CERN

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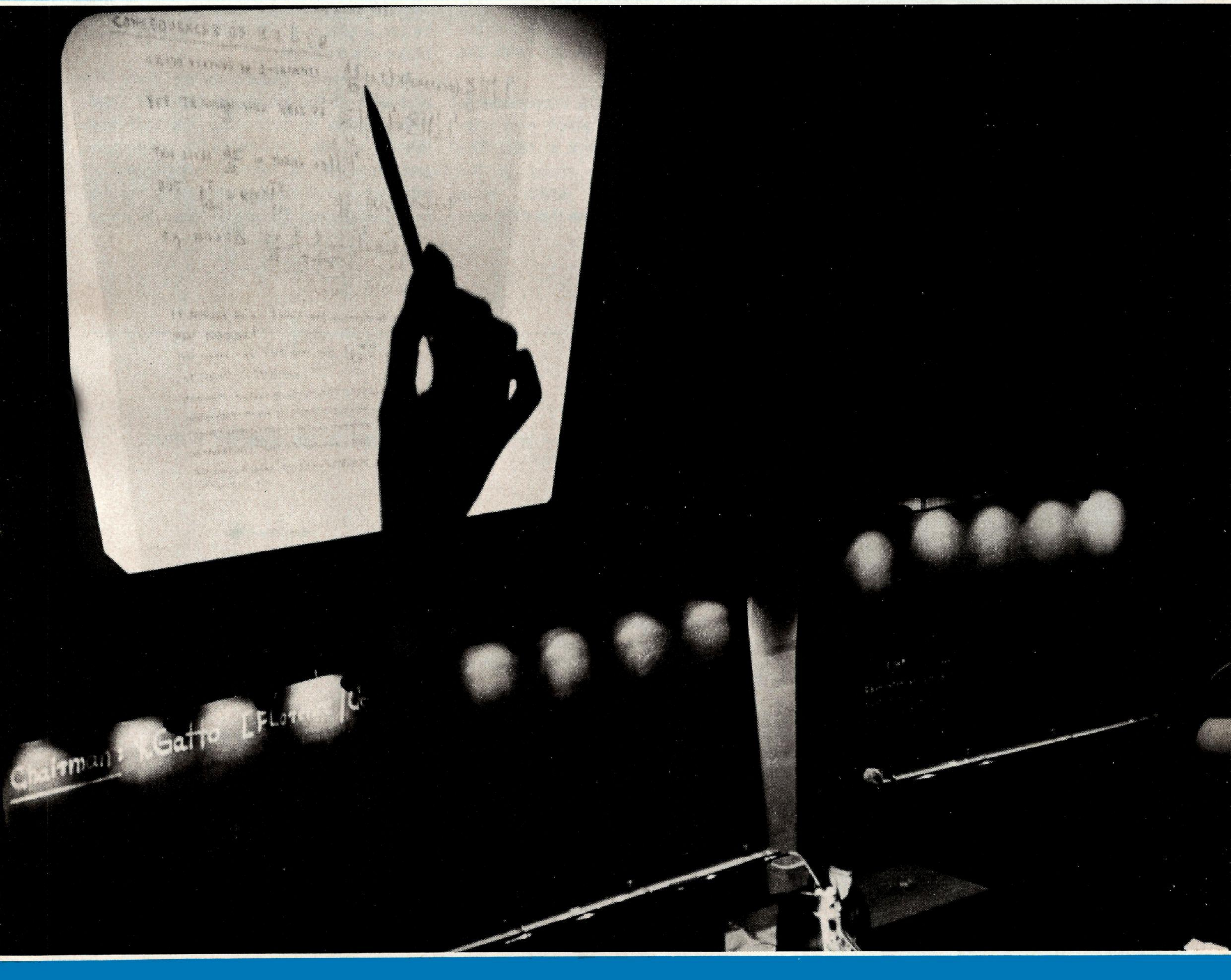

CERN, the European Organization for Nuclear Research, was established in 1954 to '... provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto'. It acts as a European centre and co-ordinator of research, 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 700 physicists outside CERN are provided with their research material in this way.

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 2350 people and, in addition, there are over 400 Fellows and Visiting Scientists.

Thirteen European countries participate in the work of CERN, contributing to the cost of the basic programme, 197.5 million Swiss francs in 1968, 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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Comment

The main article in this issue concerns a new injection system to be built for the CERN proton synchrotron (CPS). The system involves the addition of four synchrotrons stacked one on top of another, each a quarter of the size of the CPS. They will be fed by the existing 50 MeV linear accelerator (after some modifications), and will boost the energy of the protons to 800 MeV before injection into the main synchrotron. (The new synchrotrons are thus often referred to as the 'Booster'.)

With higher injection energy, more intense beams will be accelerated in the CPS and will make it possible to do more experiments in a given time, .or more detailed experiments, or even some experiments which are not feasible with the present beam intensities.

The Booster is part of the improvements programme at the CPS, which was supported by the CERN Council in 1965. The improvements incorporate many of the technological advances which have emerged in the decade since the CPS was built and are intended to meet the growing demand from European Universities to do research at CERN, and to continue to provide the finest possible equipment with which to do this research.

In addition, the design of the new injection system has been greatly influenced by the existence of the intersecting storage rings as an appendage to the proton synchrotron. Theoretical work on beam dynamics in the ISR indicated that much higher interaction rates would be possible if certain tricks could be performed on the beams fed to the ISR. The Booster has been made much more complicated than would be necessary if its only concern was better physics at 28 GeV, so that these tricks can be done.

The present preoccupation with the problems of the proposed 300 GeV Laboratory tends to submerge the fact that, thanks to the improvements programme and the ISR, a healthy programme of research in sub-nuclear physics is ensured at CERN-Meyrin for many years to come.

Contents

Cover photograph: A conference on Hadrons was held at CERN in January. The photograph has caught the hand of P. Salin, projected by a Vu-graph in the Main Auditorium, as he was giving his talk on 'Problems connected with high energy scattering near the forward direction'.
(CERN/PI 1.2.68)

The New Synchrotron Injector

K.H. Reich

Dr. Reich is Deputy to the Leader of the newly formed Synchrotron Injector Division and has acted as co-ordinator of the Study Group on the CPS improvements for the past eighteen months.

Various aspects of the improvement programme for the CERN proton synchrotron (CPS) have already been described in CERN COURIER, particularly in the issue of April 1966 (vol. 6, page 63). The present article discusses the need for a new injector, its basic performance specifications, the various possibilities considered and the final choice.

Why build a new injector?

Despite a considerable effort at both Brookhaven and CERN during the last few years, and a sizable increase in the proton current from the CPS injector, the beam intensity of neither the Brookhaven synchrotron (AGS) nor the CPS has increased markedly during this period. Both machines accelerate around 10^{12} protons per pulse. We cannot of course exclude the possibility that some further (dynamic) corrections of the magnet field at injection might lead to a certain increase in intensity. (At the CPS, several sets of dipole, quadrupole and sextupole d.c. corrections are already in use.) Also, other developments such as a lower vacuum pressure or an improved radio-frequency system might lead to higher intensity.

However, it is now thought that none of these measures could yield the improvement factor of about ten in intensity that we are looking for to enable experimenters in the 1970s to perform more and more sophisticated experiments with 25 GeV beams and faster or more precise experiments with the intersecting storage rings (ISR).

As explained in detail in the COURIER article referred to above, we believe that we are up against a rather fundamental space charge limit. These space charge phenomena are complex and not yet fully understood. They all have to do with the effects of the electric and magnetic fields created by the electric charges of the many circulating protons. Among the several known phenomena, the one believed to be determining the space charge limit of the CPS is that the repulsive forces between the protons weaken the effect of the external focusing forces, and this leads to a lowering of the frequency of betatron oscillations. When the number of betatron oscillations per revolution reaches a half integer or an integer value, a resonance occurs and the beam is lost. The only way known so far to push this limit up by the desired factor is to inject into the CPS at a substantially higher energy, say at least several hundred MeV compared with the present injection energy of 50 MeV.

What is the new injector required to do ?

In addition to achieving a substantially higher energy an obvious requirement for the new injector is that it should produce an intensity of 10^{13} protons per pulse in a way acceptable to the main synchrotron. There are however more subtle requirements.

The first one, recognized almost from the beginning of the CPS improvement studies, concerns the beam *emittance.* This somewhat abstract notion is used to characterize the beam 'size' in *phase* space rather than in *real* space. In fact, the statement that a particle beam has a cross-section of, for instance, 1 cm² is in many cases of restricted practical value. This is not only because the beam cross-section can be decreased or increased by the use of magnetic lenses, but also because it does not indicate whether the beam would pass without loss through a given part of an accelerator. In contrast, the emittance (which is defined as π times the product of half the beam width in a given plane at a beam waist and the maximum angle with which any particle crosses the beam axis at the same point in the plane - Figure 1) is independent of the value of the cross-section at any particular point. The beam can, in principle, be made to pass without loss through any element (vacuum pipe, magnet or complete accelerator) as long as the *acceptance* of that element, defined in Figure 2, is larger than the beam emittance.

The new injector is required to produce the high intensity beam with a small emittance, i.e. with a high density in phase space. The requirement arises mainly from the improved usefulness of such an accelerated beam for physics experiments. (This can perhaps be appreciated by recalling the advantages of intense point sources in light optics which, at the time, led to the use of carbon arcs despite their inconvenience from the point of view of operation.) Also, certain elements such as fast ejection kicker magnets, beam-lines, etc. become technically easier and less costly to make.

Figure 1: A beam waist where the emittance is defined as $E = \pi w \alpha$

Figure 2: An accelerator component, such as a vacuum chamber, for which the acceptance is defined as $A = 2 w$ 'α'

