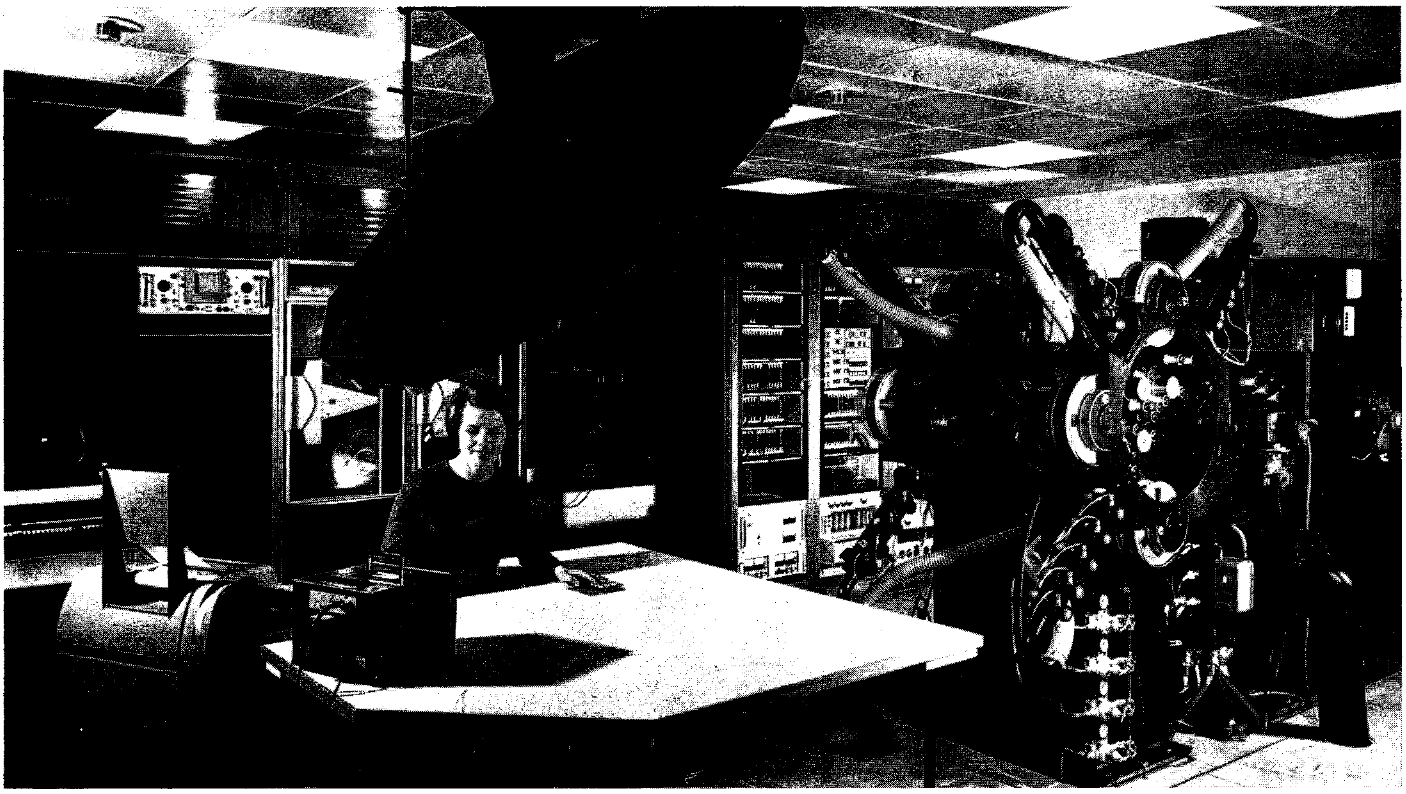
— the tension applied to the film by the vacuum boxes;
— the positional adjustment of the guide rollers;
— the inertia of the capstan which is driven by the film during the movements of the X-Y stage.

The following modifications were made and succeeded in completely eliminating the systematic error:

— installating a new film gate which, in all three views, separates the photograph to be measured from those next to it which remain subject to the force exerted by the vacuum boxes;
— adjusting the 45° rollers as accurately as possible, increasing the pressure of the compressed-air cushions and installing a buffer reservoir to stabilize this pressure;
— during the measurement stage, replacing the capstan vacuum by compressed air to provide an air-cushion over which the film can slide without friction and thus without driving the capstan and its motor (the vacuum is, in fact, needed during the actual transport of the film to give sufficient adhesion between capstan and film).

2) The present period, in which the machine is used for measurement for a week (ten hours a day for five days) and is then available for two weeks for development. The emphasis is being laid on developing the automatic system for measuring the fiducial marks. At present, they are measured manually — the operator has to pin-point accurately each fiducial mark individually. The basis for the automatic system perfected at CERN is the Berkeley automatic system (with the difference that four marks per view are measured at the same time instead of two which is intended to give a commensurate saving of time). The measuring rate, currently 20 to 30 events per hour, could be increased to rates of the order of 70 to 100.

As in the previous period, efforts to improve reliability are continuing. A new system for detecting the position of the film in the vacuum boxes has been install-



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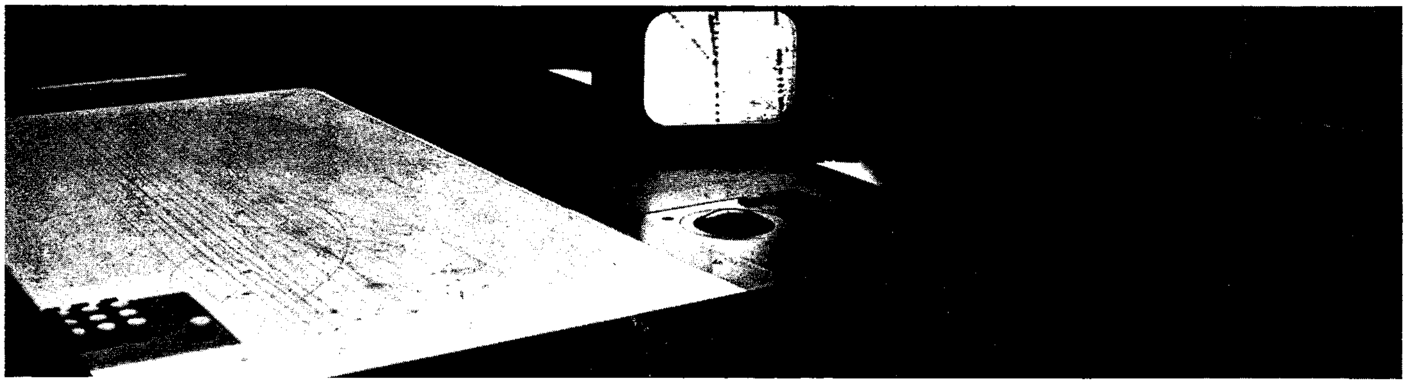


CERN/PI 284.1.69

ed. It is a very sensitive system which has made it possible to reduce the vacuum in the boxes. This has the double advantage of reducing the force exerted on the film and of lowering the maximum torque applied to the spools by the motors. In addition, new power amplifiers for the film transport spool motors have been fitted. The substitution of three-phase for single-phase power supplies has enabled the vibration of the printed-circuit motor rotors to be reduced and this should, in the long run, reduce wear on them.

Finally, modifications have been made to the electronic system which receives the photomultiplier pulses. This system automatically corrects the gain of the video amplifier in relation to the variations in luminosity during the spiral scan. The aim is to produce pulses with a height proportional to the contrast between the track and the background. Changes have mainly involved the addition of devices for adjusting the level of discrimination of useful tracks against the background of the photograph.

3) In the next stage, which will begin in a month or two's time, the machine will continuously measure the photographs made in an experiment involving 50 000 events. Clearly, this new phase depends very largely on the introduction of the system for automatically measuring the fiducial marks. The latter system, as already stated, should reduce the measurement time per event by one-third, and is virtually essential at this stage.

In conclusion, it should be pointed out that, by 1 August 1969, the machine had measured some 4000 events from the experiment involving pictures of negative pions of 3.9 GeV in the CERN 2 m bubble chamber. The interesting events have four or two prongs (four or two tracks emerging from the particle interaction point). The current reject rate, which has continued to improve in step with the development of the machine and of the filtering and spatial reconstruction programme (POOH - THRESH), is of the order of 10 to 15 % at the output of the GRIND kinematic programme. Finally, the accuracy of measurement appears to be similar to that of conventional measuring equipment (IEP). For example, in 1700 two-pronged events, the average value of the residue on the tracks is of the order of 8 microns in the film plane. It appears possible to improve this value by adjustments to the filtering programme, primarily by better elimination of the points which are not part of the desired event.

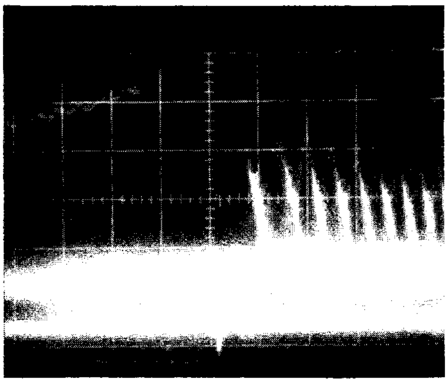
Tricks at transition

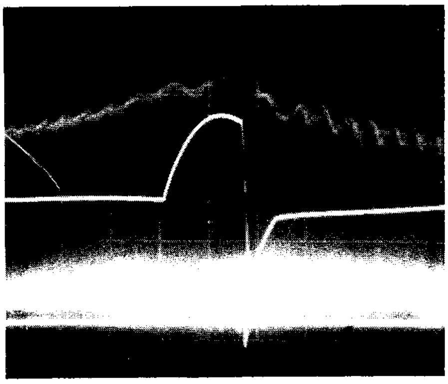
A method of reducing the disturbance felt by the beam in the proton synchrotron when it 'goes through transition' has been successfully tested. The resulting improvement in the beam quality has important implications for the Intersecting Storage Rings and the method will almost certainly also be built into the Booster of the 300 GeV machine.

What's transition ? In a bunch of protons orbiting a synchrotron there are two competing effects :

(1) It seems almost trite to say that the faster moving particles take a shorter time to travel round the machine.

(2) However, at a particular strength of the magnetic field in the ring, the faster





Two photographs (on the same scale) showing the improvement in beam quality gained by applying 'Q jump' at transition energy in the proton synchrotron. This new technique reduces the length of the proton bunches and their oscillations.
The relevant traces are the faint upper ones which record the bunch length (an inverse signal from the beam observation station in the ring). The photograph on the left is without Q jump — the blow-up and the amplitude of the oscillations are considerable. The photograph on the right is with Q jump where the improvement in beam quality is very striking.

moving particles move out onto a bigger radius and could, in fact, take longer to travel round the machine because of the bigger circumference they traverse.

Which of these effects is winning is crucial of the way in which the kick of acceleration has to be applied in the r.f. accelerating cavities. In the CERN PS, because of the strong focusing forces, effect (1) is predominant at lower energies. The higher energy proton travels ahead of the average, and the field in the r.f. cavity is arranged to be rising in strength as the bunch passes through. Then the proton arriving first, seeing a lower accelerating field than the average, is slowed down with respect to the rest of the bunch. This keeps the bunch stable.

As the energy goes up and the proton velocities get close to the speed of light, the increase in velocity per revolution becomes less, and effect (1) falls in importance. Then effect (2) predominates. The faster proton is coming round slower than the average and, if the bunch is now to be kept stable, the accelerating field in the r.f. cavities has to be falling as the bunch goes through. Then the particle coming round first sees the higher field and is speeded up with respect to the rest of the bunch.

The energy at which the switch from effect (1) to effect (2) occurs is known as the transition energy (about 5 GeV in the case of the CERN PS). At this energy the r.f. fields have to abruptly about-face.

It was in fear and trembling that the builders of the PS first took the proton beam through transition and the great surprise, which has by now contributed to a machine performance in terms of intensity a hundred times better than the design figure, was that transition caused much less trouble than anticipated.

But it still causes some disturbance to the beam mainly related to the effects of space-charge forces resulting from the positive charges carried by the protons tending to push the particles away from one another. These effects have not been too troublesome up to now but in a few years time they could be a major problem. The advent of the 800 MeV Booster will take the PS intensity even higher and will increase the space-charge forces. The advent of the Intersecting Storage Rings will require attention to the length of the PS bunches, which is affected by space-charge. The interaction rate in the ISR will be inversely proportional to the fourth power of the bunch length.

The factors affecting bunch length are complex. Without space charge forces the length decreases as the energy goes up to transition and then increases as the energy goes up beyond transition due to the effect of the r.f. fields. Superimposed on this length variation are the space-charge effects. Below transition this results in a relative increase in length. Above transition it results in a relative decrease in length. The change from one situation to another on either side of transition does not occur smoothly but results in the beam length oscillating above transition.

The aim of the recent work has been to reduce the beam blow-up and the amplitude of the oscillations by taking the beam through transition faster. The trick has been to play with the focusing forces in the ring. We have already indicated that the transition energy is dictated by the focusing forces which control the energy range where effect (1) predominates. By fast switching of quadrupole magnets the focusing situation is abruptly changed a few milliseconds before the normal transition energy (a trick known to the specialists as a 'Q jump'). The transition energy is made to fall sharply so that the beam spends less time going through transition. This greatly reduces the disturbances due to space-charge and the beam blow-up and the amplitude of the oscillations are much smaller.

