PROGRESS REPORT FROM THE STUDY GROUP ON NEW ACCCELERATORS
TO DECEMBER 1963

by K. Johnsen.

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1. Introduction

When the Accelerator Research Group (later Accelerator Research Division) was established as a separate entity within CERN in 1957, there were two important accelerator ideas that looked particularly promising for the future. One was the idea of producing very strong guiding and focusing fields by self-confined very dense electron beams of relativistic velocities ("plasma accelerators"). The other was the idea of colliding beams. Both ideas were taken up for closer examination by the Accelerator Research Group. The work on plasma accelerators was tapered off at CERN after a few years, as the preliminary results were discouraging, and the scheme, even if feasible, was limited in application. The intersecting beam idea, on the other hand, increased in importance as the CERN-PS came into operation, yielding intensities that would make 25 GeV intersecting beams feasible. We attacked the problem on two fronts. Firstly, we started the construction of an electron model to investigate experimentally the stacking process and other problems related to storage rings. This model is in the running-in stage now. Secondly, we started theoretical studies of the feasibility of intersecting storage rings (ISR) attached to the 25 GeV CERN-PS. The first preliminary conclusions were presented to the Scientific Policy Committee in the spring of 1961. These conclusions were sufficiently encouraging that it was felt that a serious design study of such rings should be undertaken.

Along with these studies of rather special ideas the Division also kept in contact with the development of the more conventional ideas like the extension of the alternating gradient principle to higher energies and higher intensities. In particular, members of the Division took part in special
summer studies of accelerator projects in the range 100 - 1000 GeV in the U.S.A.
The preliminary studies indicated that there would be no technical reasons
why the AG principle could not be used profitably up to at least 1000 GeV.
Since high energy physicists made it quite clear that colliding beam experiments
can only supplement experimentation with ordinary accelerators and not replace
it, it was felt that a design study of a several hundred GeV proton synchrotron
should be undertaken in parallel with the design study of the 25 GeV ISR-s.

At its December meeting in 1961 the CERN Council accepted the idea of
forming a special Study Group within the AR Division to carry out the two
design studies mentioned above. A nucleus for such a group existed already,
but it had to be strengthened considerably, and work on this started immediately
after the Council decision. It took, however, some time to build up the group
to full strength, since many of those involved were rather senior people who
could not be freed too quickly from their activities. The Study Group has
grown steadily till it reached 16 members this summer. These have consisted
of staff members from CERN, CERN fellows, Ford fellows and visitors from other
laboratories. The CERN staff has been mainly from the AR Division, but we
have had very valuable help from several other divisions. Outside laboratories
have contributed in several ways. In some cases they have sent specialists to
our Group, in other cases they have tackled particular problems in their own
laboratory, e.g. the R.F. lincac structure work done by the Rutherford Laboratory.

The following physicists and engineers have worked full time over extended
periods with the Study Group:

G. Bronca (Saclay), E.H.S. Burbop (University College, London),
J. Gervaise (CERN), K. Johnsen (CERN), G. Neyret (Saclay), J. Parain (CERN-
Saclay), E. de Raad (CERN), L. Resegotti (CERN), W. Schnell (CERN), A. Schoch
(CERN), R.B.R-Schersby Harvie (Rutherford Laboratory), K.R. Symon (CERN-MURA),
C.J. Zilverschoon (CERN), Miss T. Capone (CERN), G. Dôme (CERN), H.J. de Jonge
(CERN), K. Henrichsen (CERN), E. Keil (CERN), W.C. Middelkoop (CERN),
A. Nakach (Saclay).
We cannot list all the part time help that we have had, which has been of the greatest importance to the study.

The present paper is an interim progress report on the activity of the Study Group since it was formed. Attached to the report is a list of the internal reports written by the members of the Study Group. For further details reference is made to these reports.

2. The Study of a 300-GeV Proton Synchrotron

It was necessary for the group to concentrate its efforts on a specific energy, and this was chosen as 300 GeV. Initially this choice was based on the assumption that it was near to the upper limit of the range that could be considered for a European machine and near the lower limit of a possible intercontinental machine. Since the choice was made, the European Committee for Future Accelerators, established in January 1963, has given a strong recommendation that the energy of the next big accelerator in Europe should be about 300 GeV. We have nevertheless all the time kept in mind the consequences of the design of a different energy choice, in particular considerable thought has gone into the design of a 150 GeV machine.