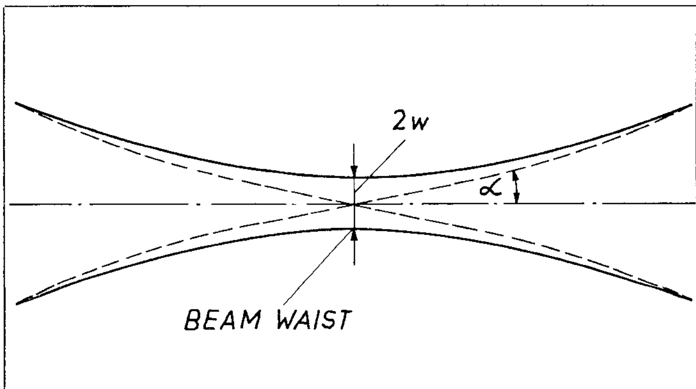


Figure 1

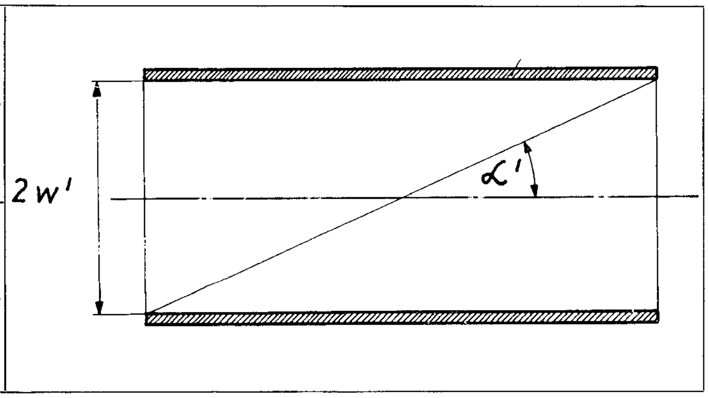


Figure 2

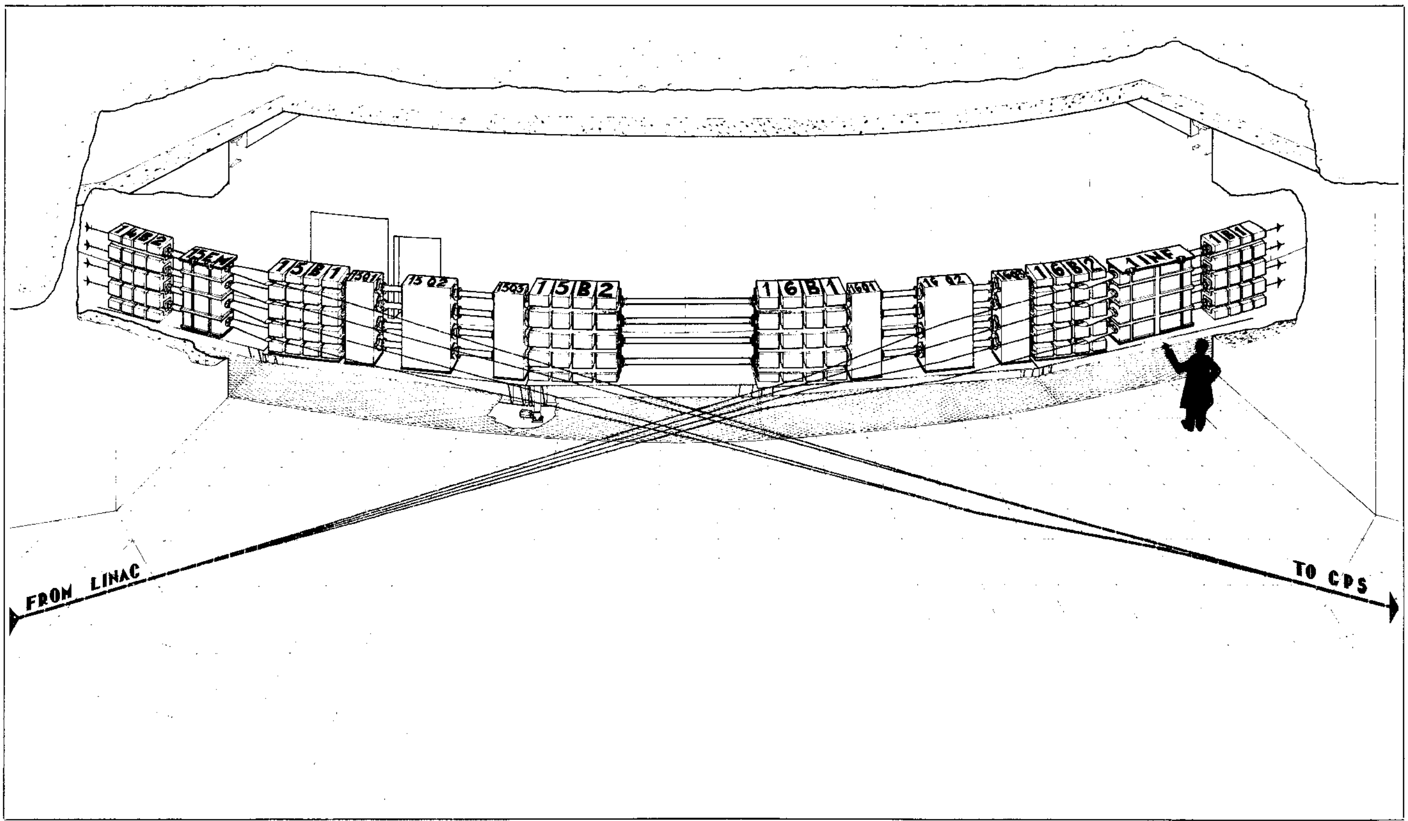


Figure 3

A straightforward extrapolation from the current situation at the CPS shows that the emittance of a beam ten times more intense should not be substantially larger than that of the present beam to avoid a decrease in the efficiency of external targets. The same was thought to be generally true for the special 'target', which is the colliding beam in the ISR. More recently however, a further consideration has been put forward by E. D. Courant, E. Keil and A. Sessler who found that, in contrast to what has just been said, a beam of a larger emittance would be desirable for filling the ISR, provided the phase space density is preserved. The reasons for this are rather complicated and we shall not explain them here. We merely note that the new injector should also be capable of providing two or three times the present beam emittance (retaining the same phase space density) to make possible an increase in the interaction rate in the ISR by up to two orders of magnitude. To achieve the best performance in the ISR two groups of particle bunches should be injected into the CPS into positions 180° apart (Figure 8b) so that they can be combined in the ISR by means of two-turn injection.

The various possibilities considered

Starting from the classical linac, a number of possible injection schemes to meet all these requirements were considered more or less thoroughly. They included cyclotrons (both of the conventional and the separated-orbit type) an FFAG accelerator, a fast-cycling synchrotron, a bootstrap scheme (the CPS with an intermediate energy accumulation ring as first suggested for the AGS by A. W. Maschke), and a single-ring slow-cycling synchrotron. While none of these quite met the above requirements (though this statement applies probably less to the fast-cycling synchrotron) a slow-cycling multi-ring synchrotron of the type proposed by W. Hardt, seemed particularly suitable, even more so when the requirement of adjustable output beam emittance was taken into account as will be shown below. It was also noted that, for equal cost, such a circular injector permits one to go to a substantially higher energy than with a linear accelerator, thereby increasing the space charge limit even more.

The chosen design

Continuing the earlier studies directed by P. Lapostolle and W. Hardt, the Study Group for CPS improvements recently presented their final proposal in an internal report (MPS/Int. DL/B 67-19). This report contains also the proposed improvements to the existing linac and the CPS, the budget estimates, the considerations concerning the use of the intense beam, and the names of all those who contributed to the work. An artist's impression of the proposed Booster is shown in Figure 3. The main parameters are listed in the Table on page 8.

The beam coming from the improved linac is electrostatically deflected into three further channels, magnetically guided to the four levels indicated, and then multiturn injected into four separate, largely independent synchrotrons stacked vertically on top of each other. The total circumference of these four rings equals that of the CPS. After acceleration to an energy of 800 MeV, the beams are ejected, magnetically recombined in various ways and transferred into the CPS. The relative locations of the Booster and the CPS are shown in Figure 4.

What is the reason for the apparent complication of using more than one synchrotron ? According to theory, the number of particles that may be contained in a synchrotron ring from the point of view of space charge, somewhat surprisingly, does not depend on the ring radius (all other parameters, in particular the beam emittance, being equal). Thus, if the CPS can contain 10^{12} protons, a booster ring of a quarter its radius can also contain 10^{12} protons. However, while in the CPS the 10^{12} protons are distributed among twenty proton bunches, they can be packed into only five bunches in each synchrotron of the Booster. Thus, the phase space density per bunch is four times higher in the latter case. As it turns out, this density can be made higher by another factor 1.5, by adding the corresponding extra length to the bunches in the Booster. Hence, ideally, the Booster should lead to an increase in the CPS intensity by a factor of six without any increase in beam emittance. To increase this further to a factor of ten, the emittance needs to be increased, always according to the same theory (which has not yet been really confirmed experimentally) by a factor 5/3, which is acceptable. It is on this value of emittance that the design of the Booster is based.

In practice, some dilution of the phase space density is unavoidable, but the two following points give some lee-way to retain the desired increase. Firstly, we hope that improvements to the linac will

Figure 3: An artist's impression of the Booster showing the beam from the linac dividing into four levels to enter the four vertically stacked rings, and leaving the rings after acceleration, to be fed to the 28 GeV proton synchrotron. This view is taken from the position of the arrow in Figure 4.
The numbers 14, 15, etc. refer to the magnet period; B denotes a bending magnet, EM an ejection magnet, Q a quadrupole focusing lens, INF an inflector.

Figure 4. A plan view of the Booster position next to the CPS ring. The Booster is to be constructed below ground (the mean beam level is ten metres down) with its centre diplomatically located on the Franco-Swiss frontier. The diameter of the four Booster rings is 50 metres — one quarter that of the CPS.

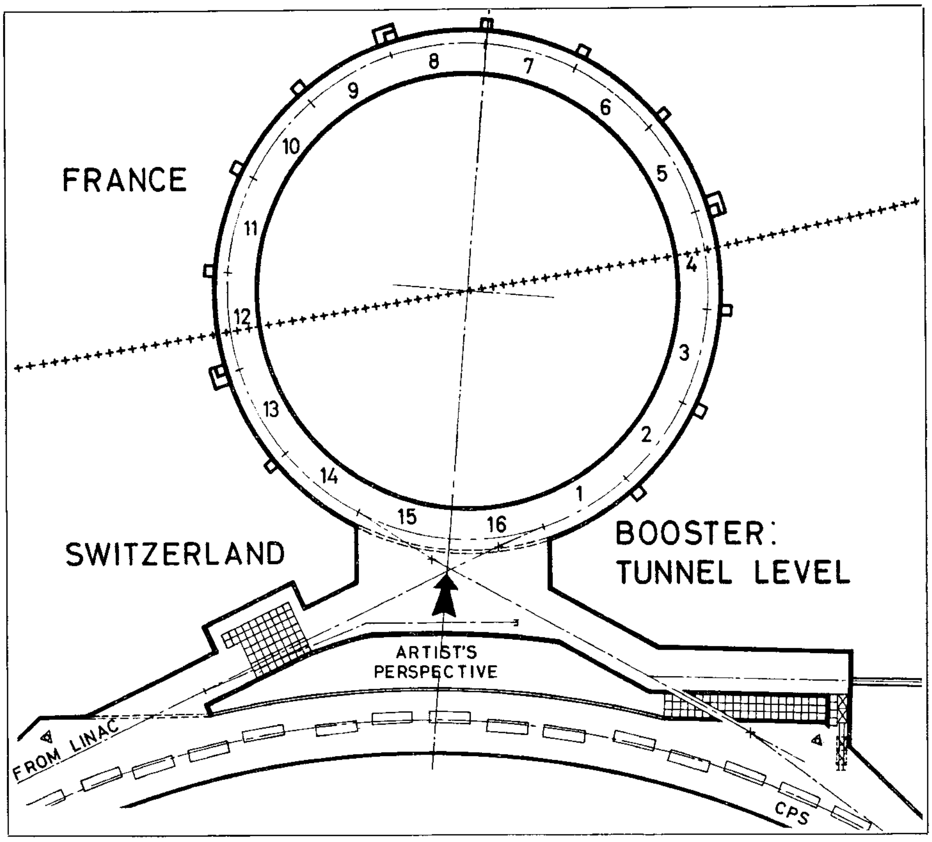


Figure 4

make it possible to inject a beam into the Booster of a smaller emittance than was assumed above for space-charge reasons. Secondly, we may be able to reduce the factor two to three by which the emittance is at present blown up in the CPS, and which has been taken into account when evaluating target efficiencies and computing the ISR interaction rates. This hope is based mainly on the fact that the Booster is designed to have a 30 to 50 times better vacuum than the CPS (which should overcompensate for the longer duration of multiple scattering whose effect is stronger at low energies) and also on the assumption that the current investigation of this blow-up should lead eventually to a fuller understanding and therefore possible elimination of its causes. These considerations should not be interpreted as a promise of even brighter beams than discussed so far, but, even in the case of an unexpected emittance blow-up by say a factor of two, there is nevertheless a reasonable hope of obtaining the good efficiency of external targets and the ISR interaction rates on which the Booster optimization was based.