Many people have contributed to this achievement. H. G. Hereward was one of the first to consider these problems in the context of the design study for the 300 GeV machine in 1965. Shortly afterwards A. Sørenssen began work on the theory. People concerned with the 300 GeV Booster, W. Hardt and D. Möhl, recently became involved and it was they who suggested the experiments on the PS in which G. Merle, visiting scientist from Karlsruhe, also participated. L. Thorndahl played an important part in quickly developing the supply to power the quadrupoles. J. Gareyte, R. Cappi and R. Ley brought invaluable expertise during the machine runs.

CERN COURIER 10th anniversary

The first issue of CERN COURIER was published in August 1959. We wish simply to use the occasion of the 10th anniversary to record our appreciation of the willing help received from many people, at CERN and elsewhere, in the gathering and presentation of information concerning sub-nuclear physics and the accelerator Laboratories where it is carried out.

In particular, we would like to list the correspondents we have in other Laboratories. Their contributions go largely unacknowledged throughout the year and it is a pleasure to recognize the valuable new interest that their reports have helped to bring to the journal:

Argonne	T.H. Groves
Batavia	C.W. Larsen
Berkeley	G. Kalmus
Brookhaven	J. Spiro
Cambridge	Wm. A. Shurcliff
Cornell	K. Berkelman
Daresbury	T.W. Aitken
DESY	G. Söhngen
Dubna	V.A. Biryukov
Frascati	M. Ghigo
Los Alamos	W.H. Regan
Rutherford	A.P. Banford
Saclay	G. Neyret
Stanford	J. Sanders
TRIUMF	E. Auld
Villigen	W. Hirt

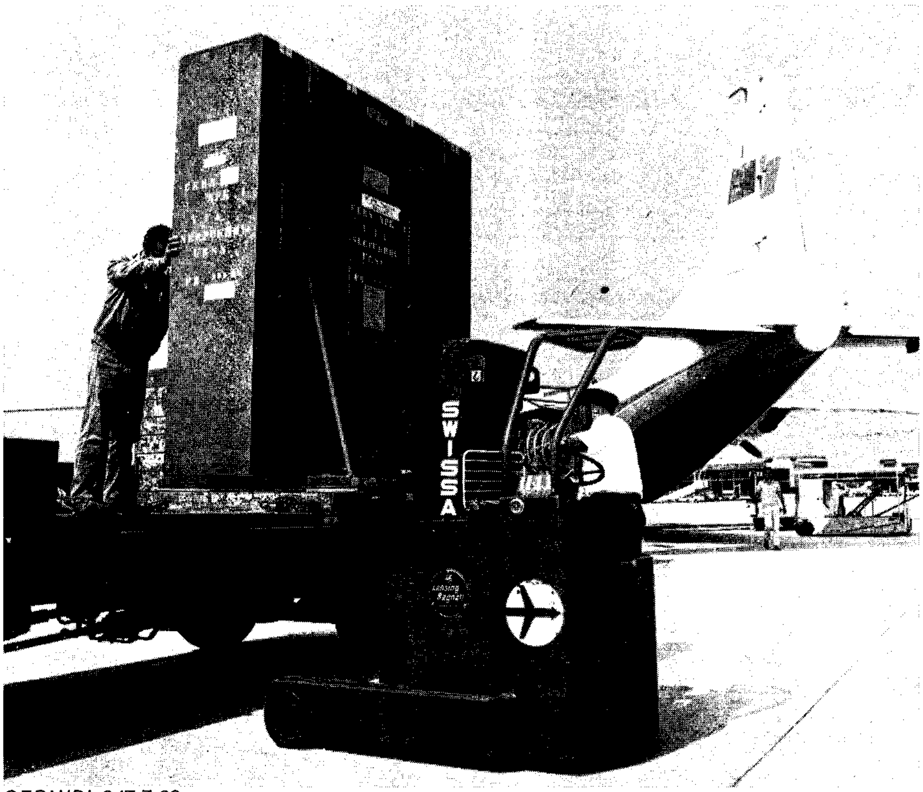
Finally a word of appreciation to the printer, Ed. Cherix et Filanosa S.A. at Nyon. Cherix have printed CERN COURIER from the first issue ten years ago (an eight page issue of 1000 copies) to the present (thirty-two page issues of 9600 copies). Far from fulfilling a passive production role, they bring to the journal an interest and a craftsmanship which contribute a great deal to its success.

It is gratifying to note that the present estimates for 1969 give an increase, compared with 1968, of 2000 people who have asked to receive CERN COURIER (an increase of 25 %). At the same time the number of pages has been increased by 20 % thanks largely to the growing involvement of other Laboratories.

On 23 July a four engined turbo-prop aircraft of Aeroflot airlines, an Antonov 12, landed at Geneva airport. The plane was chartered by CERN to carry experimental equipment (including a Cherenkov differential counter and other particle detectors) back from the first joint experiment between CERN and Soviet scientists at the 76 GeV proton synchrotron at Serpukhov. First results from this experiment, which finished on 10 July, were covered in CERN COURIER vol. 9 page 99, and further results, which have produced a considerable surprise, are covered on page 232.

The top photograph shows the plane being loaded for its return trip on 24 July with equipment for joint experiment number 2. The crate (2.33 x 2.35 x 1.3 m^3) contains a wide gap wire spark chamber to be used in an experiment which is scheduled to begin about March 1970. The joint team will be pursuing the search for negative bosons into the higher mass range available at Serpukhov, using the missing mass technique which has proved so very successful in experiments at CERN in recent years.

Receiving the wire chamber so far in advance will help the Serpukhov scientists to familiarize themselves with the equipment without interrupting the experiment (see CERN COURIER vol. 9, page 8) which is continuing at CERN until about the end of the year. The chamber is the first item of equipment to leave but there is much more to follow (a total weight of 200 tons). The largest and heaviest item is a spectrometer magnet weighing 110 tons (lower photograph) which arrived at CERN in August. This magnet will make it way to Serpukhov by train and ship after being tested at CERN. These tests will include installation in the current experiment at CERN. During the autumn shutdown of the proton synchrotron the magnet, which has a larger aperture (1.5 x 1 m^2) and higher field, will replace the one currently in use. There will then be several weeks of operation using almost all the equipment which is scheduled for the experiment at Serpukhov.



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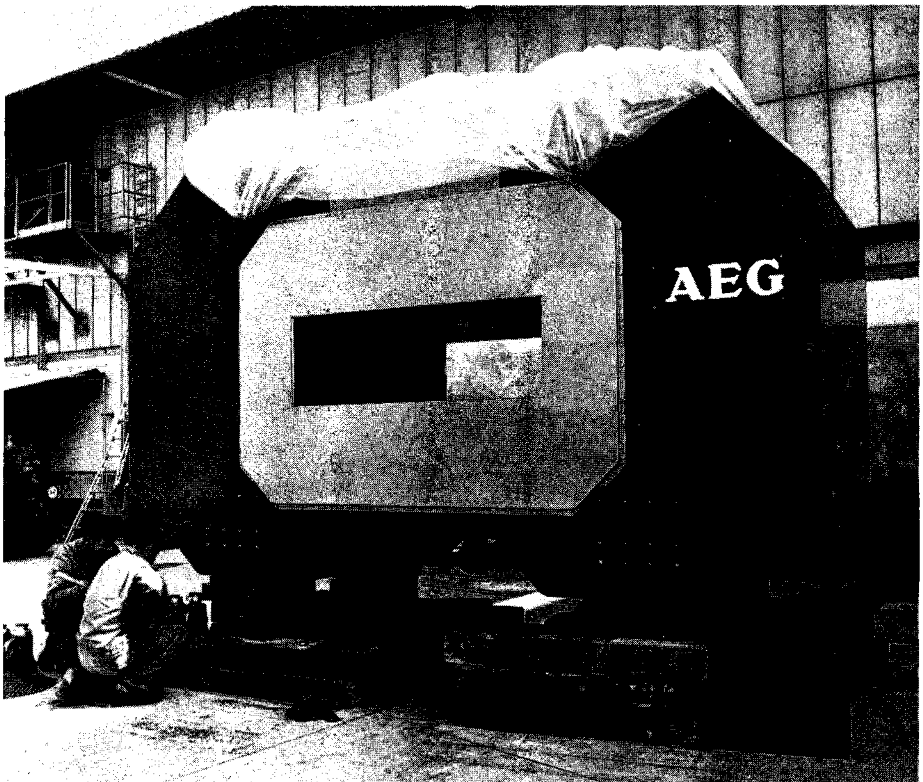

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Some Physics Post-Lund

The latest major Conference on particle physics was that at Lund in Sweden from 25 June to 1 July. It was in the series of European Conferences held in alternate years. The three topics selected for this article were important ones at Lund. They are treated here, however, not in the way of summarizing proceedings of the Conference but more generally to try to bring out their interest and the present relevant experimental evidence.

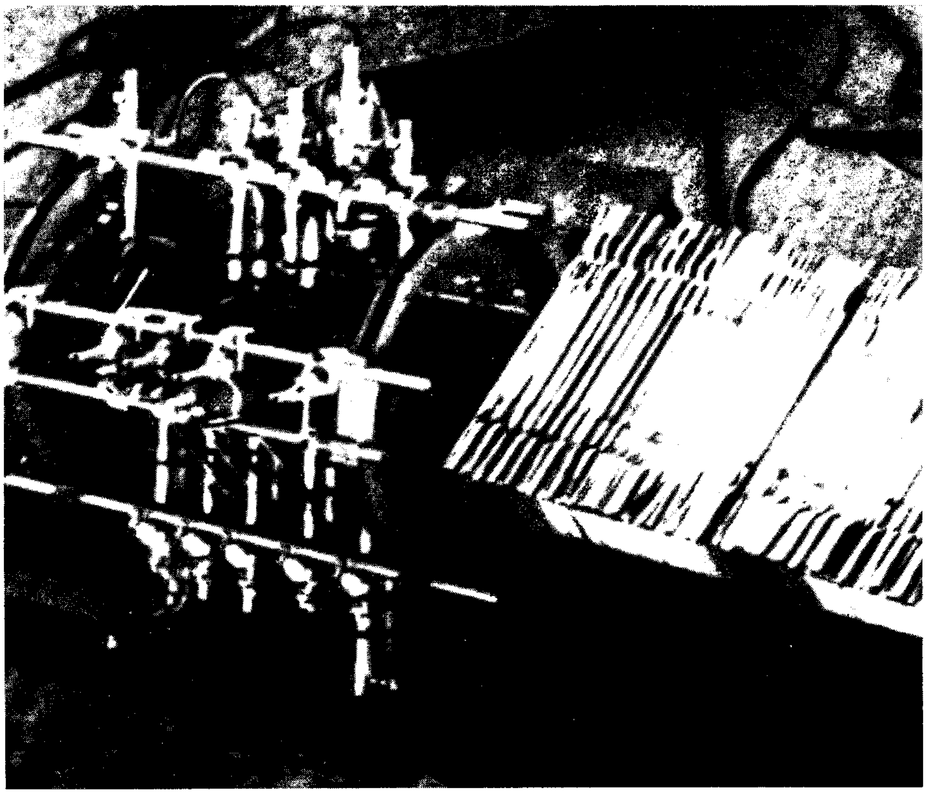
Getting flatter sooner

Is access to higher energies in the next generation of accelerators going to dot the 'i's and cross the 't's of what we know already, or is it going to overthrow many of our present conceptions ? We obviously cant say yet but it is probably significant that the first of the new machines, the 76 GeV proton synchrotron at Serpukhov, has thrown up a surprise in one of its earliest experiments. It is extremely gratifying to those who have pursued the CERN-Serpukhov collaboration that this surprise emerged from the first joint experiment between CERN and Soviet scientists.

Stage one of this experiment concerned the measurements of particle production at the newly available high energies and was reported a few months ago (see CERN COURIER vol. 9 page 99). Stage two concerned the measurement of 'total cross-sections' at high energies and the results reported at Lund have led to the scratching of many theoretical heads.

Negative particle beams of pions, kaons and antiprotons were fired at a hydrogen target. The total cross-section, that is the probability of the negative particle interacting, in no matter what way, with the proton at the nucleus of the hydrogen atom, was then measured. The momentum of the bombarding beam was varied in steps of 5 GeV/c over the range 20 GeV/c to 65 GeV/c.

What was expected to happen ? Up to the energies investigated previously, the total cross-section had been falling steadily as the energy or momentum increased. This can be explained simply as follows. The particle at a particular momentum has a wavelength associated with it, and this wavelength can be thought of as the region over which the influence of the particle is felt. As the momentum increases the wavelength decreases — the particle's region of influence decreases and the probability of it interacting with another particle decreases. In addition, the many resonances produced at low energies are having less effect. Thus the total cross-section falls off with increasing energy.



On the left of the photograph is the counter system used in the measurements of total cross-section by the joint CERN-Soviet team at the 76 GeV proton synchrotron at Serpukhov. On the right is the array from which the muon contamination of the particle beam was estimated.

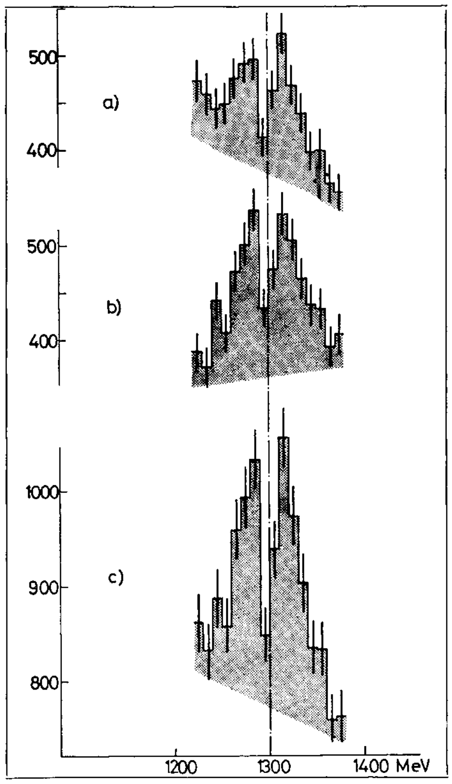
(Photo Serpukhov).