2.1. Basic Parameters

In order to arrive at a design that would be near to optimum it was found necessary to consider a large number of possible designs. At a certain stage altogether 12 designs were under consideration. Most of these could fairly easily be eliminated, but the choice of certain parameters became rather difficult, as they were rather interrelated. For instance, the choice of the maximum field on the central orbit depends on such things as profile parameter and aperture. Since the variation of machine radius is counterbalanced by variation in aperture, the economical optimum with respect to this parameter is fairly flat.
After balancing the various factors the parameter list presented in the report AR/Int. SG/62-13 Revision 1 was arrived at. More or less the whole group took part in the discussions leading to these parameters, but much of the detailed preparation of the data was done by Rossetti.

From the above mentioned report we find the following parameters of most general interest:

- Maximum field on central orbit: $B_{0\text{ max}} = 12$ kG
- Maximum field in minimum gap: $B_{\text{ max}} = 16$ kG
- Profile parameter: $n/\rho = 6$ m$^{-1}$
- Bending radius: $\rho = 840$ m
- Average radius: $R = 1200$ m
- Aperture: $55$ mm x $90$ mm
- Length of long straight section: $L_{\text{l.s.s.}} = 54$ m
- Number of long straight sections: 12
- Betatron phase shift per period: $\mu \simeq \pi/4$
- No. of betatron oscillations per revolution: $Q = 28.75$
- Repetition rate: 18 pulses/min.

For further details see the above mentioned report.

2.2. Magnet

Some detailed magnet dimensions have been calculated by Rossetti and the results are presented in the report mentioned in the previous section. The machine would require 27000 tons of steel plates and 2500 tons of copper. Since the steel making and the magnet manufacturing are big jobs, several firms have been sounded on their interest in this field. These contacts have been encouraging, as it has become evident that one can obtain even better steel for this machine than we got for the P.S. Better quality, however, may mean a higher price, and it may become a matter of economy how far to go in
quality requirements. There seem to be several firms in Europe that are able
to deliver steel in sufficient amounts and of sufficiently high quality.

Preparations for magnet model work are in progress.

2.3. Magnet Power Supply

The power supply for the magnet has been studied by F. Grütter
(Engineering Division) and the results presented in the report AR/Int. SG/63-26.
Various solutions have been considered. Taking into account the losses in the
supply itself together with the requirements for the magnet, the supply must
have a peak rating of about 220 MVA. This, however, is a pulsed load and
cannot be tolerated on an ordinary supply network. An arrangement with MG
sets coupled with flywheels is therefore necessary. Although it seems possible
to supply the whole magnet power by one single MG set, a splitting into two
sets appears preferable as this solution offers partial reserve in case of
a major failure of a component of the rotating plant. The centrally placed
motor-alternator-flywheel sets will feed 12 power converter units distributed
at equal distances around the ring, connected in series with the coils in
such a way that the centre of the individual units is always at about earth
potential so as to avoid excessive voltages with respect to ground on the
magnet coils.

2.4. Radio Frequency Systems

There are various possible ways of making the R.F. system for a large
synchrotron. The following three methods have been under consideration during
the last few years:

a) Ferrite tuned system \( (f \lesssim 30 \text{ MHz}) \)
b) Mechanically tuned system \( (f \text{ in the range } 100-300 \text{ MHz}) \)
c) Fixed frequency, phase-jump system \( (f \gtrsim 500 \text{ MHz}) \).
The Study Group has not attempted a detailed evaluation of the various systems. But some general considerations have made us draw the following conclusions:

a) The ferrite system should be avoided due to its bulkiness and high losses.

b) The mechanically-tuned system is attractive because of the high Q cavities that can be built and the rather convenient frequency range for which it is suitable. If a booster synchrotron is used as injector, this can also have a mechanically-tuned system, and one can have a match of the systems all the way from the buncher in front of the linear accelerator to the synchrotron.

c) The fixed frequency system (proposed by Robinson) requires a rather high frequency and there is some difficulty in accommodating the injected energy spread. It would not offer the matching of the different R.F. systems if a booster synchrotron injector were used. This might be less of a disadvantage if one injected straight from a linac. Also beam loading difficulties are expected to be severe at intensities above about \(10^{13}\) particles per pulse.