In contrast to almost all existing synchrotrons, the primary consideration for the new injector is to accelerate without fail a high number of protons, rather than to reach a certain energy. It brings us into an intensity region which is believed to be governed increasingly by the, as yet, not very well known space charge effects, and there are undoubtedly some risks involved. However, these are thought to be reasonable by CERN and also by the Scientific Policy Committee with whom they have been discussed repeatedly. Some uncertainty is always involved in building a new accelerator.

To minimize this risk our basic policy is to plan for a maximum of flexibility (an alternative would have been to embark on a lengthy and costly programme of building models and experimenting with them). In particular, we have proposed

(i) a magnet structure without systematic non-linear resonances over a wide range of betatron frequencies near the working point
(ii) the possibility of easy, continuous and independent adjustment of betatron frequencies in both planes
(iii) a structure with a number of free straight sections for locating various correcting devices if they prove necessary and
(iv) the possibility of commissioning the Booster, if necessary for an extended period, in parallel with normal CPS operation. The linac would supply beam to the Booster in the interval between two pulses delivered to the CPS.

Why four rings ?

Starting from the original two ring TART (Twin Accelerator Ring Transfer) scheme, variants with three, four and five rings were examined. A higher number of rings leads to a higher phase space density, but cost and complexity also increase. Three rings would be a good compromise solution and this has been tentatively adopted for the Karlsruhe 40 GeV machine proposal. However, in our case the numerology for the various schemes for filling the ISR becomes more favourable in the case of four rings. In particular, bunches from pairs of rings can be combined in the transfer channel, as discussed below. There is also the small point that, since the CPS has 20 bunches, all 20 bunches (4 × 5) accelerated in the Booster can be used, whereas a three ring solution would have meant discarding one bunch at each cycle (3 × 7 = 21). On paper, a five ring booster would yield even higher interaction rates in the ISR, but cost and complexity are against such a choice.

Because of the new ideas for filling the ISR, the design energy of the selected four ring booster was increased from 600 MeV, which is appropriate for the required improvement in 25 GeV physics, to 800 MeV.

Magnets, r.f. accelerating units and buildings

We now describe some of the technical aspects of the Booster components for those reasonably familiar with accelerator design, putting particular emphasis on novel features.

One of the sixteen magnets periods in each ring is shown in Figure 5. The design is of the separated-function type, i.e. separate magnets do the jobs of bending the particles round their orbit (dipole magnets) and of focusing (quadrupole magnets). While all synchrotrons built so far use combined-function magnets, separated-function magnets have been used for storage rings such as ACO, ADONE and CESAR. Among the advantages of this type of design are the convenient adjustment of betatron frequencies by means of the lenses (rather than by pole face windings or extra correcting lenses), and the relatively easy injection and ejection into a

Figure 5: One of the sixteen magnet periods is shown at the bottom and the beam behaviour as it passes through such a period is represented by graphs of β and Ø in the horizontal plane (H) and the vertical plane (V). The components of a period are
O — field-free straight section
B — bending magnet
F — radially focusing quadrupole lens
D — radially defocusing quadrupole lens

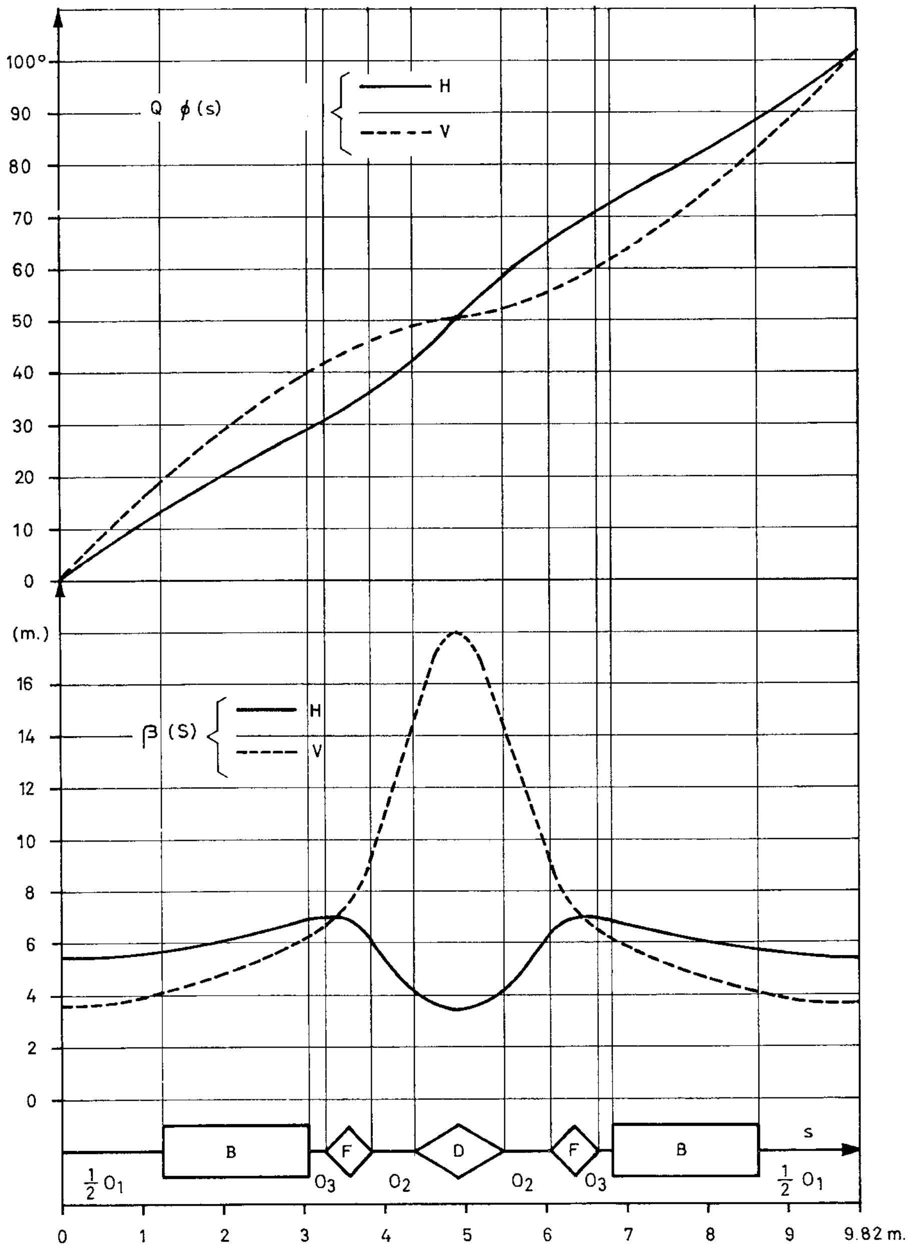


Figure 5

straight section located between septum type dipole magnets.

The focusing magnets are arranged in triplets which results in a relatively narrow beam both horizontally and vertically inside the bending magnets and the long straight sections. This reduces the vertical size of the ring elements, which is an important point when four rings are stacked vertically. In fact, despite the larger emittance, beams in the Booster can be contained in vacuum chambers whose dimensions in the long straight sections are smaller than those of the CPS chamber. Thus, the same fast kicker magnet design can be used for ejection from the Booster and injection into the CPS. Also, the new CPS radio-frequency cavities, vacuum sector valves, correcting multipole lenses, etc., could all be installed in the long straight sections of the Booster as far as their aperture is concerned.

The periodic change of the beam cross-section along the orbit due to the focusing forces is also indicated in Figure 5. The lower graph shows the amplitude-function, β, which is proportional to the square of the betatron oscillation amplitude in the corresponding plane. The phase advance, Ø, refers to the same oscillations and is more than twice as high as in the CPS. Thus, despite a circumference only 1/4 and a number of magnet periods only 1/3 the CPS values, the number of betatron oscillations per turn is $Q = 4$ to 5 as compared to $Q = 6.25$ in the case of the CPS. These relatively strong focusing forces have the effect not only of compressing the beam cross-section but of giving a sufficiently high Booster transition energy.

The tentative cross-section of a bending magnet unit and a quadrupole magnet unit, worked out by A. Asner and his group, are shown in Figure 6. While the four air gaps are geometrically identical, the magnetic fields in the bottom and top gaps are slightly lower than in the two middle ones because of the difference in the magnetic reluctance of the return path. However the resulting effects can be reduced to acceptable values by selecting a steel with a sufficiently high low-field permeability, using d.c. corrections of the remanent fields and slightly reducing the excitation of the middle gaps by electrically shunting the corresponding coils.

The r.f. cavities studied by H. Fischer, Y. Mendelsohn and D. Zanaschi in cooperation with C. Arnaud and P. Coet, basically resemble the CPS cavities except that the cooling system is different because of the higher r.f. power. Also, the return yoke of the tuning magnet will be mounted sideways (Figure 7) rather than underneath in order to save vertical height. All power amplifiers and the transistorized tuning amplifiers will probably be located in a central equipment room.

A solution to the novel problem of synchronizing the individual r.f. systems with each other and then with the CPS system, without diluting (longitudinal) phase space density intolerably, has been worked out by U. Bigliani.

At transfer from the Booster to the CPS, the r.f. phase of three rings will be servo-controlled from the fourth ring, thereby making all four phases (and frequencies) equal. If the Booster transition energy were infinitely high, the momentum compaction would compress the orbits of particles with different momenta into a single one. In this case, the r.f. frequency would uniquely determine the particle velocity and hence all momenta would be equal for equal revolution frequencies. In a practical case of finite transition energy, i.e. separate orbits for different momenta, a difference in magnet field between two rings (under the condition of equal revolution frequency) leads to a difference in the momenta of the respective beams. However, in our case, the transition energy is so much higher than the transfer energy that this momentum difference should be tolerable for practically obtainable values of magnet field tolerances from ring to ring. After beam transfer, the CPS r.f. system will automatically adjust its phase and frequency to the correct values.