The most popular theoretical interpretation predicted that this fall off would continue until a certain total cross-section, an asymptotic value, was approached at very high energy. This would correspond, loosely speaking, to the energy at which the wavelength of the particle becomes smaller than its physical dimensions. The region of influence would continue to decrease until it corresponded to the physical boundaries of the particle itself. Some theoreticians put the energy at which this would occur in the region of a thousand GeV.

The surprise from the experiment at Serpukhov is that the steady fall off flattened out very much sooner than anticipated, well above the predicted asymptotic limit. Already over the investigated momentum range up to 65 GeV/c the curves for pions and kaons look flat, and for all the particles the total cross-section values are higher than expected from theory.

Most of the head scratching is concerned with another aspect of the theory which said that at extremely high energies, the total cross-section of particle and of antiparticle would be the same. At such energies, the differences between particle and antiparticle, which prohibit certain interactions and have a considerable impact at low energies on the total probability of an interaction taking place, would be insignificant because of the many different ways in which an interaction could occur. Thus the total cross-section of negative pion and proton would be identical to that of positive pion and proton, negative kaon and proton would be identical to positive kaon and proton, antiproton and proton would be identical to proton and proton.

This all looked feasible pre-Serpukhov. The total cross-sections, though not identical over the energy range investigated, could, if they had continued to fall off slowly at different rates, have approached the same asymptotic value. Since the new measurements show that the fall off for negative particles gets flatter sooner than expected, it looks as if the positive kaon and negative kaon curves will never come to the same value, unless this were to occur at very much higher energy than expected or unless in some extraordinary way the total cross-section for the



Splitting of the A2 meson. The graphs show —
a) results from the CERN Boson Spectrometer
b) results from the CERN Missing Mass Spectrometer
c) the combined results from these two different experimental techniques.
The number of events corresponding to the A2 meson are plotted vertically against energy. The double peak appears clearly and the symmetrical shape suggests the presence of two particles, with almost the same mass, with identical quantum numbers.

positive kaon starts to increase with increasing energy.

A Serpukhov team hopes to look at positive particle cross-sections over the same momentum range in the near future and their results will be eagerly awaited.

Split over splitting

One of the liveliest topics at the Lund Conference was concerned with the splitting of the neutral A2 meson and the theoretical attempts to explain it. New measurements were presented at the Conference and a transatlantic confrontation has developed with results from the USA in conflict with those from Europe.

The A2 splitting story started with the first Missing Mass Spectrometer experiment at CERN over the years 1964 to 1966 (see CERN COURIER vol. 7 page 31). Besides identifying seven new mesons, this experiment showed that a particle with a mass of about 1300 MeV, called the A2 meson, instead of appearing as a single peak like other particles, consists of two peaks of about equal height close together with a deep and very narrow gap between them. (This can be seen, and is fuller explained, on the diagram.)

It was obviously important to have another look at this strange phenomenon and several experiments have been carried out since. At CERN, the A2 mass region was re-examined using a new missing mass technique (the CERN Boson Spectrometer which measured the momentum of the recoil proton (in the interaction $\pi^- p \rightarrow pA2$ as opposed to measuring the angle of the recoil proton as done in the MMS experiment. Again the splitting of the A2 emerged clearly and the experiment recorded a very large number of events in the region of the A2 mass (the combined MMS and CBS results give about 1000 events within each mass range of 10 MeV).

Bubble chamber experiments at Brookhaven and CERN (some of these results being announced at Lund) have also confirmed the splitting. A Brookhaven experiment in 1968 used the bubble chamber effectively as a missing mass spectrometer picking out the decays of the A2 into three pions (75 % of A2 decays are into three pions). A CERN-Collège de France collaboration picked out the rarer decays into kaons (a neutral kaon and a charged kaon produced in antiproton annihilations) and a Bonn, Durham, Ecole Polytechnique, Nijmegen, Torino collaboration picked out the pion decays (an experiment done in the British National Hydrogen Bubble Chamber during its stay at CERN). The statistics from the bubble chamber experiments are in general lower — an order of magnitude down on the spark chamber experiments.

So everyone is now agreed that the A2 is split. The controversy begins when we ask what does this mean.

The first possibility is that two radically different particles, both with legitimate quantum numbers (a qualification which may become clearer later), just happen to have almost identical mass. This would mean that we have discovered a new particle with mass close to that of the 'true' A2. The A2 has been known for some time to fit nicely into the particle grouping scheme. The new particle has no obvious slot waiting for it but could well belong to some new group.

The second possibility is that the two halves of the A2 (call the heavier one of mass 1318 MeV 'A2 high', and the lighter one of mass 1278 'A2 low') have identical quantum numbers. This is an attractive possibility because the symmetric shape of the double peak seems most likely to come from the interference of two identical particles.

If this is so, then the quark model, which has been so very successful in explaining the regular occurrence of the mesons, has to stretch itself to accommodate the observation, and in so doing would loose some of its simplicity.

The quark model says that the meson is a quark and an antiquark in combination rather like an electron and positron in combination in positronium. To understand how the different masses, or energy levels, can arise we need to consider the combination in terms of its orbital angular momentum 'L' (the quark — anti-quark rotating around one another) and of the intrinsic spin 's' of each quark. s has the value $1/2$ and thus the total intrinsic spin 'S' of the quark, and anti-quark combination is I when the two spins are parallel, and O when they are anti-parallel. Then for each value of L (which can have values 0,1,2,3,...) we have several possible energy levels (several possible particles of different mass) depending on the possible ways in which L and S come together to give the total spin 'J'. (This is exactly analogous to the explanation of the energy levels corresponding to the atomic spectral lines much earlier this century.) Just to add to the complication, at each mass level there are in fact nine particles of an SU3 group. So far, these concepts have worked beautifully.

But let us go back to the A2. A possible assignment for its spin value is $J=2$ with positive parity quantum number. Then $J^P=2^+$. If it is found that A2 high and A2 low both have $J^P=2^+$, the quark model can say that one of them is the top member of the $L=1$ group of mass levels and the other is the bottom member of the $L=3$ group of mass levels. This is not easily acceptable because the separation between the $L=1$ group and the $L=3$ group is expected to be about 2 GeV while within a group of mass levels the four members are separated by only about 100 MeV (judging by the observations of the groups at the lower values of L). Thus the $L=3$ and $L=1$ groups should be very well apart. However it may be that the members within the $L=3$ group are GeVs apart which could bring the $J^P=2^+$ member down to the $L=1$ group mass range. Not easily acceptable in the quark model but not impossible.

There is an experiment which could add weight to this argument. We said above that each member of a group of mass

A cartoon, given the title 'Where we stand - 1969', shown in April by H. Lipkin when speaking about 'The spectrum of hadrons' at the Inaugural Conference of the European Physical Society in Florence. It illustrates the troublesome time that theory is having in trying to accommodate the discovery of the splitting of the A2 meson.

levels in fact represented nine particles of an SU3 group. If the A2 finds itself invaded by a particle of almost identical mass, then other members of the SU3 group containing the A2 might very well show a similar splitting due to interference from another particle from the SU3 group of the A2 invader. An experiment with high statistics is now being analysed at Berkeley precisely to look for the splitting of the K* particle which has a mass of 1400 MeV and which is in the same SU3 group as the A2. The result will be very important.

The remaining possibility is that the A2 splitting is due to two different particles which have quantum numbers which are not permitted under the quark model outlined above. Such an overthrow of the model is not looked on with enthusiasm. Some theoretical attempts to accommodate this possibility have already been made but they involve considerable contortions and, in general, the beauty of a model is in direct proportion to its (or her) simplicity.

The experimental results on the examination of the quantum numbers of A2 high and A2 low divide in mid-Atlantic. From Europe comes a Dalitz plot analysis of some 400 events from the Missing Mass Spectrometer measurements giving
J^P (A2 high) = J^P (A2 low) = 2^+

The CERN, Collège de France bubble chamber experiment gives the same result from its measurements of the decay into charged kaons which showed a double peak. And the Bonn, et al. bubble chamber experiment gave the same result from a Dalitz plot analysis of three pion decays.

From the USA, analysis of the 1968 bubble chamber experiment gave J^P(A2 high) = 2^+. Since only A2 high was seen in looking at the decay into kaons, this leads by indirect arguments to J^P(A2 low) = 1^-. This has the wrong charge conjugation parity under the quark model and, if it is true, destroys the quark model as we know it. A further Brookhaven bubble chamber result, newly reported at Lund, looked at the A2 produced together with a lambda hyperon. They saw only one narrow peak at the position of A2 low and give the most likely quantum numbers for A2 low as $J^P = 1^-$.

The present CERN Boson Spectrometer experiment has high statistics and their analysis is expected to clarify the situation. Place your bets.

About time

There are a lot of intriguing questions about the weak interaction, the interaction which controls particularly the decay of long-lived particles, and about the leptons, the small group of four particles (electron, muon, electron-neutrino, muon-neutrino) which play such an important role in the weakinteraction. We have known the muon for thirty years but are no nearer understanding why such a 'heavy electron' should exist. Are we at the beginning of discovery of a spectrum of leptons resulting from an internal structure even in the electron ?

But the question we are going to pursue here is that of the weak interaction's lack of respect for some of the sacred symmetries in Nature. This topic has been covered several times before in CERN COURIER (see for example vol. 6 page 171 and vol. 8 page 11) and we will not spend long on the history now.

It has been known since 1956 that the weak interaction violates parity or left-right symmetry (P). It was shown that only left-spinning neutrinos emerge from the decay of the neutron. There are no right-spinning neutrinos in Nature. The combination of charge conjugation and parity (CP) restored some semblance of order — there are right-spinning antineutrinos. (Pauli's remark following the observation of parity violation, 'God is not left-handed' was recently balanced by J.G. Taylor with, 'There is an anti-God who is right-handed'.) But this too fell down in 1964. CP symmetry is violated at the rate of about once in five hundred times in the decay of the long-lived neutral kaon.

This has called into question yet another symmetry — the symmetry of time (T). Since the combination, CPT symmetry is one of the pillars in the structure of modern physics only a Samson would dare to shake it. Therefore the rare occurrence of the violation of CP symmetry implies the rare occurence of T violation in order to preserve CPT. People have therefore been looking hard for evidence of the violation of time symmetry. If time symmetry is violated it implies that the same laws of physics do not necessarily apply if one reverses the time sequence of events.

The one place where T violation seems to be definitively established is again in the decays of that very sensitive particle the long-lived neutral kaon. The reasoning whereby observation of these decays shows T violation is rather complex. Suffice it here to say that knowing such quantities as the masses of the long-lived and short-lived kaons and the amplitudes and phases of their decays into two charged pions and two neutral pions, T violation or conservation can be seen. These quantities have been measured particularly in experiments at Brookhaven, CERN and Princeton (the last necessary figure — the phase of the decay into two neutral pions — being slotted into place recently from a CERN experiment). No-one would hold all the existing measurements as being very exact but they do set upper limits on the important quantities and, from these, T violation appears quite clearly.

This does not necessarily say that T violation has been demonstrated in the weak interaction. Its origin could be in the electromagnetic or the strong interaction which are not excluded in the measurements which have been taken. However separate looks at the strong and the electromagnetic have not revealed any evidence of T violation. We mention a few relevant experiments here.

Two teams have had a go at the electromagnetic interaction in trying to obtain an accurate measure of the rate of the reaction when a proton and a neutron bond together to form a deuteron and release a photon $p + n \rightarrow d + \gamma$
(This is not an easy measurement to make because it tends to be drowned in the much more frequent production of a

deuteron and a neutral pion.) The time reversed reaction, the so-called photo-disintegration of the deuteron

$$d + \gamma \rightarrow p + n$$

has been well measured at DESY, Cornell, Stanford and Orsay (though there is some conflict in the results). The two reaction rates should be the same if T symmetry holds.

The first indications on the p + n measurement came from a Michigan, Princeton team working at the 3 GeV Princeton-Pennsylvania accelerator and seemed to show a large difference in the reaction rate, compared to photo-disintegration of the deuteron, indicating a breakdown of T symmetry. The other group (Michigan, UCLA and LRL) working at the 184 inch synchro-cyclotron at Berkeley also seemed to see a slight difference. However further analysis in both experiments came out with no evidence of breakdown. From these experiments then, T violation has not appeared in the electromagnetic interaction.

Another way of examining the electromagnetic interaction comes from a consequence of T violation that particles could have electric dipole moments. Experiments at Brookhaven and Oak Ridge searched for any electric dipole moment of the neutron and saw nothing down to the level of 4×10^{-23} e cm. This is lower than the dipole moment that would be expected of the basis of most calculations if there was T violation in the electromagnetic interaction. A recent result comes from the Clarendon Laboratory, Oxford, where an experiment has searched the dipole moment of the proton. A beam of tellurium fluoride molecules was fired through parallel magnetic and electric fields. A dipole moment would reveal itself when the magnetic field was reversed with respect to the electric field. None appeared down to the level of 10^{-20} e cm (a value ten thousand times lower than any previous measurement).

Finally, in the strong interaction two experiments have looked at the rates of transformation of nuclei in both directions. A University of Washington team using their Van de Graaff studied the reaction $Mg^{24} + d \rightarrow Mg^{25} + p$ and its inverse. A team from the Max Planck Institute für Kernphysik, Heidelberg, on the Heidelberg tandem Van de Graaff studied the reaction

$$Mg^{24} + \alpha \rightarrow Al^{27} + p$$

and its inverse. Neither saw evidence of T violation.

Thus the situation is that T violation has been seen only in the decay of the long-lived neutral kaon. Does this mean that the guilty party is the weak interaction, or its newly-proposed variant the 'super-weak' interaction whose effects can, at present, only be observed in the neutral kaon?

Professor C. F. Powell

On 10 August Professor Cecil Frank Powell died from a heart attack while holidaying in Italy. Professor Powell was an outstanding physicist (Nobel Prize winner in 1950 and recipient of many other honours) and an outstanding personality whose deep concern for the social implications of science played a major part in his life.

He was born at Tonbridge, England, in 1903 and studied science at Cambridge University doing two years research at the Cavendish in the great days of Rutherford. In 1928 he moved to the H. H. Wills Physics Laboratory of Bristol University where he stayed for the rest of his life becoming Professor of Physics in 1948 and Director of the Laboratory in 1964.

His distinguished career reached a peak in the 1940s when his work with nuclear emulsions investigating cosmic rays resulted in the discovery of the pion in 1947. This confirmed the Yukawa theory of the strong nuclear force, opened the door to research with pions (which are now, some twenty years later, such 'everyday' particles at accelerator Laboratories) and exposed the mystery of the muon. Around this major achievement was a mass of work on cosmic rays, atomic nuclei, particle scattering which won a world-wide reputation for his Bristol group.

In addition to the Nobel Prize, awarded 'for his development of the photographic method in the study of nuclear processes and for his discoveries concerning mesons', he received the Hughes Medal of the Royal Society in 1949, the Royal Medal of the Royal Society in 1962, the Lamonosov gold metal in 1967 (the highest award of the Soviet Academy of Sciences), and honorary doctorates at the Universities of Dublin, Bordeau, Warsaw, Berlin and Padua.

This international list of Universities is indicative of his international reputation and his international interests. Professor Powell was among those who helped to promote the idea of CERN in the early 1950s and has been closely associated with the Laboratory ever since. From 1961 to 1963 he was Chairman of the CERN Scientific Policy Committee and remained a member of the Committee until his death. From 1965 to 1968, he was Chairman of the Nuclear Physics Board of the UK Science Research Council.

As a personality Professor Powell was held in great affection. His breadth of interest, maturity of judgement and, above all, his obrious love of so much in human achievement and aspiration, made him a fascinating speaker on many subjects. He was always concerned with the human responsibilities of the scientist. His death is felt with sadness throughout the world of physics.

As we go to press we learn of the death at Berkeley on 18 August of another Nobel Prize winner in physics — Professor Otto Stern.

Professor O. Stern was awarted the prize in 1943 'for his contributions to the development of the molecular ray method and for his discovery of the magnetic moment of the proton'.

Professor Powell (right) in conversation with Professor Van Hove when he visited CERN in 1964 for the 10th anniversary of the signing of the CERN Convention.

Around the Laboratories

1. The emitter of ultrasonic waves used (in conjunction with a conventional mechanical expansion system) to apply the required pressure changes to the liquid hydrogen in the 25 cm bubble chamber alongside. The dimensions of the emitter are: outside diameter 115 mm, inside diameter 70 mm, length 60 mm. The emitter is installed on the front flange of the chamber.

2 and 3. Photographs of particle tracks obtained in the 25 cm chamber. The chamber was fed with negative pions at an energy of 340 MeV from the Dubna synchro-cyclotron. Photo 2 was taken without the ultrasonic system operating; Photo 3, with the ultrasonic system operating.

DUBNA

Physics results

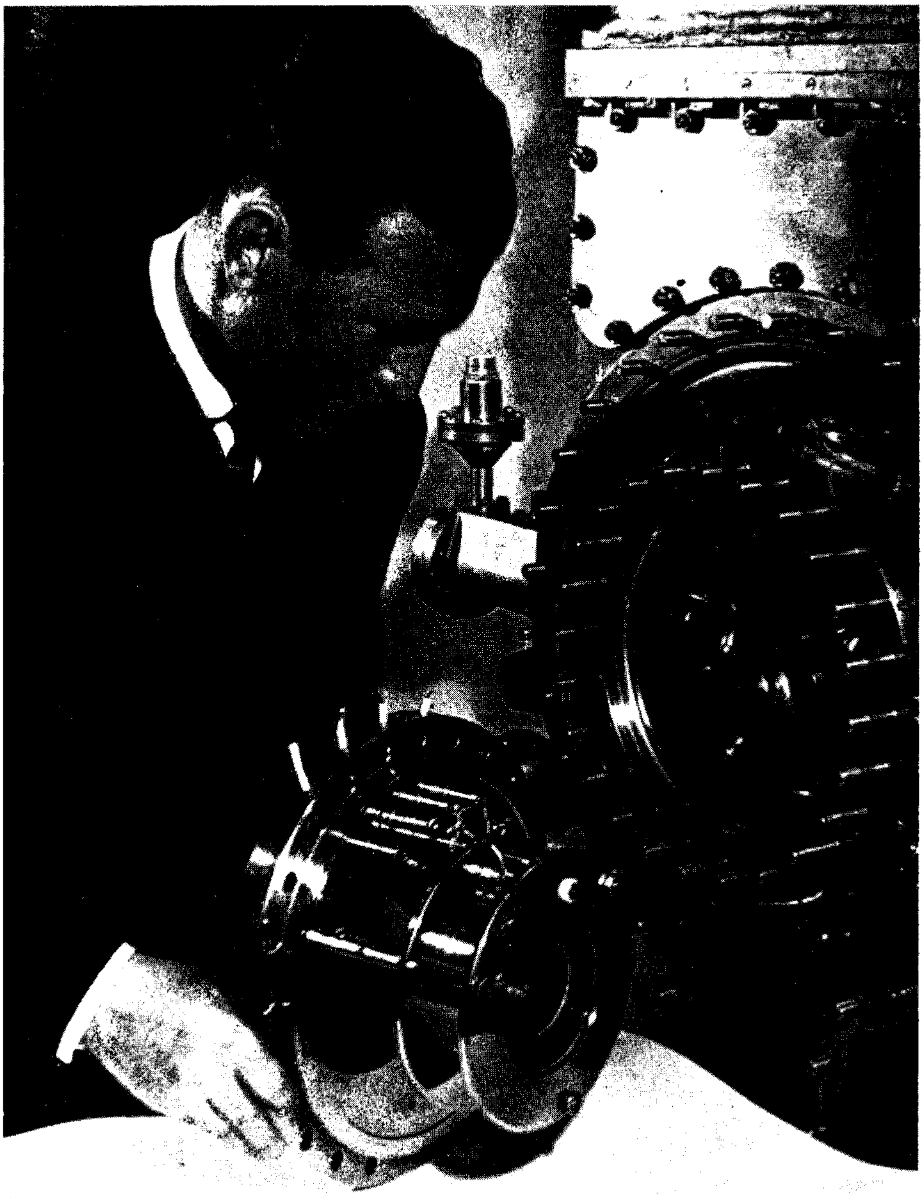
An interesting result was recently obtained by the group operating the 1 metre propane bubble chamber at the Laboratory for Nuclear Problems when studying the production of strange particles using a beam of negative pions with a momentum of 5.1 GeV/c. In the case of interactions which may be attributed to collisions with free protons, a narrow peak was observed in the spectrum of the effective mass of the system 'lambda hyperon plus gamma' emerging clearly (four standard deviations) from the background. The position and shape of the peak give the mass of the resonance as 1327.5 $\pm$ 3.5 MeV with a width of 20.0 $\pm$ 4.4 MeV. The same peak is also observed in 'carbon' events, where it is rather weaker.

Calculations show that the interactions which occur through the formation of the resonance and non-resonance states already known cannot produce such a narrow peak. The group therefore believes that it now has a serious indication of the existence of a new resonance $Y^{*\circ}_{1327}(\Lambda\gamma)$. A more attractive alternative would, of course, be to explain this phenomenon by the existence of a new baryon! Further work is continuing to obtain more statistics and detailed analysis of the results.

Nucleon clusters

At the Dubna synchro-cyclotron, studies are being made of the interaction of high energy protons with nucleon groupings or clusters within nuclei in experiments involving high momentum transfer but without breaking up the clusters.

The first stage of these studies, which has recently been completed, concerned the measurement of the differential backward scattering cross-section of 665 MeV protons on free He^3 and He^4 nuclei and measurements on the knocking out of He^3 and He^4 fragments from light nuclei. Observation of the fragments has yielded a rather clear physical interpretation, but calls for measurement of processes with relatively small cross-sections (of the order of 10^{-30} to 10^{-31} cm^2 ster^{-1}). The experiments used the proton beam from the synchro-cyclotron focused on targets con-



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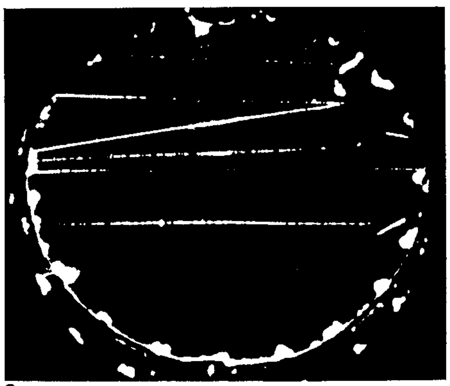

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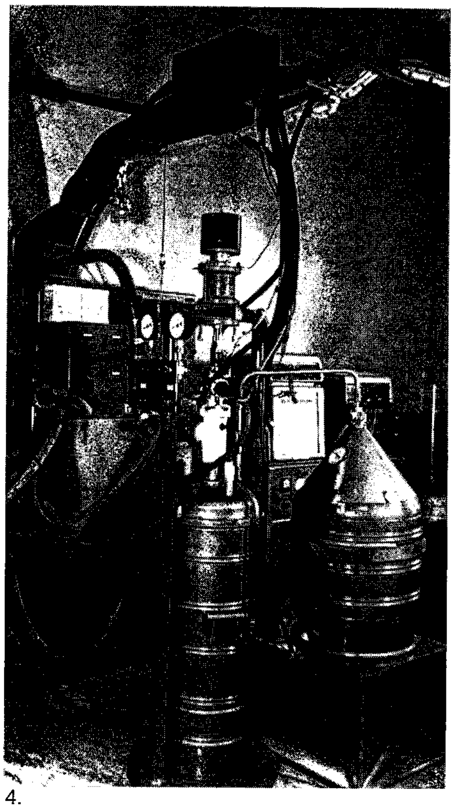
4. A view of the test rig at Dubna where the use of an electrodynamic expansion system for rapid cycling of a bubble chamber, taking advantage of high fields from superconducting coils, is being studied.

5. The coil with a mobile superconducting winding before installation on the test rig.

(Photos Dubna)



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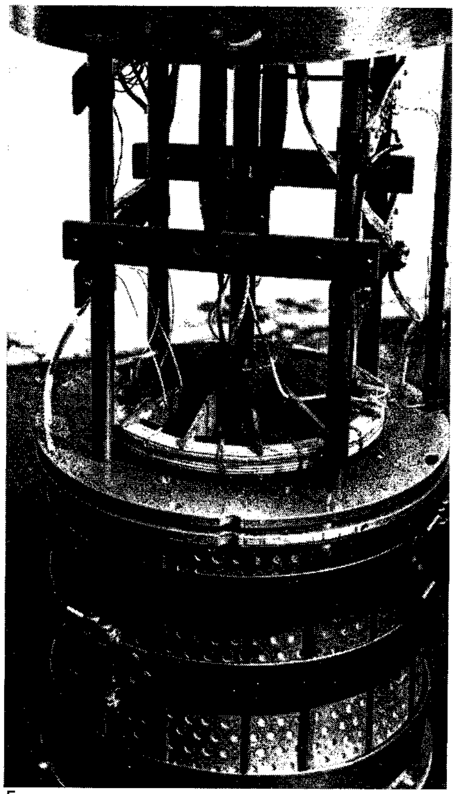

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taining the nuclei under investigation; the He^3 clusters with an energy of about 530 MeV and He^4 clusters with an energy of about 470 MeV, which were knocked out at a small angle, were analysed for momentum, time of flight, ionization and free-path. The spectra from Li^6 and Be^9 nuclei revealed a peak caused by quasi-elastic scattering of protons on 3- and 4-nucleon clusters in these nuclei. By comparing the cross-sections of quasi-elastic and elastic scattering on free helium nuclei an estimate was made of the total effective number of such clusters. The values obtained are consistent with calculations based on an oscillatory shell model; the size of the observed cross-sections can be explained by the representation of the straight interaction of protons with density fluctuations in nuclei.

Chemical reactions of muonium

Investigations at the synchro-cyclotron into the chemical reactions of muonium (the association of a muon and an electron or positron circulating about each other) are beginning to take an interesting turn. A number of experiments have been carried out to study the possibilities of using muonium for physico-chemical investigations.

Assymetry in the angular distribution of the μ — e decay was measured as a function of temperature (in the range + 90° to — 196°C) using monocrystals of germanium containing varying amounts of arsenic. The results agree qualitatively with the pattern of change in the electron (vacancy) density in a semi-conductor and with the existence of free muonium in pure germanium at a low temperature.

Investigation of an homologous series of organic compounds, with a view to explaining the dependence of their reaction capacity on their structure, showed that, in a number of cases, the speed of chemical reactions is additive. Measurements were also made of the dependence of polarization on the direction and intensity of a magnetic field using a plastic scintillator with a polyvinyloxylene base. The influence of the number of methyl groups of the original molecule was recorded for various types of plastic.

Ultrasonics in bubble chambers

CERN COURIER has already carried information on the operation at CERN of a small helium bubble chamber using ultrasonic waves to establish the required pressure changes (vol. 8 page 316) and has briefly reported similar work at Dubna (vol. 9 page 136).