The location of the Booster (Figure 4) and the design of the buildings was complicated by stringent boundary conditions which left E. Leroy and N. Morgan with little room for manoeuvre. There was firstly the wish to minimize extra bending of the beam from the Linac and even more so of the beam between the Booster and the CPS. Any such bending not only costs money, but is likely to reduce the beam

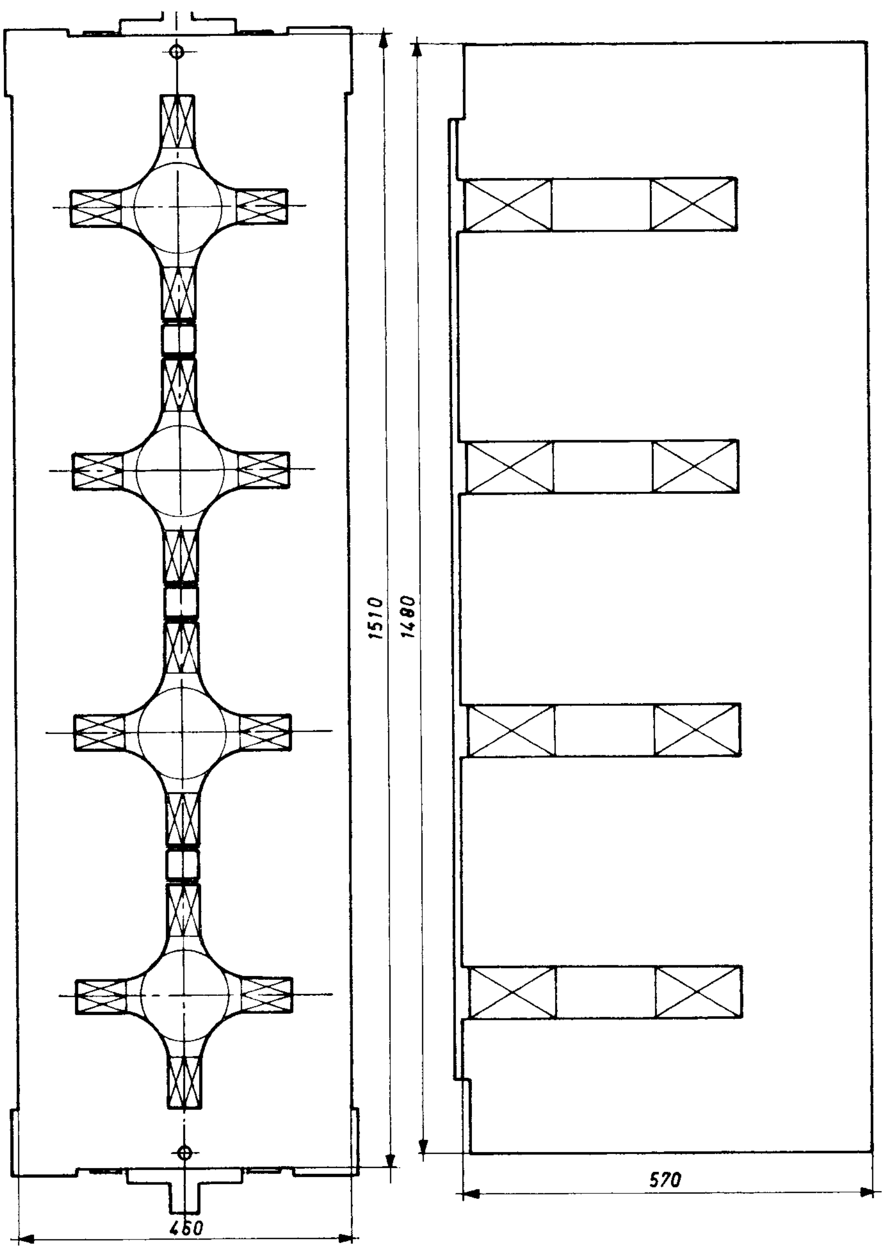


Figure 6

Figure 6: A cross-section of, left, a quadrupole lens unit and right, a bending magnet unit. Note the combination of the magnets to serve the four rings in the same blocks. The figures give the measurements in millimetres.

quality. Secondly, buildings had to be positioned 5 m away from the beam tunnel to the ISR because of radiation shielding requirements studied by K. Goebel and, on the surface, 5 m from the Swiss side and 10 m from the French side of the border, because of frontier regulations. Nevertheless, an acceptable solution has been found which allows permanent access to all equipment except that located in the machine room and connecting tunnels.

Beam injection, ejection and transfer

The transport of the beam from the linac to the four rings as well as injection into the Booster, has been studied by M. Weiss. For the vertical switching to the three additional levels he envisages three pairs of electrostatic electrodes, which, at 50 MeV, are more advantageous than kicker magnets. An additional debuncher is proposed for handling a large range of energy spreads. The multi-turn injection into the Booster is based on the experience gained with the AGS and the CPS and involves injecting say four to eight turns to obtain the 270 mA of circulating current which is required per ring in order to accelerate 10^{13} protons with a trapping efficiency of 90 %.

One of the arguments in favour of a linear injector is the 'automatic' beam ejection. In the case of the Booster, beam ejection requires a heavy duty, not yet conventional, system which must work reliably many millions of times. (One machine cycle every second means 18 million cycles per year for 5000 working hours). Such a system could hardly have been envisaged with confidence a few years ago, but the experience gained with beam ejection from the CPS and the easier conditions in the Booster case (apart from the life-time requirement) make us now feel optimistic.

A total of eight full-aperture fast kicker magnets is required: four for ejection from the rings, three for combining the beam on transfer and one for injection into the CPS. They will all be of the same basic design and cross-section but probably of different length. Despite the relatively short overall rise time required (50 ns), A. Brückner proposes the use of jitter free deuterium thyratrons as switches for the several thousand amperes of excitation current.

Using a passive non-linear pulse-sharpening network after the relatively slow thyratron, he has already obtained switching times of about 15 ns for a 4 kA pulse in a first test experiment. It seems entirely feasible to design the kicker magnets themselves for a 'filling time' of 35 ns, thus meeting the 50 ns required.

The requirements for the various beam transfer schemes, including future improvements, are illustrated in Figure 8. The standard transfer scheme, when the synchrotron beam will be used for 25 GeV physics, consists of transfering *sequentially* first the five bunches of ring III into the CPS, then, with the correct time delay, the five bunches of ring IV and so on until the CPS is filled with twenty bunches equally spaced (Figure 8a).

This filling procedure can also be used for the ISR and is all that will be provided initially. However, at a further stage, the scheme shown in Figure 8b could come into operation. Here the five bunches each from, say, rings III and IV are ejected *simultaneously*, vertically combined in the transfer line as discussed below, and injected into the CPS. Then the five bunches each from rings I and II are dealt with in the same way. Depending on the interval between the two operations, the two groups of bunches can either be injected into opposite positions (as shown) or simply into neighbouring positions if single-turn transfer from the CPS into the ISR is desired. A similar result can also be obtained by injecting first sequentially the bunches from rings III and IV, and then, with two-turn injection, the bunches from rings I and II.

The beam recombination scheme, proposed by A. Asner and C. Bovet, is shown in Figure 9. In the sequential mode, as already said, one first ejects the beam from ring III which is on the same level as that of the CPS. Next the beam from ring IV is ejected and kicker K2 is energized to put this beam on the same beam line. Then kicker K3 is energized and the beam from ring II ejected. Lastly, the kicker K1 is energized and ring I emptied.

In the simultaneous mode the double septum magnets DSM 1 and 2 are energized

Figure 7: A photograph of the model of the magnetic tuning circuit of the radio-frequency cavity.

Figure 8: A schematic representation of how the five bunches of protons circulating in each of the four rings in the Synchrotron Injector (SI, left) can be transferred to the CPS. In (a), they are put one after another to give the usual twenty bunches orbiting the CPS and this will be the standard filling method when the accelerator is used for 25 GeV physics. In (b), which is a possible future development, 2 × 5 bunches are put in opposite positions in the CPS which has particular advantages

permanently. These magnets deflect the two incoming beams in opposite directions, thereby making them parallel to each other. Kickers K1 and K2 are not used in this case.

Conclusions

After about two years of study the main parameters of the new synchrotron injector can now be considered as established, barring the discovery of some new principle in the near future. There remains of course much work to be done to optimize the design and to decide on major technical options. For example, we will have to decide whether to power the main magnet via a motor generator set as for all synchrotrons built to date or whether to power it directly from the electricity grid as originally proposed by J. A. Fox and studied here by B. Godenzi and R. Mosig. In the first case one has a risk of breakdowns (though perhaps less so than is the case for larger machines) and a supervision and maintenance task. In the second case, one enters into a new experience both for the Electricity Company and ourselves.

There are many other important aspects of the Booster which have been studied but which we have not space to comment on here. We should also remark that there are many repercussions for the existing linac, the CPS itself and the beams in the Experimental Halls where modifications will be needed if full use is to be made of the capabilities of the new synchrotron injector. In particular, the increase of the interaction rates in the ISR, discussed above, requires that the increased longitudinal phase space density is not diluted when passing transition energy in the CPS. Also, despite all the modifications envisaged, it is at present thought necessary to limit the average proton intensity to 3×10^{12} protons per second in order to keep the problems arising from radiation and induced activity in the CPS manageable.

I would like to use this opportunity to thank all my colleagues, particularly in the ISR Department, the Nuclear Physics and Technical Services and Buildings Divisions, as well as in Health Physics, for their very valuable contributions to the CPS improvement studies.

A list of the main parameters of the Booster

Orbit parameters	
Design energy	800 MeV
Number of superposed rings	4
Mean radius	25 m
Number of focusing periods, N	16
Betatron wavelength, Q	4 to 5
Phase advance per period, μ	90° - 112°
Transition energy, γ_{tr}	4.2 GeV
Momentum compaction function, α_p	1.0 to 1.5 m
Beam emittance E_H	$130 \pi 10^{-6}$ rad m
E_V	$40 \pi 10^{-6}$ rad m
Vacuum chamber dimensions	
magnet	6×13 cm²
lenses	11 cm dia

Magnet system	*(see Figure 5)*
Bending magnets:	
Radius of curvature, ρ	8 m
'Gap' dimensions	7×14 cm²
Magnetic field	0.13 to 0.6 T
Quadrupole lenses:	
Bore diameter	12 cm
Lens strength	< 0.5 m^{-1}
Maximum gradient	5.5 T m^{-1}
Radiofrequency accelerating system	
Harmonic number, h	5
Number of cavities per ring	1
Frequency	3 to 8 MHz
Peak voltage per turn	12 kV
Other parameters	
Vacuum pressure	10^{-7} Torr
Repetition period	15
Number of protons accelerated per pulse	10^{13}

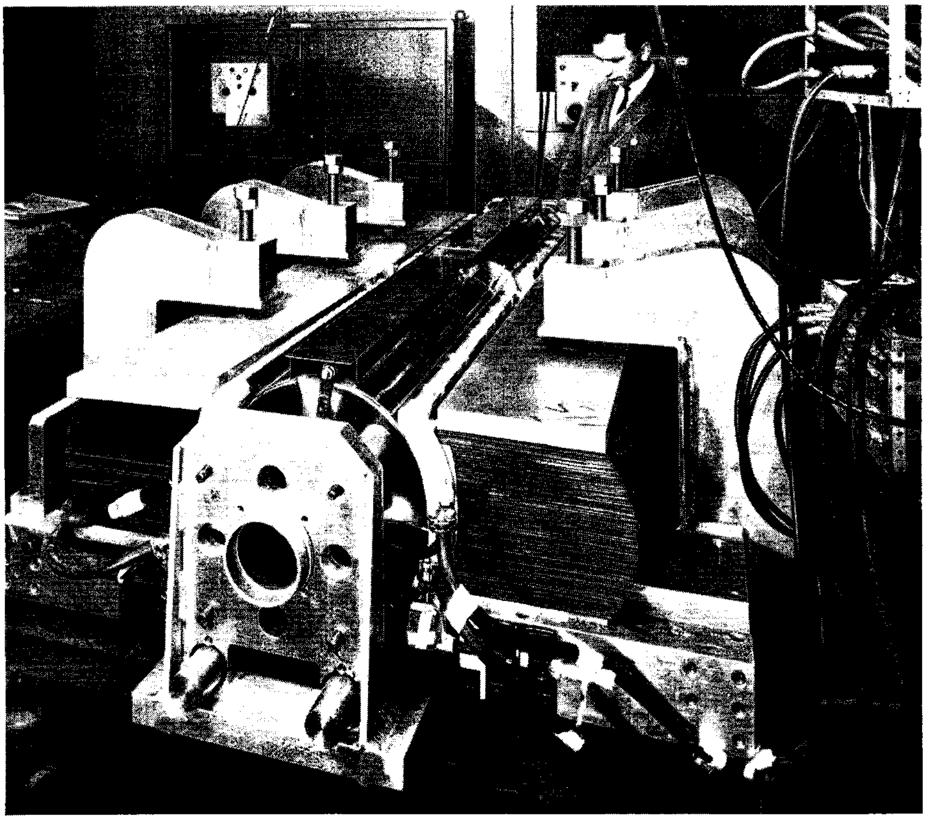


Figure 7 *CERN/PI 165.12.67*

to achieve higher interaction rates when the protons are later fed into the intersecting storage rings.