The Dubna work began in 1967 and has been carried out jointly by a group from the Laboratory for Nuclear Problems and the Acoustics Institute of the USSR Academy of Sciences. The aim was to examine the effect of ultrasound on the sensitivity of liquid hydrogen, which is the most desirable liquid for the study of the interactions of elementary particles.

The experiments were carried out in a 25 cm liquid hydrogen chamber, in whose working volume were located an ultrasonic emitter and receiver. The emitter had a cylindrical focusing system made of a ceramic of barium titanate emitting ultrasonic energy at a resonant frequency corresponding to the first vibration mode (14 kHz). The emitter was placed axially in relation to the working volume of the chamber. The chamber was installed in a beam of negative pions with an energy of 340 MeV obtained from the synchro-cyclotron.

The ultrasonic system was operated at the same time as a conventional mechanical system while the chamber received pions from the synchro-cyclotron. The ultrasonic pulse lasted 15 ms (a voltage of 1.2 kV was fed to the emitter simultaneously with the mechanical expansion) and the amplitude of the pressure swing in the chamber due to the ultrasonic pulse was approximately 1 atmosphere. With the chamber operating at 27°K the mechanical system needed to apply only half its normal pressure. The introduction of ultrasound has a marked influence on the growth of the bubbles along the particle tracks. The acoustic field in the working volume of the chamber was such that continuous tracks could be observed and the use of the focusing system made it possible to create pressure amplitudes which were much higher than the pressure on the surface of the emitter, which is of considerable importance for reducing parasitic boiling.

The results obtained demonstrate the possibility, in principle, of replacing the entire mechanical expansion system of a hydrogen bubble chamber by an ultrasonic system.

Rapid cycling bubble chambers

Great attention has recently been paid to the problems of achieving rapid cycling bubble chambers. The fact that the new generation of chambers use strong magnetic fields created by superconducting coils means that the expansion system can be based on a method which uses a movable coil carrying a current which interacts with the radial component of the magnetic field of the main superconducting coil. Such an electrodynamic expansion system is quite similar to pneumatic or hydropneumatic systems but differs from them in that it has the advantages of a control system that is rapid in operation and simple in design.

In order to carry out a comprehensive study of such a rapid cycling electro-dynamic expansion system for the bubble chamber which is being built at Dubna, an experimental rig has been assembled. It has a superconducting coil giving a field of 30 kG at its centre. Situated at the outside end of the coil, in the region where the radial component of the stray magnetic field is at its maximum, is a mobile superconducting winding. The force which is developed on the winding is transmitted through a bar to the moving parts of a dummy chamber. The weight of the moving parts and the 'rigidity' of the chamber can be varied within specified limits.

A test run showed that a pulsed current of up to 1000 A in the mobile winding produces an active force in the system reaching a value equivalent to 1240 kg. No undesirable phenomena occurred in the main magnet coil or in the mobile winding, and there was no substantial increase in the liquid helium consumption.

STANFORD (SLAC)

90 bubble chamber pictures per second

The two sections at the end of the report from Dubna above indicate two approaches in the pursuit of bubble chambers capable of very high cycling rates. From the Stanford Linear Accelerator Centre comes the news that H. Barney, A. Rogers (who also played a leading role in the ultrasonic chamber work at CERN) and S.J. St. Lorant have developed and tested a small hydrogen chamber to a cycling rate of 90 per second.

Existing large chambers have rather ponderous mechanical systems to apply the required pressure changes to the liquid in the chamber and are limited to a small number of expansion cycles, and therefore to a small number of pictures, during each burst of particles from an accelerator. For example, it was a quite exceptional achievement for Argonne to reach five pictures per accelerator pulse (see CERN COURIER vol. 8 page 312). It will probably be many years before any great advance on this becomes possible for the very large chambers (for which the picture-measuring specialists may breath a sigh of relief) but there will probably be great interest if small bubble chambers, which are as continuously sensitive for recording particle tracks as they can be made, become available soon. They could

On 28 July, the UK Minister of State for Education and Science, Mrs. Shirley Williams, visited Daresbury Nuclear Physics Laboratory where research is centred on the 5 GeV electron synchrotron NINA. Mrs. Williams was accompanied by Sir Brian Flowers, Chairman of the Science Research Council. (Professor Flowers received a knighthood in the Queen's Birthday Honours List.)

1. *Mrs. Williams listening to an explanation by E. Erickson of an experiment being carried out by an Orsay/Strasbourg/Daresbury team on backward positive pion photoproduction.*
2. *Grouped between the spectrometer arms of the Lancaster/Manchester experiment which looks at inelastic electron scattering, left to right: R.G.P. Voss (acting Director of the Laboratory), A. Merrison (Vice Chancellor of Bristol University), Mrs. Williams, A. Clegg (leader of the experimental group) and Sir Brian Flowers.*
3. *Members of the Nuclear Physics Board of the SRC on the Laboratory's barge which makes use of one of the most pleasing features of the Laboratory site — the Bridgewater canal which runs along one of its boundaries.*
4. *J.B. Adams, Director Designate of the 300 GeV Laboratory, emerging from the barge.*

(Photos Daresbury).

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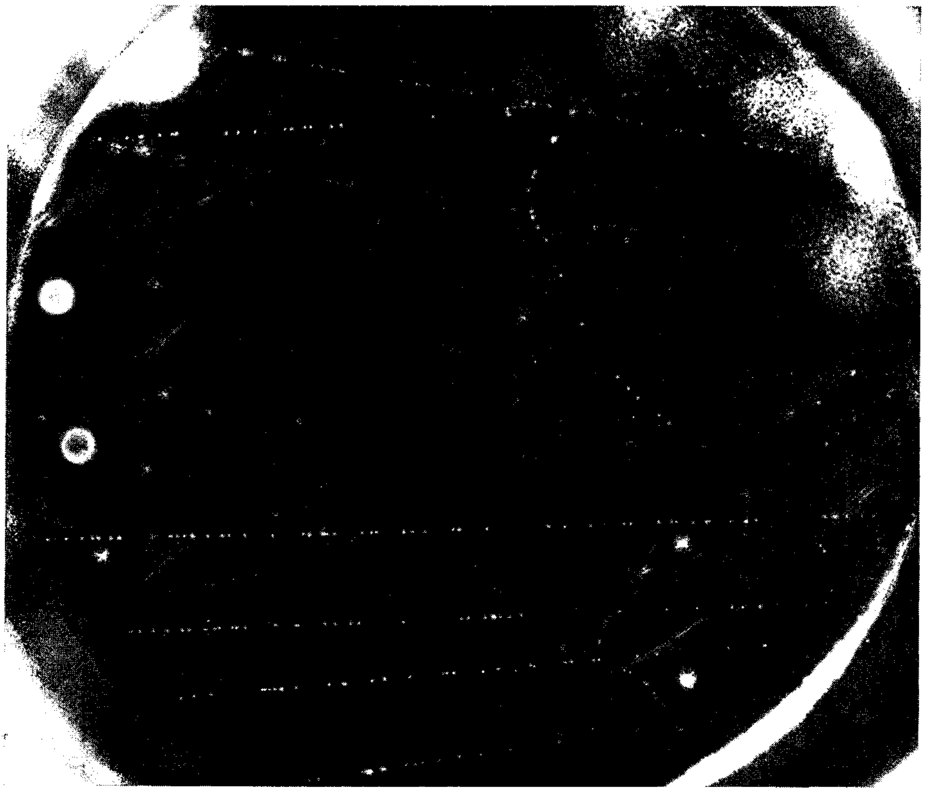
A photograph taken in the original 5 cm hydrogen bubble chamber at Stanford when operating at a rate of 90 pictures per second.



be extremely useful as the hydrogen target, yielding a visual record of the immediate interaction region, for example in a wide variety of experiments involving counters and spark chambers.

Under reasonable operating conditions in a hydrogen chamber, bubbles can grow to a size at which they can be photographed in a time of about a quarter of a millisecond and can be snuffed out in just over a millisecond. From this consideration alone then it could be possible to take pictures at the rate of several hundred per second.

To see how far in this direction they could go, the Stanford team built a small cylindrical chamber 5 cm in diameter and 5 cm high in which the chamber body consisted of a convoluted bellows. This was connected to a 'Vibration Exciter' so that the bellows were driven in and out like the diaphragm of a loudspeaker by powering its loudspeaker coil.

Initial parameters of the system allowed operation upto 60 cycles per second and, following successful operation at this frequency, the piston and coil of the Exciter were modified to allow still higher rates. Successful operation continued at 90 Hz under the following operating conditions — steady pressure on the liquid, P_o, was 9.2 atmospheres; pressure below which bubbles formed, P_v, was 6.8 atm.; amplitude of the pressure swing produced by the expansion system, Δp, was 3.8 atm. The chamber proved sensitive to minimum ionizing particles from a cobalt 60 source and from the SLAC electron linac. No 'residue' from uncompressed bubbles from the previous expansion was observed on the photographs (checked by photographing an expansion following one in which particles were fired in).

A larger chamber, 10 cm diameter, 7 cm high is now under test and has also operated successfully at 90 Hz. This research has shown that very rapid cycling bubble chambers are feasible and the performance limits have not yet been reached. The Stanford group consider that it is already feasible to build a chamber with dimensions of 25 to 30 cm which could operate at cycling rates of around 120 per second.

ARGONNE

Negative hydrogen ion injection into ZGS

On 1 July negative hydrogen ions were injected into the Zero Gradient Synchrotron at an energy of 50 MeV, stripped of their electrons, and accelerated as protons to the full synchrotron energy of 12.5 GeV. This experiment was part of a programme of tests being carried out in preparation for a proposed Booster Injector for the ZGS, designed to increase the intensity of the machine by about a factor of ten. It is probably the first time that the proton beam in a large synchrotron has been drawn from negative ion injection.

The technique of charge exchange injection was proposed by G.I. Budker at Novosibirsk in 1959 (reported for example at the Dubna Accelerator Conference in 1963) as a way of defying Lioville's theorem. The theorem dictates that having produced a particle beam one is stuck with the phase space density throughout the acceleration cycle. Thus one can only pack the beam into a smaller physical cross-section by introducing a wide-angular spread in the particles passing through that cross-section. With the use of the charge exchange process during injection, however, the theorem does not apply and it is possible to achieve higher phase space density in the converted beam compared with the incoming beam. Budker and his colleagues carried out successful tests of the idea in August 1964 (reported briefly at the Frascati Accelerator Conference in 1965). Their main concern was for intense beams in the storage rings at Novosibirsk. They use a double stripping — converting the negative hydrogen ion first to neutral hydrogen which passes straight through the fringe field of the ring magnet (unaffected by the field because it carries no charge) before being further converted to a proton.

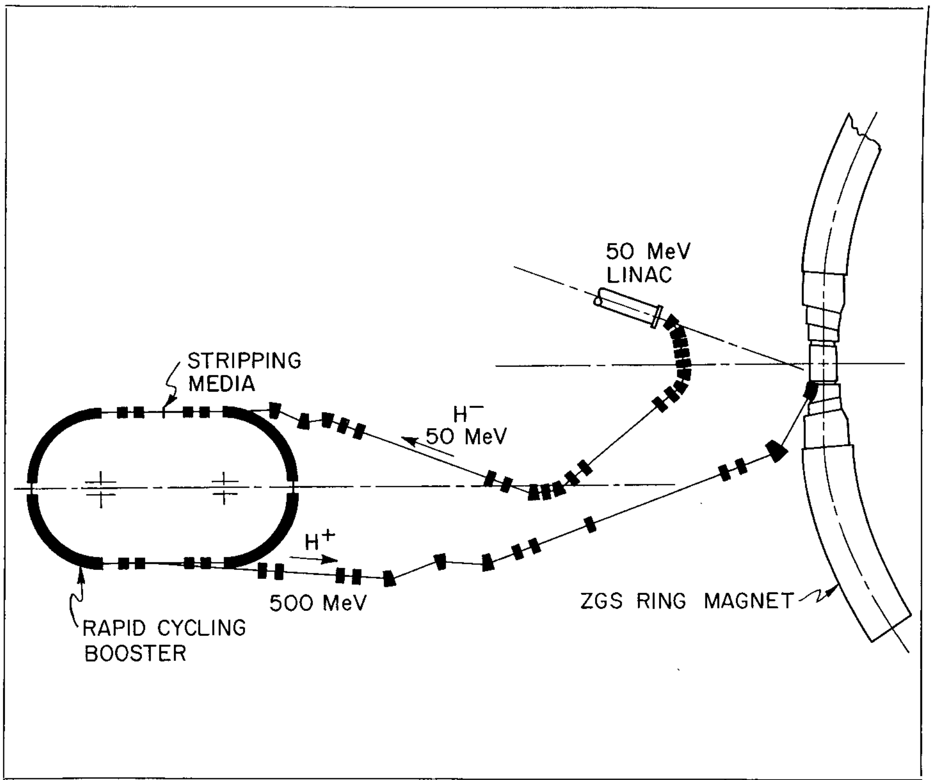
The interest in this technique at Argonne is in the context of a proposed 500 MeV Booster. By injecting negative hydrogen ions into a rapid cycling booster, it is believed possible to achieve a high phase space density of converted protons. These protons would be accelerated to 500 MeV for injection into the main synchrotron ring

1. *Layout of the proposed 500 MeV Booster to increase the intensity of the Argonne Zero Gradient Synchrotron. Negative hydrogen ions are fed to the rapid cycling Booster where they are converted to protons which are accelerated to 500 MeV for injection into the ZGS.*

2. *Photograph of the stripping foil in its holder which was used in preliminary tests of the charge exchange injection technique.*

3. *Beam paths at the stripping foil. The incoming negative ion beam converts to protons and the magnetic field holds the proton orbits at the position of the foil while injection continues over many turns.*

(Photos Argonne)



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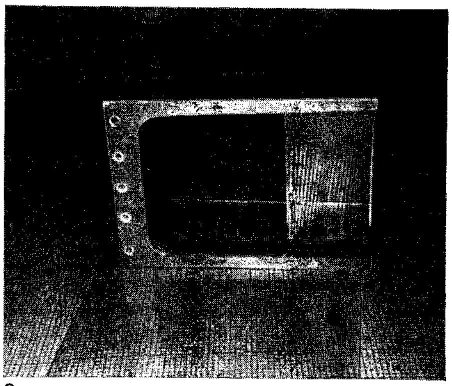

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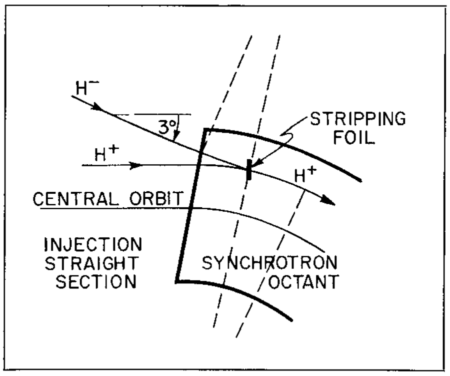

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of the ZGS where, at this injection energy, the normal space charge limit should be 1.4 x 10^{14} protons.

For the experiment, negative ions were produced in a hydrogen gas charge exchange cell (15.2 cm long, 1.19 cm diameter) which received the positive ion output of an extended stationary arc duoplasmatron source.

During preliminary bench tests, this system yielded a negative (unanalyzed) current of 8 mA. Free electrons produced in the hydrogen target gas were trapped in the cell and positive ions emerging from the cell were stopped by the retarding field of a tandem acceleration arrangement which doubled the energy of the particles making the transition from H^+ to H^-. The contribution to the measured current by secondary electrons in the beam path has not yet been determined.

For the initial attempt at H^- injection into the ZGS, only 0.4 mA of negative ion current was accelerated by the 750 kV column and transported to the linear accelerator. Of this, 0.2 mA was accelerated to 50 MeV and injected into the ZGS. After stripping the electrons off the ions by means of a foil positioned in the synchrotron, 150 μs of injected beam (corresponding to 1.8 x 10^{11} H^- ions injected over many turns) yielded 3 x 10^{10} protons/pulse accelerated to 12.5 GeV.

The conversion from H^- to H^+ was accomplished using a Poly (P) Xylylene foil 5800 Å thick, 5.1 cm wide and 11.4 cm high. (The Union Carbide Corporation trade name of the foil material is Paralene C.) Preliminary measurements with the stripper foil in the 50 MeV beam transport system showed that the H^- to H^+ conversion efficiency was better than 90 %. For injection into the ZGS, the stripping foil was located 61 cm into the first magnet octant and 28 cm outside the central orbit location. At this position, negative hydrogen ions injected into the preceding straight section at an angle of 3° are deflected outward in the magnet field and are converted into protons which, at the correct field strength, travel on an equilibrium orbit located at the foil.

The inflector magnet normally used for the injection of protons was removed for the negative ion injection. Injection could thus continue for a long time (over many turns) without the necessity of increasing the magnetic field rapidly to move the equilibrium orbit inwards to keep the orbiting protons from colliding with the septum of the inflector. The scattering of the circulating protons as they passed through the foil during succeeding turns after injection was expected to be small, but no attempt was made to measure this scattering during the initial injection experiment. The rate of rise of the synchrotron magnetic field was reduced from the normal value of 20 kG/s to 10 kG/s to reduce the spread of betatron oscillation amplitudes for long injection times. In the future, still smaller rates of rise for the field will be tried.

In the Booster proposal, during the preliminary H^- injection studies and tune-up of the Booster, normal operation of the ZGS would continue with injection and stripping of H^- ions at 50 MeV. This would require improvement of the source and better matching into the 750 kV column and linear accelerator to produce acceptable beam intensities.

EEV thyratrons-for better high speed switching

EEV glass and ceramic hydrogen thyratrons are extensively used to provide more precise and efficient high speed switching. Here are some of the reasons why:

1 Their short anode delay time of between 20 and 120 nanoseconds depending on triggering method.
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5 The low trigger power required.
6 The wide operating voltage range of 1kV-120kV with four tubes.
7 The ability to control anode delay time and rise time of current, using reservoir.
8 The wide reservoir range for maintenance of gas pressure typically 4.5V to 5.7V.

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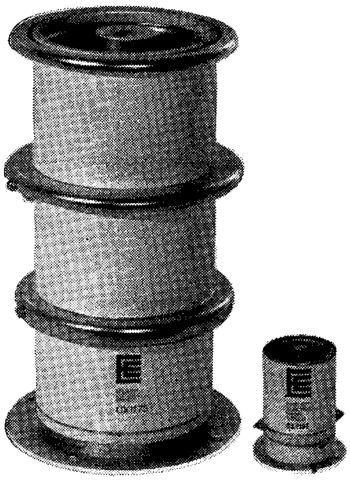

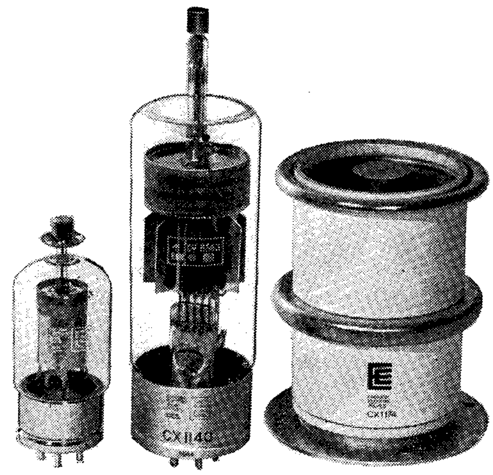

Brief data on some of the ceramic types available.

Type	Peak power output max (MW)	Heating Factor (V.A.p.p.s.)	Peak forward voltage max (kV)	Peak anode current max (A)	Mean anode current max (A)
CX1154	50.0	30 x 10⁹	40	2500	3.0
CX1157	3.5	7 x 10⁹	20	350	0.35
CX1168	100.0	70 x 10⁹	80	2500	2.5
CX1171	150	70 x 10⁹	120	2500	2.5
CX1174	120	60 x 10⁹	40	6000	6.0
CX1175	200	140 x 10⁹	80	5000	6.0
CX1180	12.5	9 x 10⁹	25	1000	1.25

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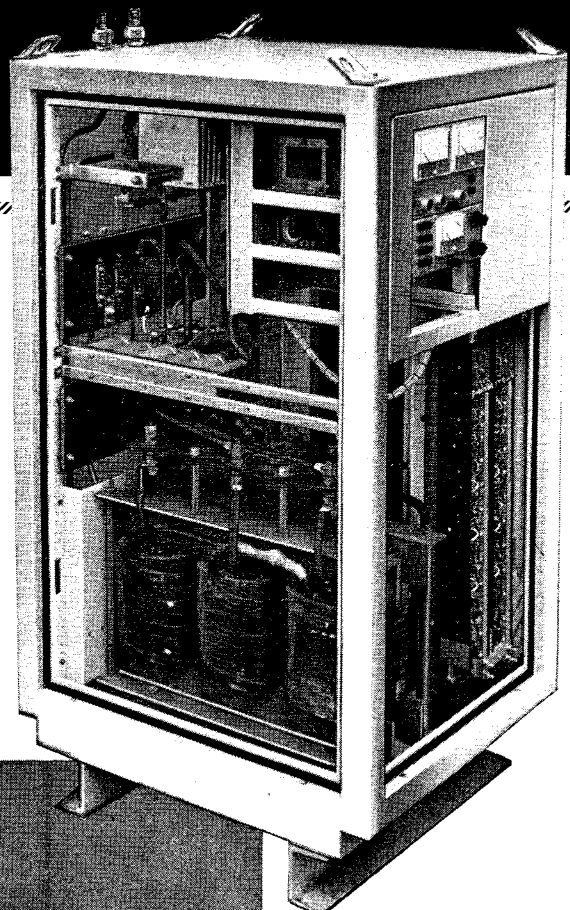

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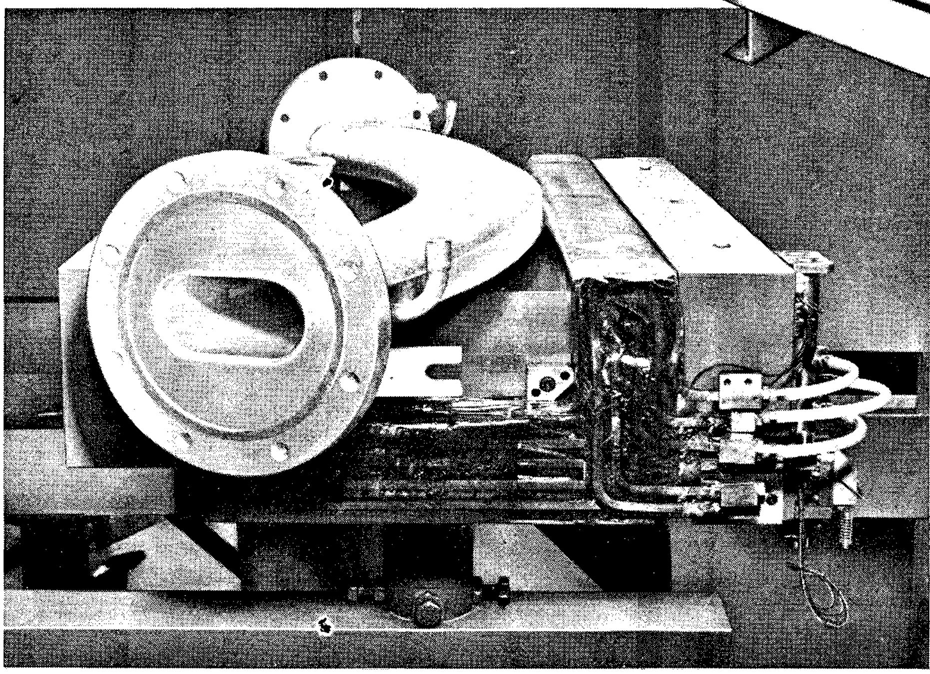

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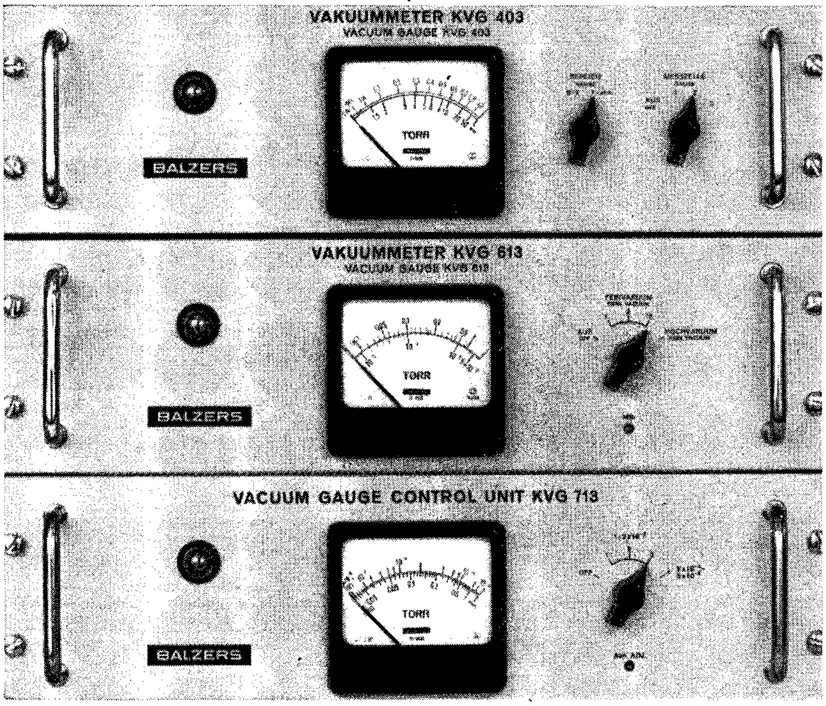