Figure 9: The main elements involved in the schemes for recombining the beams from the four Booster rings as they are transferred to the CPS. (VSM denotes a vertical steering septum magnet, DSM a double septum magnet and K a fast kicker magnet). The different ways in which they are combined in operation are explained in the article.

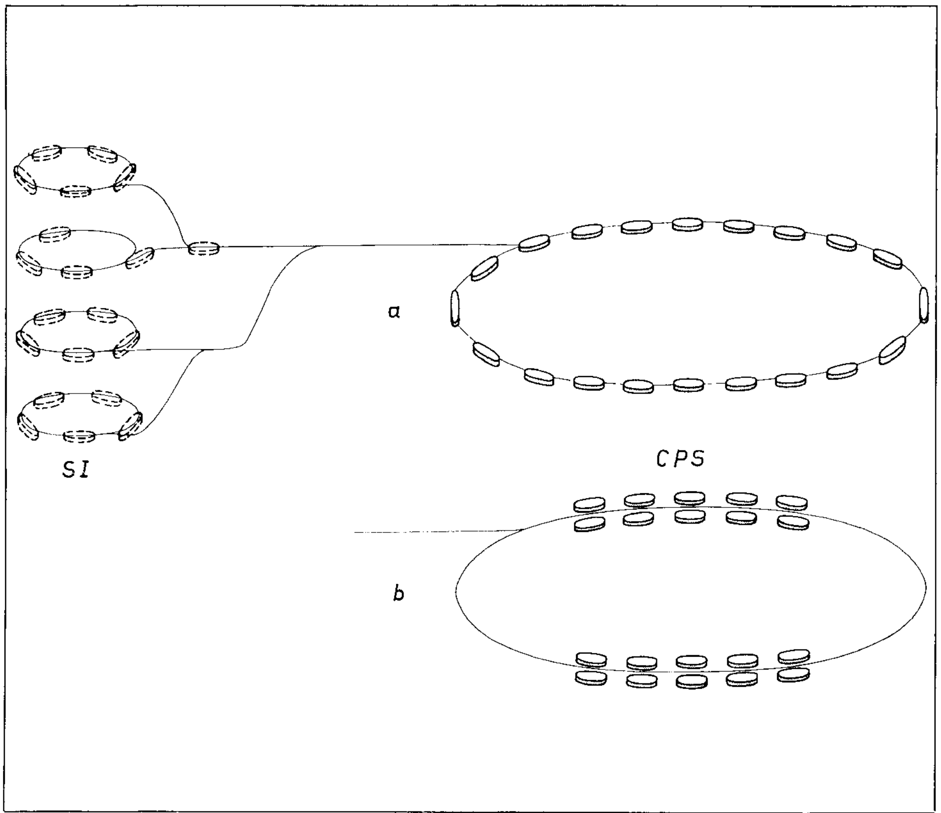


Figure 8

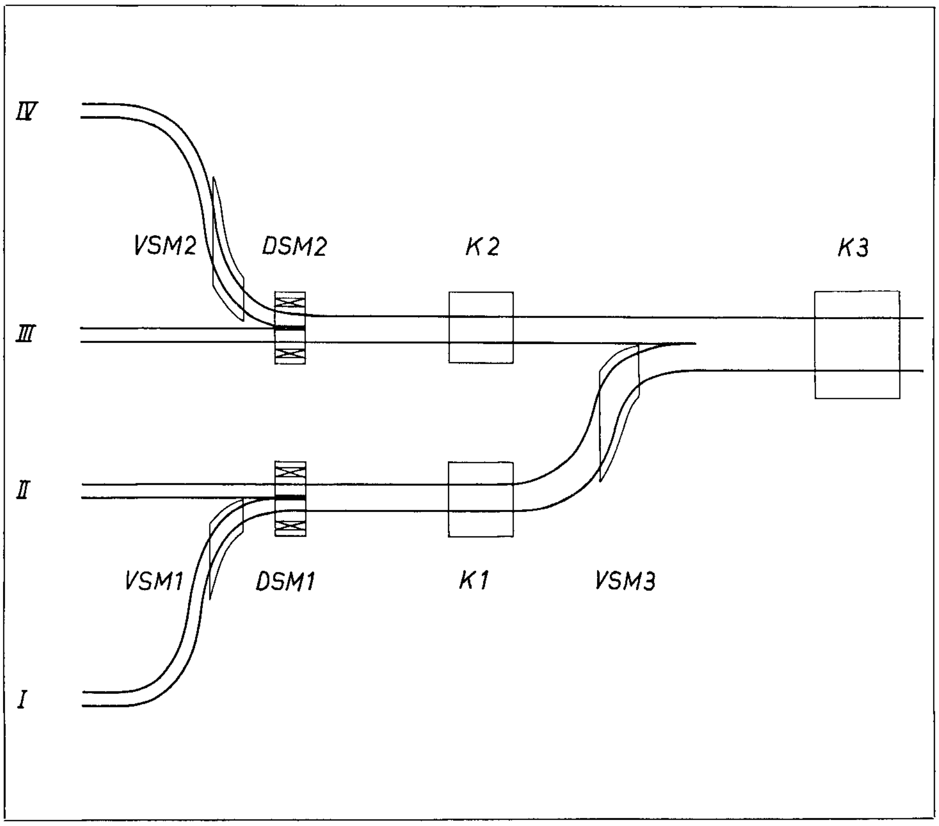


Figure 9

CERN News

Film on CERN completed

During 1967 a new film of CERN has been made by the Swiss film director Guido Franco in collaboration with the Public Information Office. Its title is 'European Organization for Nuclear Research'. It has been produced in four languages (English, French, German and Italian) and 16 mm copies in each version are available free for loan. Any organization wishing to screen the film should contact the Public Information Office at CERN.

Concerts

As in 1967, CERN will this year organize a further series of concerts of classical music. The concerts will be on the same basis as last year and the Geneva studio of the 'Radiodiffusion Suisse Romande' will again collaborate closely with CERN, particularly in the choice of artists and programmes. The concerts, given in the CERN Auditorium at Meyrin, will be recorded for broadcasting at a later date.

Five concerts have been arranged for 1968. On 11 March, the Tel Aviv Quartet, consisting of Chaim Taub (violin), Menahem Breuer (violin), David Benyamini (violin) and Uzi Wiesel (cello) will perform works by Beethoven, Schumann and Seter.

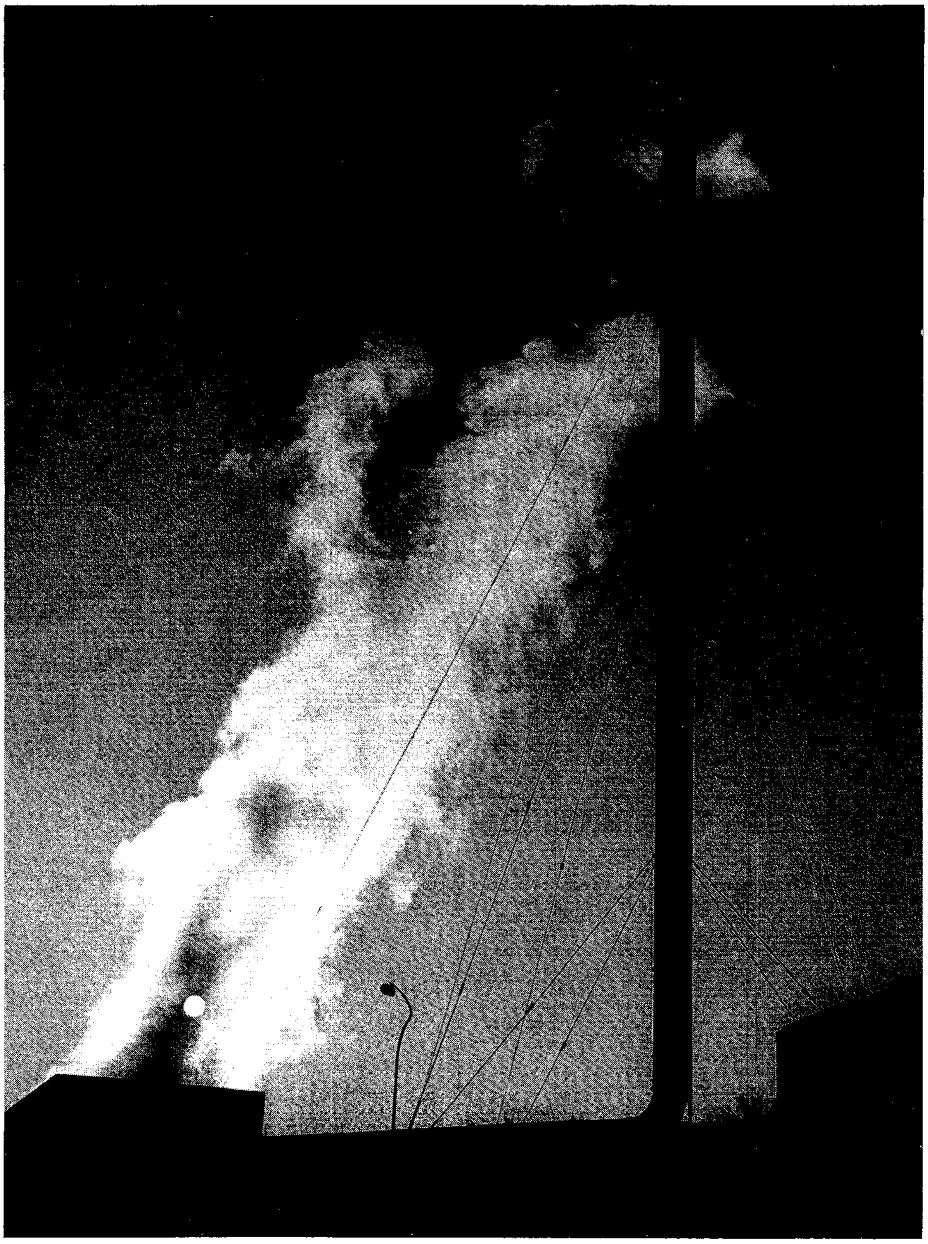
On 2 April, the Choir of the 'Radio Suisse Romande' conducted by André Charlet will give a programme of 16th century music, contemporary music and popular songs from Switzerland and elsewhere. Among the composers chosen are: Jannequin, Stravinsky, d'Alessandro, Petrassi and di Venosa.

On 9 May, Edgar Fischer (cello) and Edith Fischer (piano) will give a programme including works by Boccherini, Mendelssohn, Becerra, Hindemith and Bartok.

On 28 May, works by Bach, Schibler and Brahms will be performed by Arlette Chedel (contralto), Ron Golan (viola) and Denise Dupont (piano).

Finally, on 18 June, the Ensemble Ars Antiqua of Geneva will appear in period costume (based on old pictures and engravings) using instruments from the 'Musée Instrumental'. Their programme is by several 15th, 16th and 17th century composers, namely: Schein, Gesualdo da Venosa, Diego Ortiz, Claude Lejeune, Samuel Scheidt and Claudio Merulo.