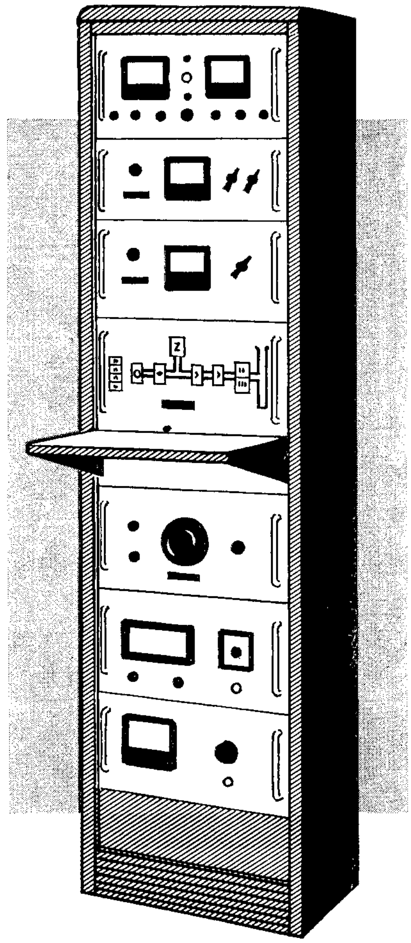

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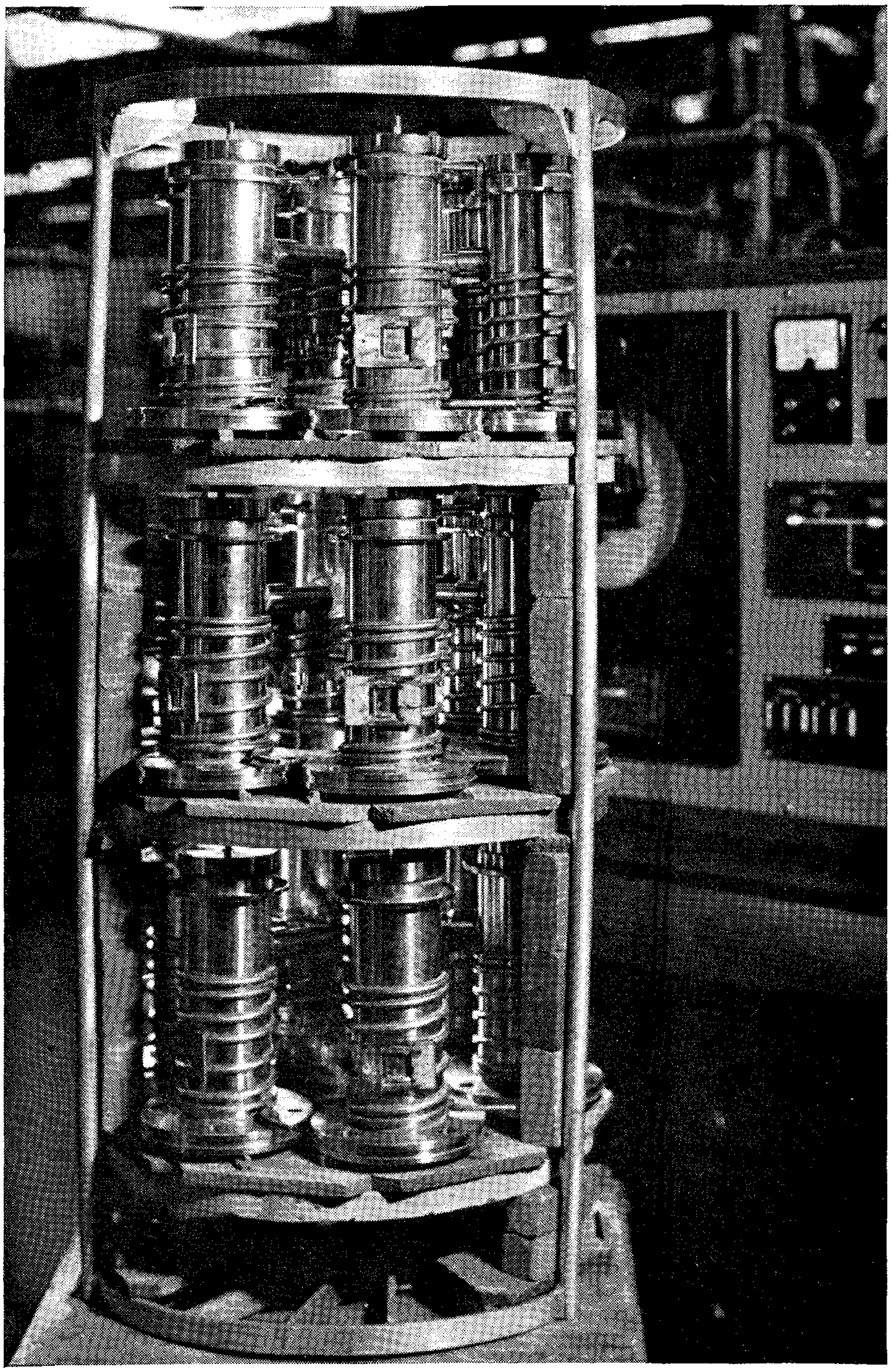

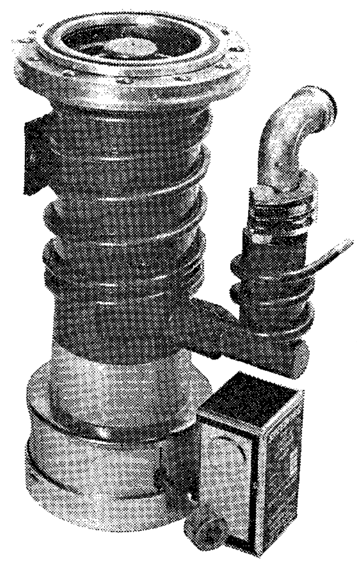

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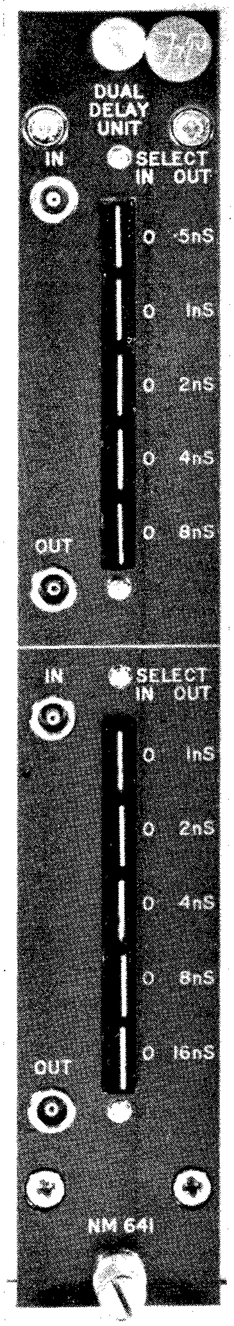

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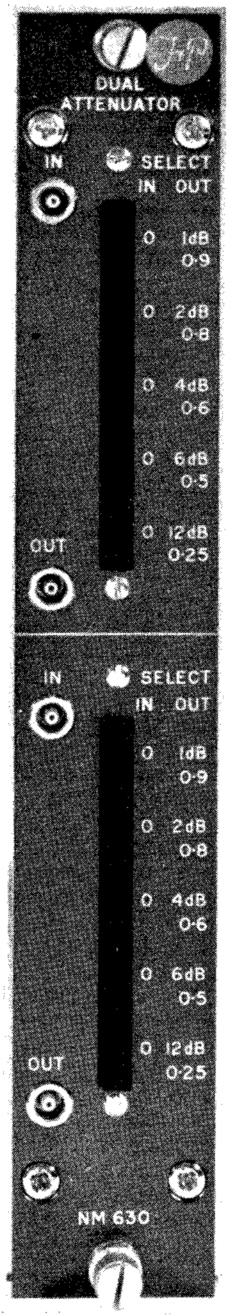

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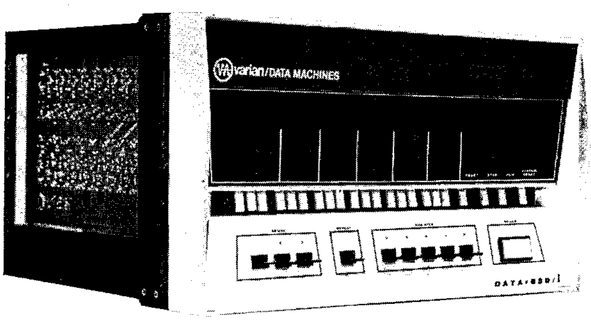

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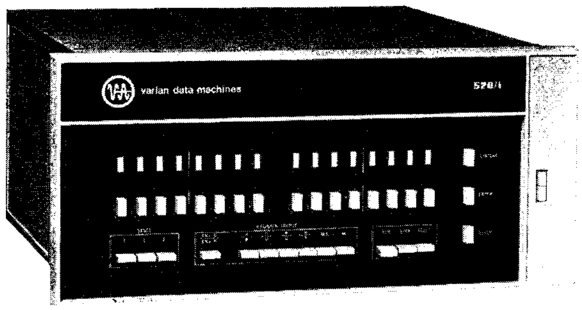

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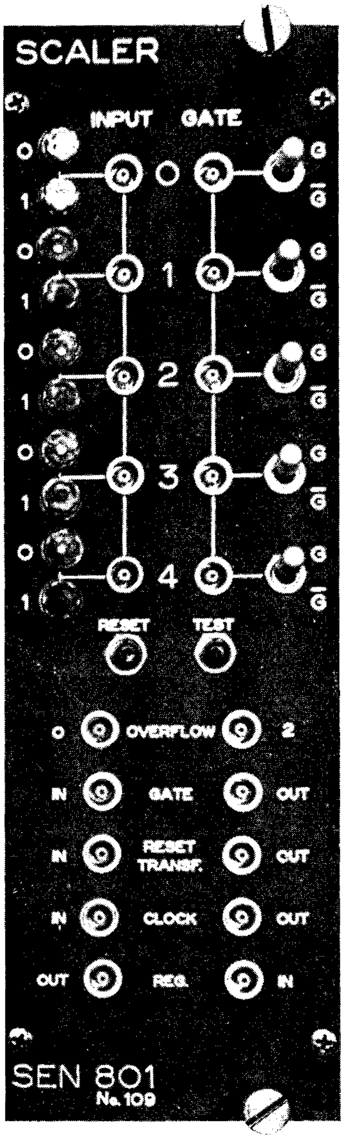

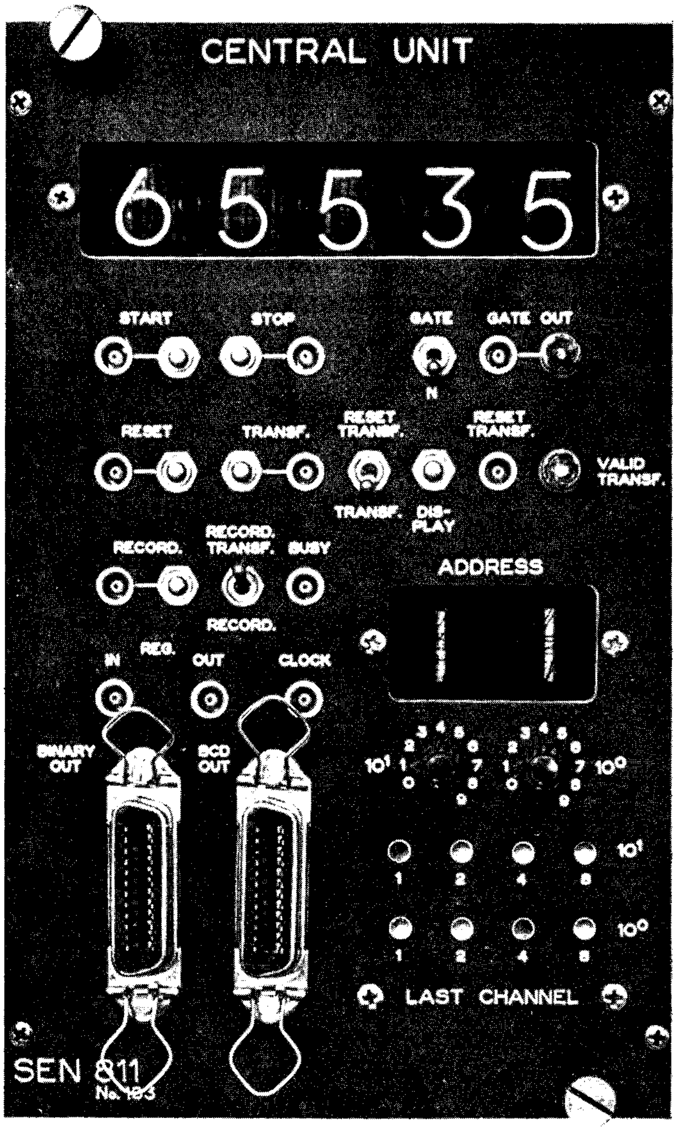

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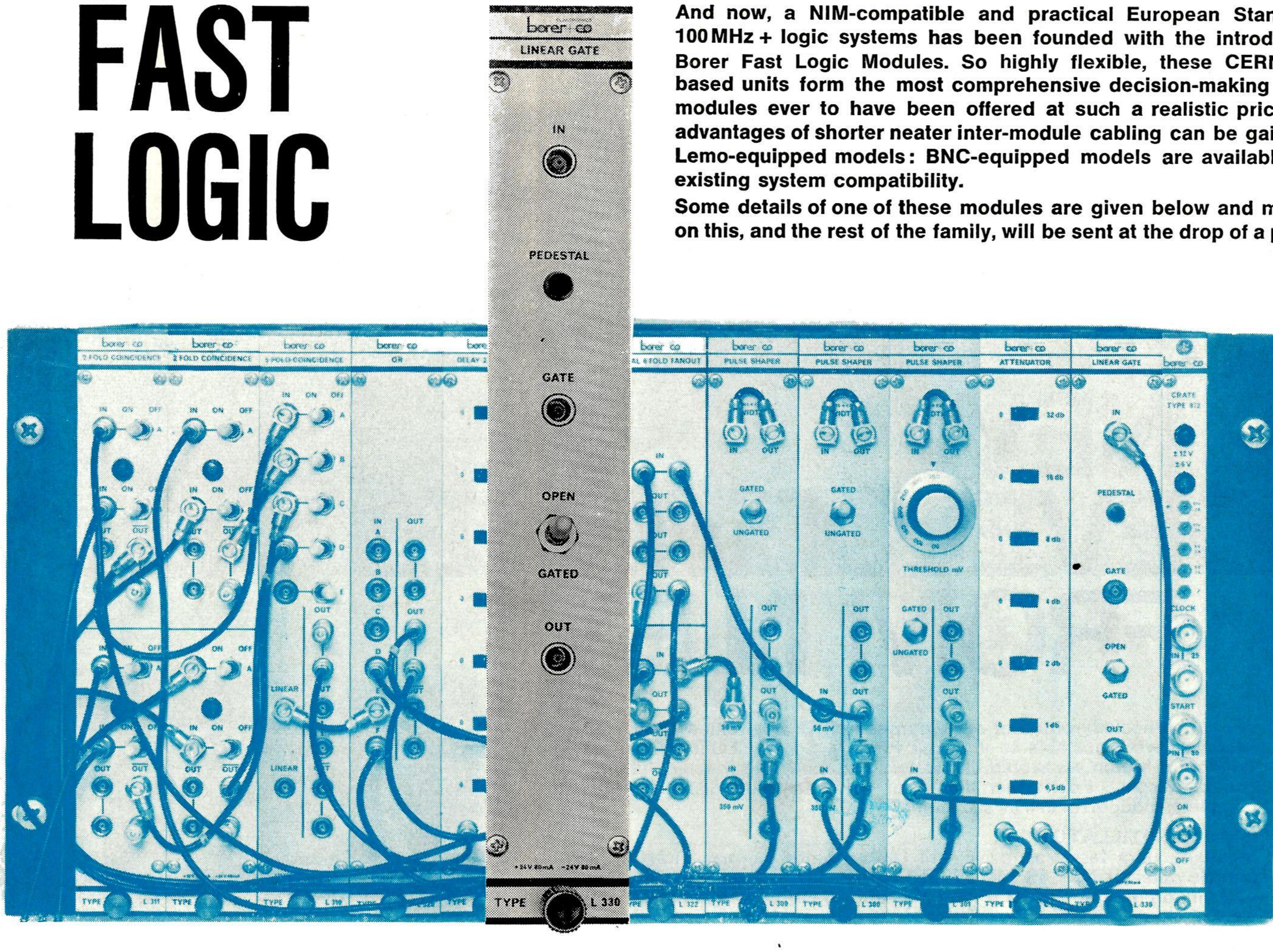

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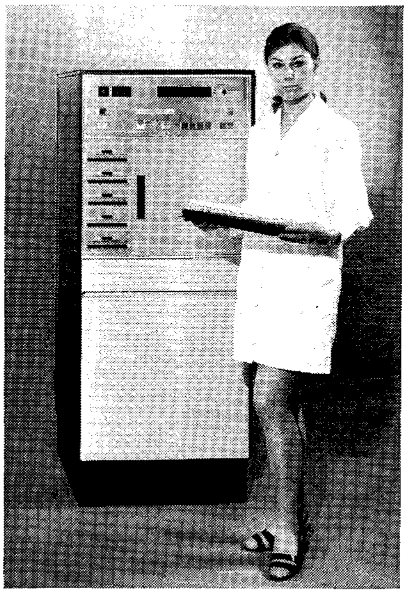

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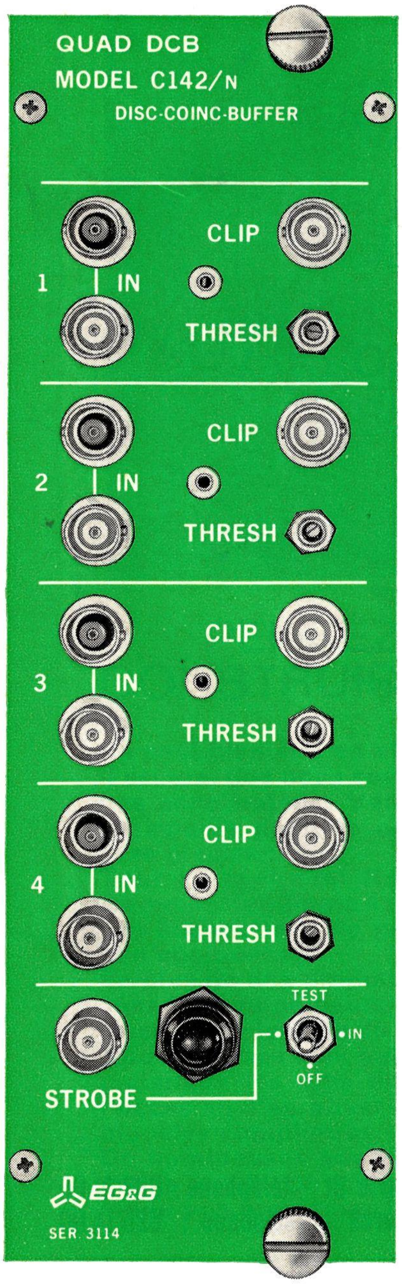

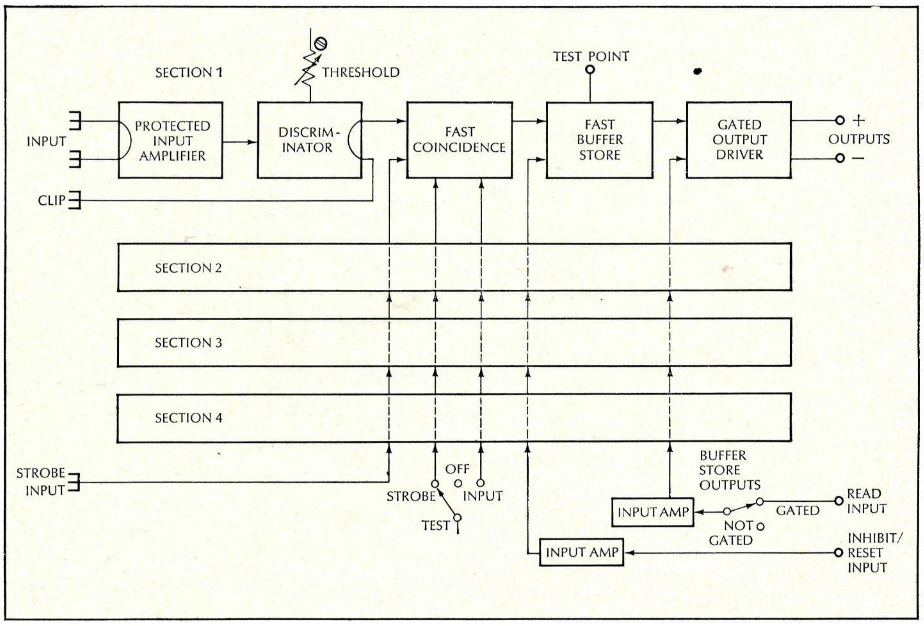

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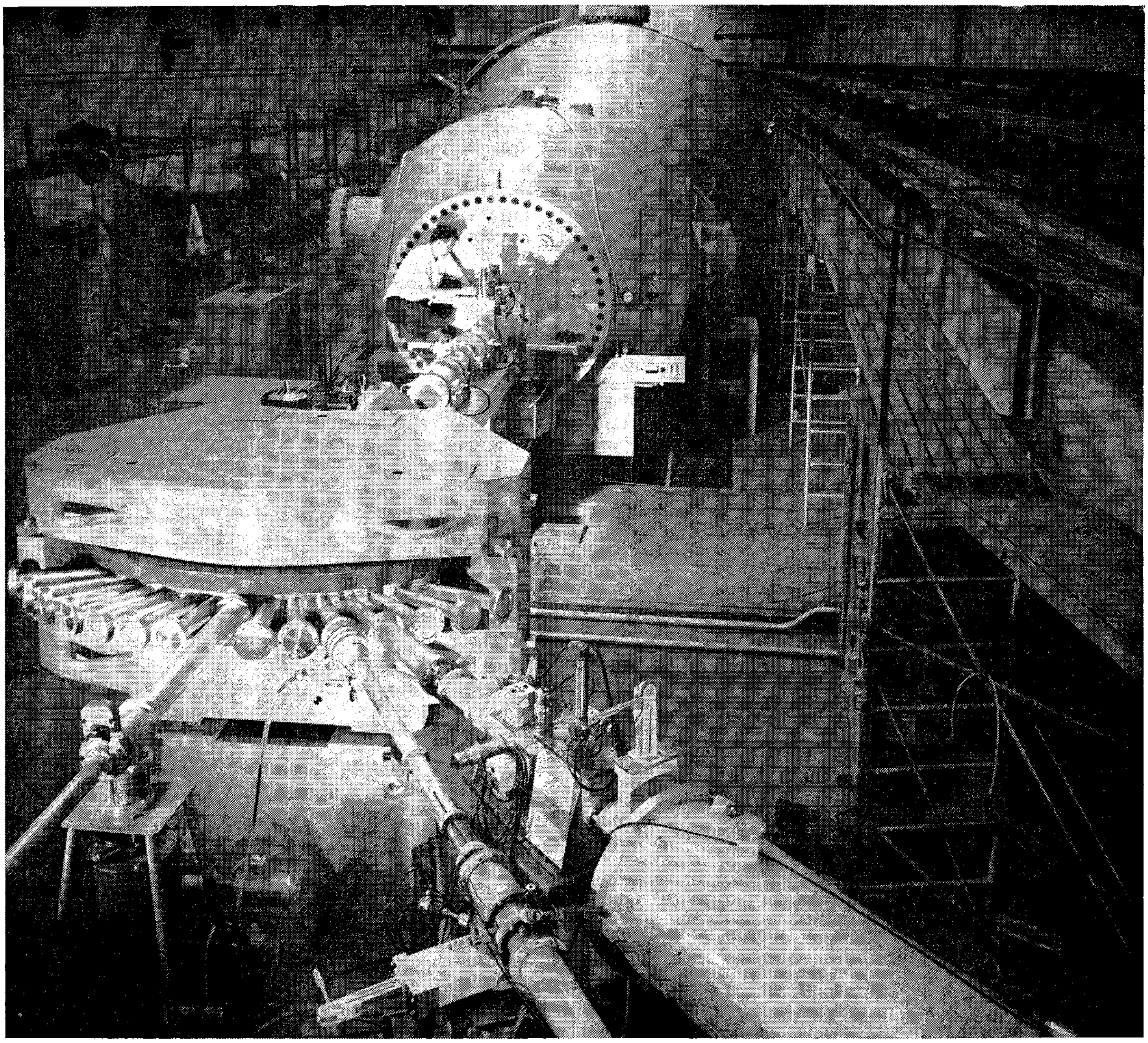

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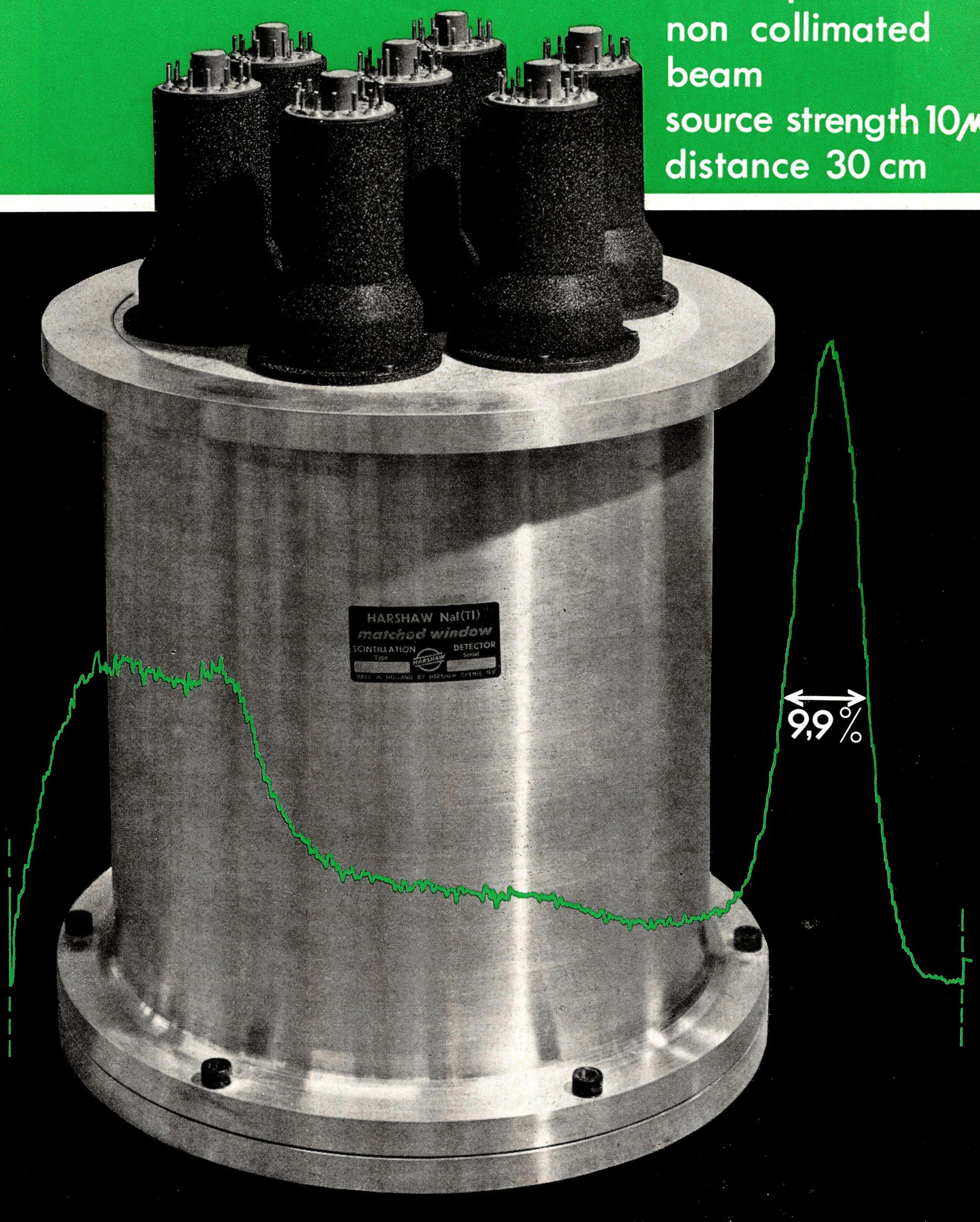

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