The January sun hiding behind a plume of water vapour from the cooling towers. In the foreground is the tall propane chimney next to the neutrino beam-line.



CERN/PI 2.2.68

Hadron Conference

A 'Topical Conference on High Energy Collisions of Hadrons' was held at CERN on 15-18 January. In addition to about 40 participants from CERN itself, some 160 scientists from 20 countries (Europe, USA, USSR, Israel, Japan) pooled the latest developments in the experimental and theoretical attack on understanding the behaviour of hadrons.

Hadrons are the large group of particles whose properties are dominated by the most powerful of the forces which have been found to operate in Nature — the strong nuclear force. They include the baryons (such as the proton, neutron, lambda hyperon etc.), the anti-baryons, and the mesons (pion, kaon, eta, etc.).

Over the past few years the list of identified hadrons has suffered a dramatic population explosion as a result of the work at the particle accelerators, but this profusion has been brought to order by the representation of the similarities and symmetries existing among the hadrons, by mathematical group theory (SU3, SU6). The underlying reasons for this order are not yet clear but considerable progress has been made with the 'quark model' which attempts to interpret the observations in terms of more fundamental particles, or quarks.

Visits in 1967

A total of more than 11 000 people toured the CERN site in 1967. The majority of them (6663) took part in the visits organized on Saturdays. On weekdays 1715 people (mostly physicists or physics students) came to the Laboratory. All of them were accompanied by expert guides, and were able to familiarize themselves with the largest European Laboratory specializing in fundamental sub-nuclear physics research.

As in previous years, the press, radio and television have all shown a lively interest in CERN's work; a total of 117 journalists were welcomed by the Public Information Office either individually or on press days.

530 VIP's, including many world-famous physicists and outstanding political personalities, also came to CERN during 1967. They included a head of state, 10 ministers and 73 parliamentary representatives.

Finally, on the family day, 23 September, 2351 people (staff members and their families) were able to see where their colleagues or relations worked.

Contracts

A contract for the supply of 800 poleface windings for the ISR magnets has been awarded to Brown, Boveri and Co., Switzerland for a value of almost 1 ½ million Swiss Francs.

The poleface windings have the job of adjusting the focusing strength of the magnets which hold the protons in the storage rings. They make it possible to change the shape of the magnetic field, especially at high fields when the ideal field shape can be lost as the magnet starts to saturate. The windings have to be very accurately manufactured and accurately positioned on the magnet poles. Another requirement is that their insulation should retain good mechanical properties when it is subjected to radiation in the storage rings.

The piles and moulded walls for the buildings, which will be built on the French half of the CERN site to house the 3.5 m hydrogen bubble chamber, will be supplied by Soletanche, France, at a cost of just over 1.3 million Swiss Francs. For some of these buildings, the weight of the equipment they will contain makes it necessary to construct special foundations to transfer the load right down to the molasse under the site.

A contract for the vacuum tubes for the ISR has been placed with Avesta, Sweden, at a value just over 630 000 Swiss Francs. It involves the supply of 2000 metres of stainless steel tube — elliptical tubes 2.4 mm thick to pass through the bending magnets and circular tubes 1.5 mm thick to pass through the quadrupole focusing magnets and straight sections. The steel has to have very low magnetic permeability, so as not to disturb the field shapes inside the magnets, and high mechanical strength.

The first batch of tubes is scheduled to be delivered in May and all the tubes will be at CERN at the beginning of next year. Avesta has also got the contract for the other stainless steel components of the ISR vacuum system.

Of C and P and T and combinations thereof

A short review of some of the news on the topic of symmetries from the research of 1967.

The story so far: An article in CERN COURIER, September 1966 (vol. 6, page 171) described in some detail the remarkable recent developments concerning the respect which Nature has, or has not, for the symmetries of parity (P), charge (C) and time (T).

To recap very briefly — In 1956, P symmetry was observed to be violated in the weak interaction; Nature was seen to be choosy about the direction in which things happen when the weak force is involved. The combined symmetry, CP, restored order however until 1964 when a Princeton team, in an experiment at Brookhaven, found that the decay of the long-lived neutral kaon violated CP on a very small scale. To preserve the overall CPT symmetry, which evolves from fundamental postulates of quantum theory and special relativity, CP violation implies also a violation of T. Then came the suggestion, initially supported by an experiment on the eta meson at Brookhaven, that what was really happening was a violation of C symmetry in the electromagnetic interaction. This did not stand up to a fuller examination of the electromagnetic decay of the eta meson at CERN.

The present experimental status of the symmetries

Interaction	Symmetry				
	CPT	P	C	CP	T
Strong	✓	✓	✓	✓	✓
Electromagnetic	✓	✓	✓	✓	✓
Weak	✓	X	X	X	✓ (?)

We now select some of the news which came from this front in 1967.

In January, from Princeton and from CERN, came the announcement of the observation of a further CP violation decay of the long-lived kaon, this time into two neutral pions (CERN COURIER, vol. 7, page 31). The previous observation had been of decay into two charged pions.

Although further examples of CP violation have been looked for in the weak decays of other particles, such as the lambda and sigma hyperons, none have been found.

The Princeton and CERN experiments were particularly important because, taken together with the measurements on the CP violating decay into two charged pions from Brookhaven, Rutherford and CERN, they made possible a comparison between the rates of the decays into two charged and into two neutral pions. This comparison indicated that the source of the trouble does not lie solely in the composition of the long-lived kaon, which is built up from the neutral K meson and its antiparticle. Prior to 1964, it was believed to be a one to one mixture. It is now believed to be an unequal mixture but this inequality cannot be the only mechanism of the CP violation.

In February, a further result from the CERN experiment on the eta meson reinforced the confidence in C symmetry in the electromagnetic interaction. Also, a consequence of any T symmetry violation in the electromagnetic interaction, was investigated during the year in the USA. Three teams carried out experiments on neutrons to see whether they could detect any electric dipole moment. T symmetry violation would involve the existence of a small electric dipole moment on some particles including the neutron. Two of the teams, one at Oak Ridge looking at slow neutrons and one at Brookhaven looking at fast neutrons, were led by N.F. Ramsey. They used a neutron magnetic resonance technique. The other team, led by C. Schull was also at Brookhaven using the scattering of polarized neutrons. No electric dipole moment was observed down to a value for the separation of two charges producing the moment of 3×10^{-22} cm. (This is about 160 times smaller than the previous value). So T symmetry in the electromagnetic interaction still stands.

In October, results appeared from Brookhaven (a team led by J. Steinberger) and Stanford (a team led by M. Schuartz) which showed that CP symmetry is violated in the leptonic decay of the long-lived neutral kaon. At Brookhaven, observation of the decay into a pion, electron and neutrino showed that the decay producing a negative pion occurs more often (a few times per thousand) than that producing a positive pion. At Stanford, a similar result — negative pion favoured — was found for the decay into a pion, a muon and a neutrino.

(This underlines the possibility, mentioned in many general articles following the experiment which seemed to show a violation of charge symmetry in the electromagnetic interaction, of communicating to a person on a distant galaxy what is positive and what is negative in our world. All he has to do is build a synchrotron, produce long-lived K mesons, look at the appropriate decays and note which charged pion predominates. That tells him our negative. We can thus find out whether his galaxy is constructed of matter or antimatter and therefore whether we would wish to meet the person in question ... Who said that sub-nuclear physics has no practical application ?)

In December, a preliminary result, based on 60 % of the data collected in the experiment, was reported from a CERN/Geneva/Lund team who measured the β parameter in the decay of the lambda hyperon into a proton and a pion. This is a test of T symmetry in the weak interaction. No evidence for the violation of this symmetry was observed.

The problem has thus been tackled on many different fronts in many Laboratories. No deeper understanding, no breakthrough, has been achieved but much more raw data has been accumulated on which to base an eventual theoretical explanation.

News from abroad

The elegant building which houses the ADONE storage ring at the Frascati Laboratory. (Photo CNEN)

ADONE Commissioning

Commissioning of the electron-positron storage ring, ADONE, is under way at the Frascati Laboratory in Italy. Electrons and positrons have been successfully injected into the ring and some acceleration of the beams has been achieved.

The Adone project was first proposed in 1962 by the Italian National Institute for Nuclear Physics (INFN) and has been financed mainly by the Comittee for Nuclear Energy (CNEN). The National Research Council (CNR) granted the necessary funds for the linear accelerator. Construction of the linear accelerator began in 1963, and of the storage ring itself in 1964.

The main design parameters of the ring are:

Energy per beam	300-1500 MeV
Number of particles stored in each beam	2×10^{11}
Beam lifetime	5 to 10 hours
Luminosity at crossing points	10^{33} per cm^2 per hour
Vacuum pressure	10^{-9} torr
Positron filling time	about 15 minutes

The ring is a separated-function magnet structure with an average radius of 16.7 m, though the bending magnet radius is only 5 m. There are twelve sectors each with a straight section 2.5 m long and four of these can be used for experiments. The other straights are taken up with inflectors for the injection of the beams, radio-frequency cavities, and beam monitoring and control units. There are two twin r.f. cavities, each capable of 100 kV, operating on the third harmonic of the revolution frequency (8.54 MHz). Their job is to compensate for the energy lost by the orbiting particles as synchrotron radiation, and also to accelerate the particles beyond their injection energy (350 MeV) up to the maximum energy of 1.5 GeV in a time of the order of a few seconds.

The useful aperture for the beams is 22×6 cm^2 and they can be made to cross at an angle up to 6 mrad (in the vertical plane) by means of electric fields distributed around the ring. The vacuum system, all bakeable, is equipped with 26 getter-ion pumps each capable of 400 litres per second; rough vacuum is achieved with mechanical pumps and sorption pumps (conventional rotary pumps down to 0.1 torr, then molecular pumps).

A wide experimental programme has already been proposed by physicists of several Italian Universities and of the Frascati National Laboratory. The approved experiments which are now in an advanced state of preparation, are listed below:

- — Single boson production (Naples University/Frascati)
- — Electron-positron annihilation into two bosons (Padua University/Frascati)
- — Electron-positron annihilation into two gammas, neutral pion plus gamma, or eta plus gamma (Rome University/Frascati)
- — Muon pair production (Rome University/Frascati)
- — A study of the phi resonance through its charged kaon, muon and neutral decays (Istituto Superiore di Sanità)
- — Nucleon pair production (Naples University/Frascati)
- — Search for leptonic quarks and heavy leptons (Bologna University/Frascati).

Parents unknown

News emerged in December from a group of physicists who have disappeared down a mine in search of neutrinos. The news is in Physics Review Letters, 25 December, the group of physicists (led by J. W. Keuffel) are from the University of Utah and the mine is the Park City lead mine in Utah.

This mine is different from the others being used for research on cosmic and solar neutrinos in that it is only about 600 metres down and it is possible for the very high energy muons in cosmic rays to penetrate to this comparatively modest depth.

The team carried out a preliminary investigation of this muon background. They looked at the variation in the intensity of the muon flux, in the energy range 1000 to 10 000 GeV, with depth and with angle. The variation with depth was in excellent agreement with what was expected but the variation with angle produced an unexpected result.

It is generally assumed that the high energy muons result from the decays of pions and kaons and on this assumption it is possible to say something about the muon intensity one would expect to observe at different angles. If the muon parents are in fact pions and kaons, one would expect to detect more muons at large angles to the vertical direction and progressively less as one looks at closer and closer angles to the vertical. This is because the pions and kaons are more likely to undergo interactions other than their weak decay, the more dense is the atmosphere where they are produced. The pions and kaons coming from 'inclined primaries' are produced at higher attitudes and are more likely to decay than to interact with other particles. The Utah team, however, observed hardly any variation in high energy muon flux as they looked through a wide range of angles.

Their detection equipment consisted of a large bank of cylindrical spark counters, nine columns with forty counters in each. These counters were 15 cm diameter 10 m long steel pipes with wires down the centre, sparks being located acoustically to an accuracy of a few millimetres. The sensitive volume was 6 × 10 m² and 6 m thick. The counters were pulsed, being triggered by fast coincidence between two water-filled Cherenkov counters.

The conclusion they draw from their observations in that the majority of muons in cosmic rays with energies greater than 1000 GeV are either produced directly in some interaction or are the decay product of some unknown parent, with a much shorter average lifetime than the kaon, which decays copiously into muons. An obvious candidate for such a parent is the intermediate boson, the postulated mediator of the weak interaction, which has been searched for without success in neutrino experiments at CERN and elsewhere. They suggest looking in nuclear emulsions for high energy muons (though the energies involved are at the upper limit for direct detection in nuclear emulsion) and for high energy electrons which would be expected if the intermediate boson were being produced.

ING recommended

The Science Council of Canada has recommended in principle the project to construct an intense neutron generator (ING) at the Chalk River Laboratory. The Council in their report drew particular attention to the benefits, not in themselves scientific, which this machine, unique of its kind in the world, would have for Canada. They contend that for a country in the position of Canada, specialization in some form is essential in order to achieve high standards, to attract world-class scientists and to produce results which are internationally significant and competitive. A preliminary survey at a cost of $ 7.5 million will now go ahead.

The proposed machine consists of a linear accelerator to produce a very intense proton beam (65 mA continuous) at an energy of 1 GeV. The beam would be directed into a target of liquid lead-bismuth surrounded by a heavy-water moderator. From this target arrangement the flux of thermal neutrons, calculated as 10^{16} per cm² per s, would be used for research in solid-state physics, isotope production, etc. If a start on the project can be made fairly soon, it is estimated that ING could be in operation in 1974.

Another piece of news relating to Canada — The University of Toronto has joined the Universities Research Association Inc., the body responsible to the U.S. Atomic Energy Commission for the construction and operation of the 200-400 GeV machine at Weston.

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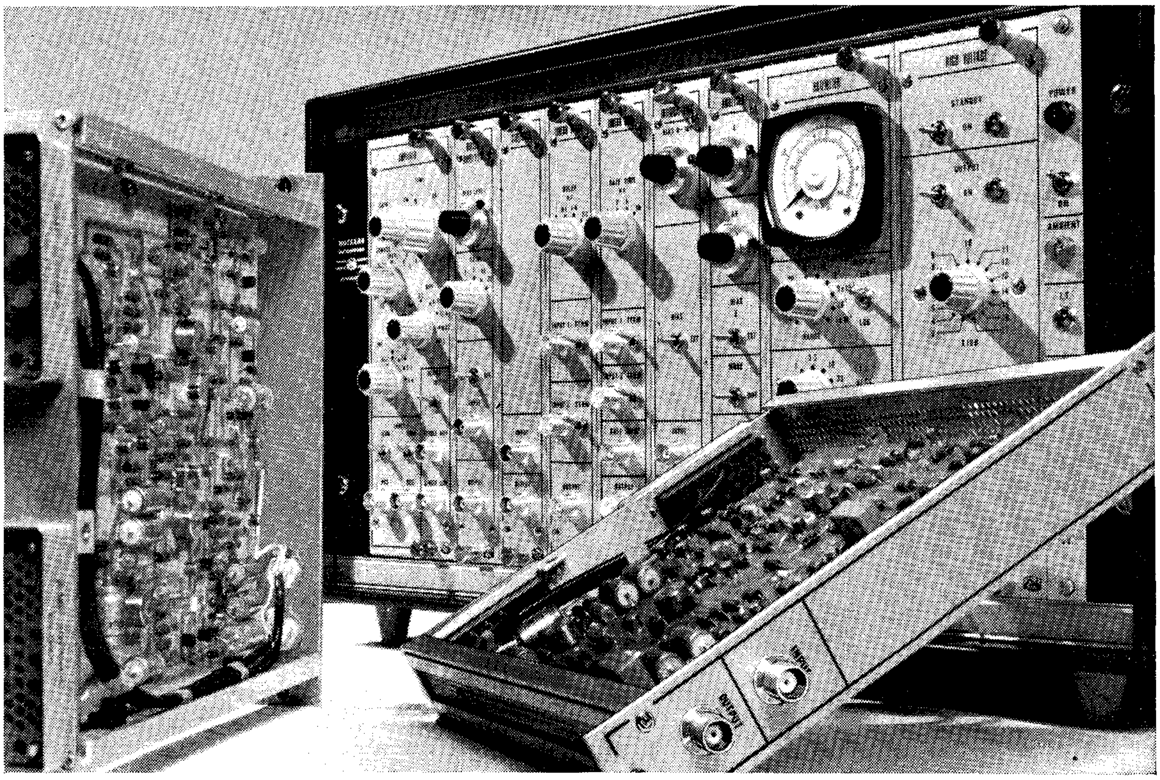

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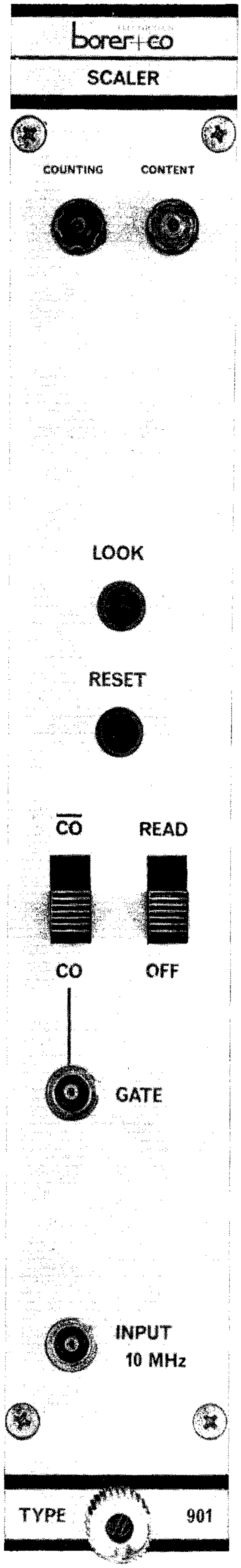

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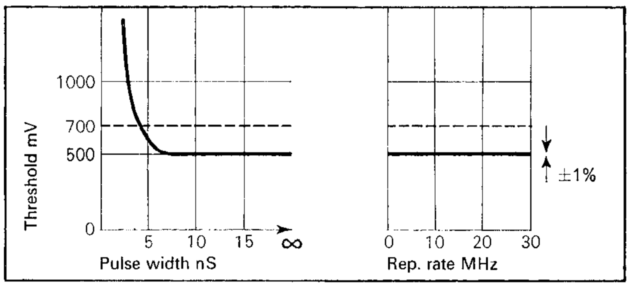

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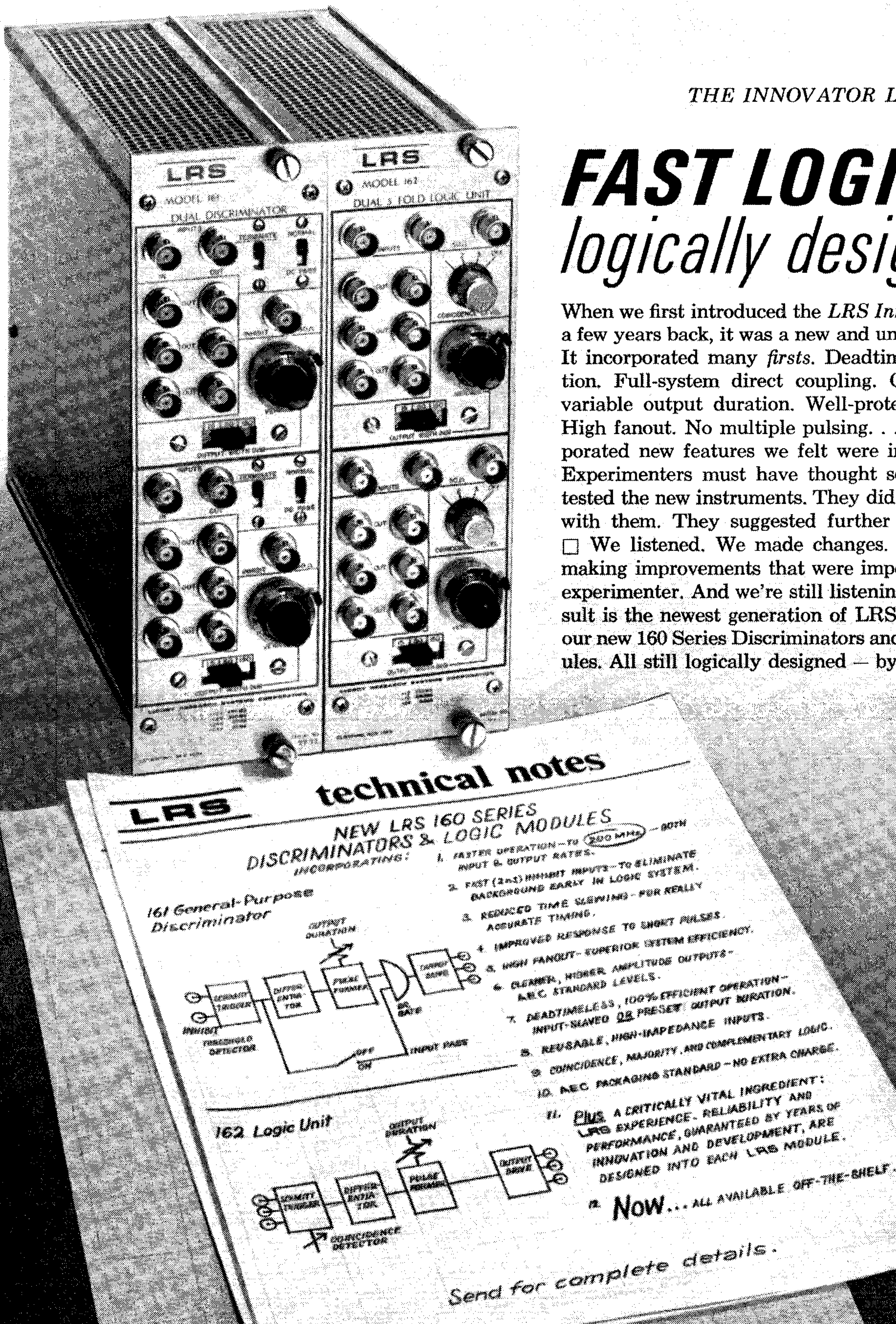

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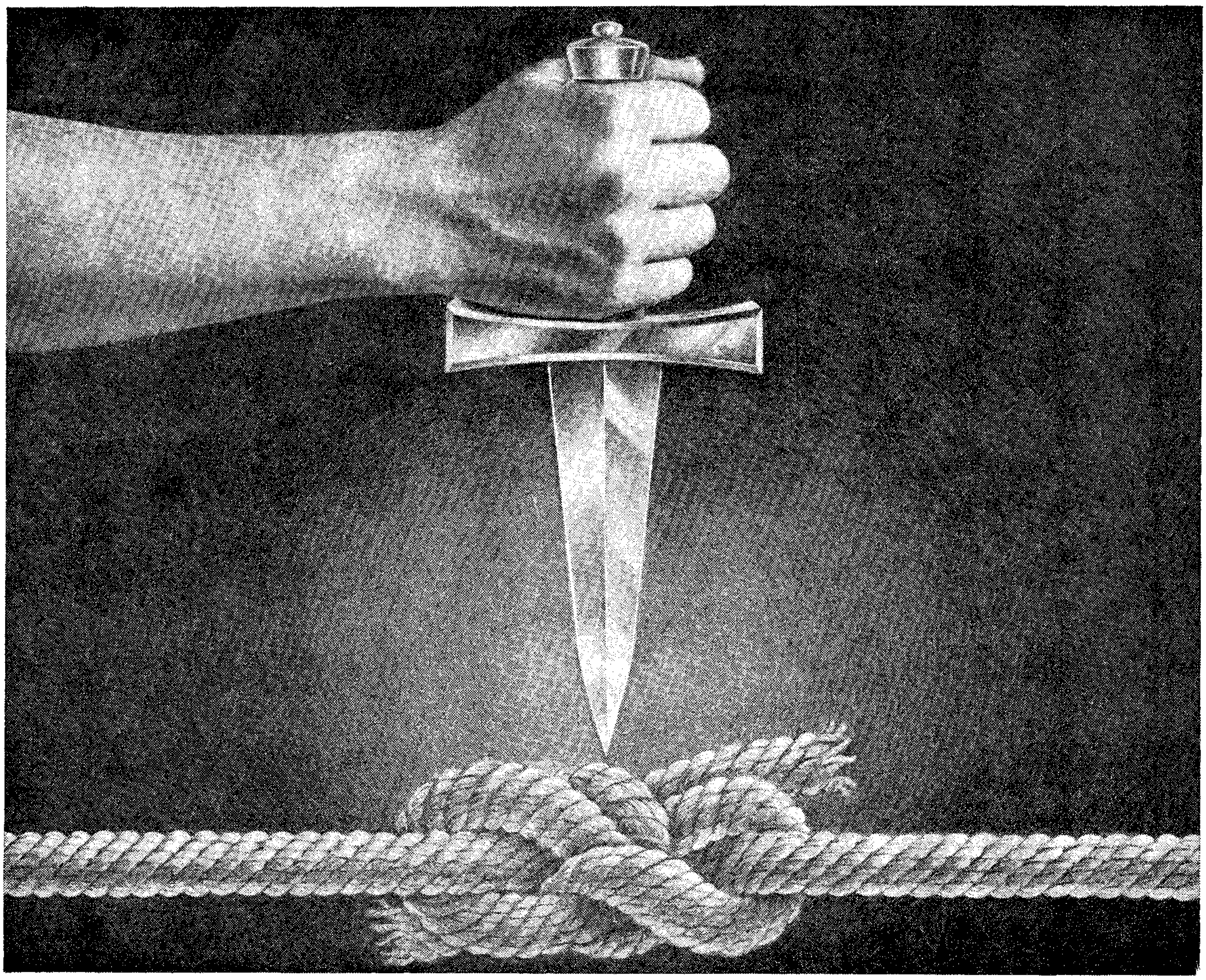

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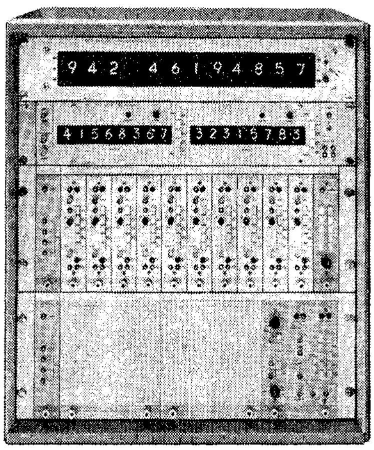

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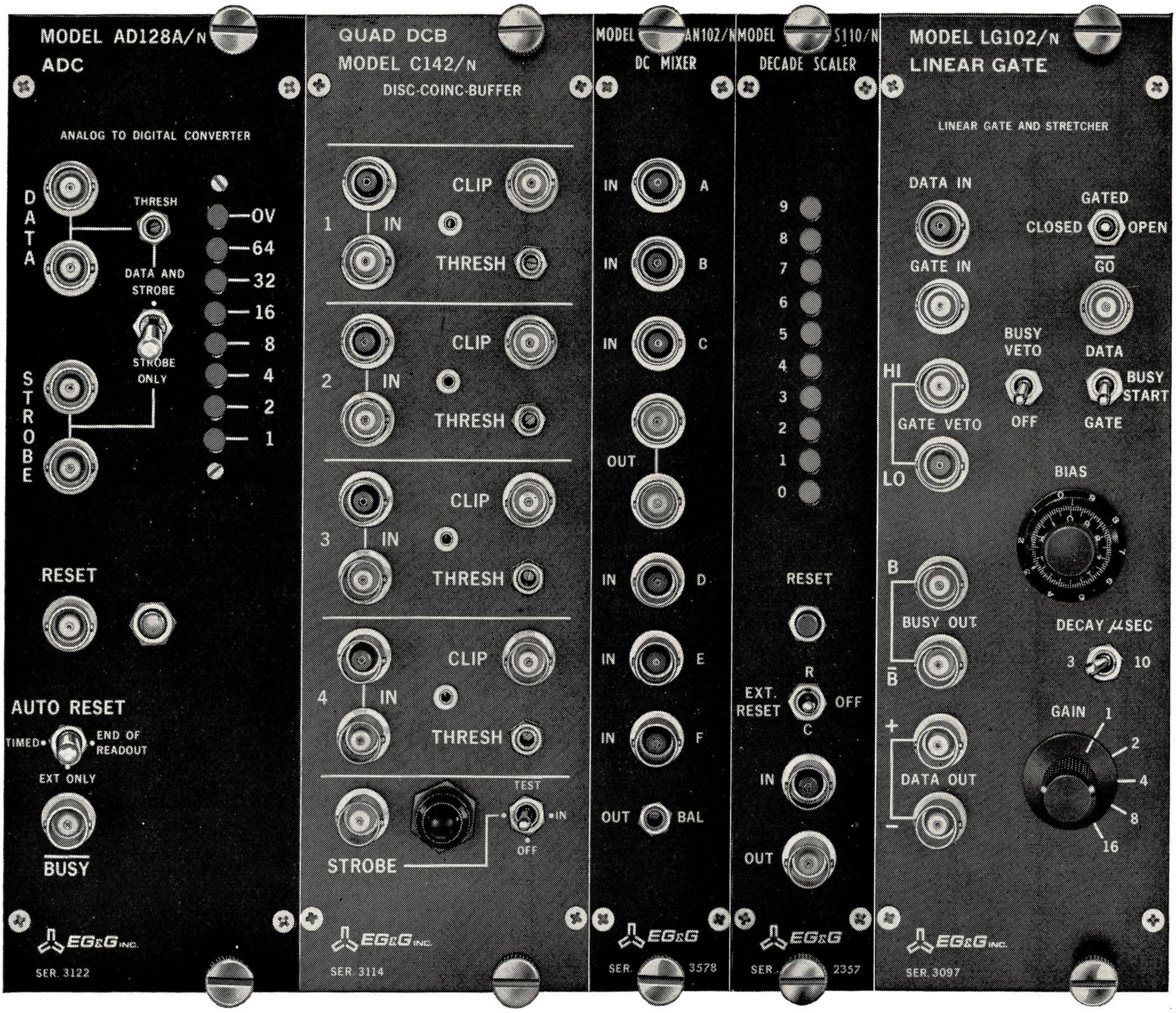

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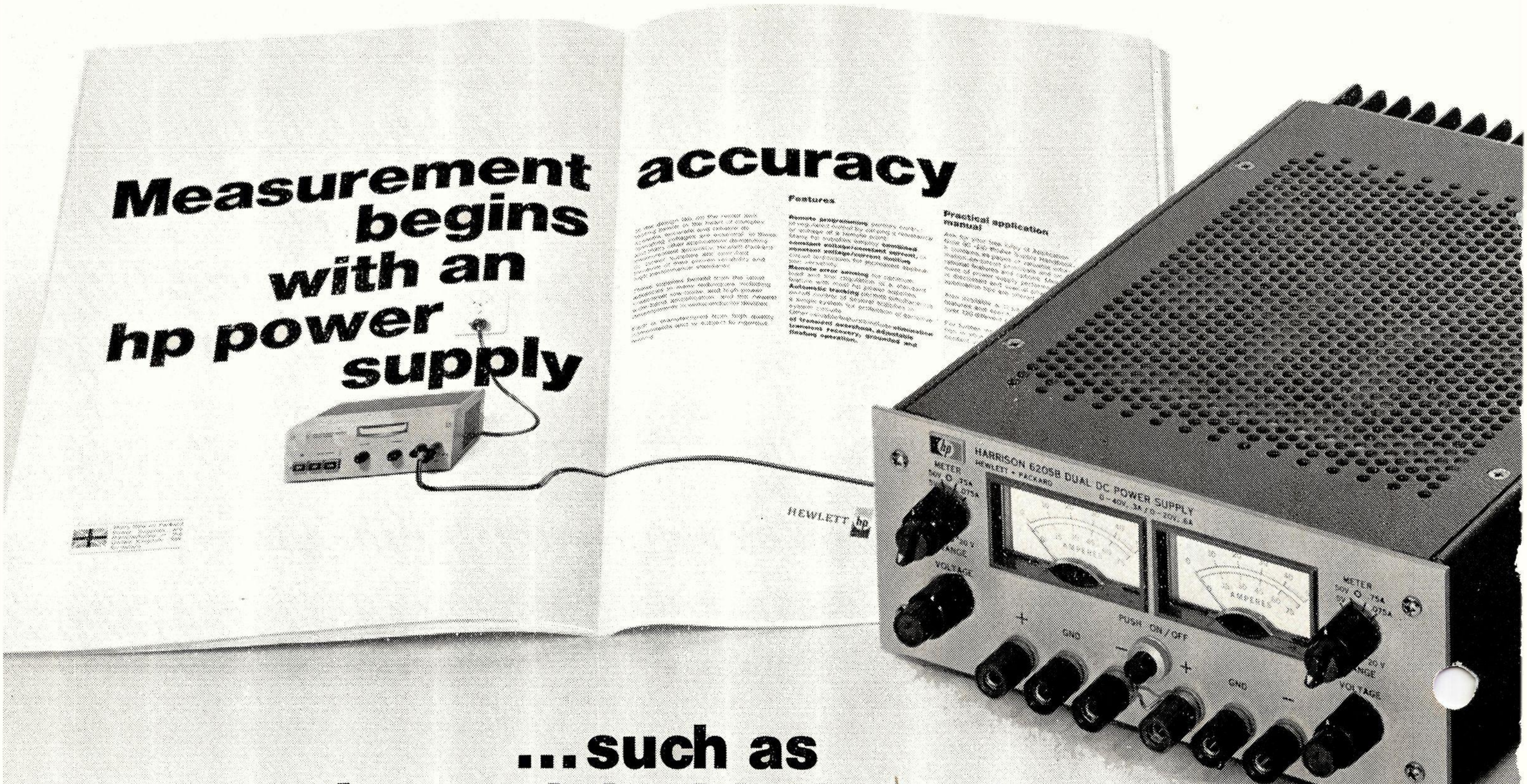

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