Such considerations made us concentrate on the mechanically-tuned system. The method was invented by Schnell while he visited Berkeley for a year, and some basic work on the system was done already there. The R.F. parameters have been worked out by Schnell and presented in the report already mentioned in section 2.1. The main R.F. parameters are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerating frequency</td>
<td>(\sim 200) MHz</td>
</tr>
<tr>
<td>Frequency swing</td>
<td>1 c/o</td>
</tr>
<tr>
<td>Peak R.F. voltage per turn</td>
<td>19 MV</td>
</tr>
<tr>
<td>No. of R.F. cavities</td>
<td>144</td>
</tr>
<tr>
<td>Cavity Q</td>
<td>(10^4)</td>
</tr>
<tr>
<td>Max. total R.F. power loss</td>
<td>2.1 kW</td>
</tr>
<tr>
<td>Total length of acc. structure</td>
<td>87 m</td>
</tr>
</tbody>
</table>
A low-power model has been built at CERN and construction of a high power model has started. The models are full scale, their dimensions correspond to the application in the booster synchrotron (see later) but most results are applicable to the large machine as well.

For more details one can refer to the report AR/Int. SG/63-19.

2.5. Injection

Two methods of injection are being studied. One method is to go directly from a linac into the large synchrotron. This would require a linac of several GeV in order to have a reasonable injection field in the 300 GeV machine. The other method is to have a booster synchrotron between a relatively low-energy linac, say 150 - 200 MeV, and the main machine. This booster would then have to be a high repetition rate machine.

The linac solution is in principle the most straightforward one. However, to build a 3 GeV linac is very much more than an extrapolation of present-day linacs and it would be an expensive device unless an important change in technique would occur during the next few years.

The booster solution applies better established techniques, the main difficulties probably being in the rather strict requirements on the beam transfer from the booster to the synchrotron. Careful studies, however, have shown that this can be solved.

An important consideration is whether one solution would have important advantages over the other one with respect to the performance of the machine for physics. The interesting possibility of using the injector as a separate physics tool during the 80 c/o of its time that is not spent on injection into the big machine, has recently been actively put forward as a reason for choosing a high injection energy, which is an argument in favour of a synchrotron as
injector. For further details on the general injection considerations, one can refer to the report AR/Int. SG/63-21.

The Study Group has studied in some detail both the booster synchrotron and the linac:

a) Booster

Bronca has presented some possible parameters for a 6 GeV synchrotron injector in the report AR/Int. SG/63-7, and for details we refer to this report. Later the parameters have been modified to apply to an 8 GeV synchrotron. The main parameters for such a machine would be:

- Maximum kinetic energy: \( E_{\text{max}} = 3 \text{ GeV} \)
- Injection energy: \( E_{\text{inj}} = 200 \text{ MeV} \)
- Average radius: \( R = 100 \text{ m} \)
- Bending radius: \( \rho = 45 \text{ m} \)
- Number of pulses to fill the main synchrotron: \( N_{\text{pulses}} = 12 \)
- Repetition rate: \( = 20 \text{ s}^{-1} \)
- Filling time: \( T = 0.6 \text{ s} \)
- Maximum energy gain per turn: \( E_{\text{max}} = 1090 \text{ keV/turn} \)
- Accelerating frequency: \( f = 100 - 180 \text{ MHz} \)

Special attention has been given to the R.F. system of the booster and model work is in progress. Schnell proposes to use a mechanically-tuned system also for this machine. This would have the advantage of operating at the same frequency as the R.F. system for the main machine at the transfer energy. Thus one can match the buckets of the main synchrotron to the bunches of the booster synchrotron without having to debunch and rebunch again. The loss of particles during the transfer operation should therefore be negligible. A detailed analysis of the R.F. system for a booster injector is given in the report AR/Int. SG/63-2.
The problem of R.F. synchronization of the two machines has been studied earlier by Tollestrup, who proposes an adiabatic phasing method. However, the time required for synchronization with Tollestrup's method is somewhat too long for our planned cycling rate of 20 Hz. We have therefore considered a different method. Schnell has suggested that, once the booster frequency has reached the value of the main ring frequency the booster bunches can be shifted into phase with the main ring buckets by applying a bucket which is centered around a phase halfway between the actual bunch phase and the desired phase. The bunches carry out a coherent phase oscillation inside this bucket and arrive at the correct phase after half a phase oscillation. Then the booster-R.F. is locked to the main ring R.F. and synchronization is finished. The phasing time would be short - 80 μs - and the small radial shift during phasing, due to field rise, could be compensated by starting synchronization with the beam circulating at a slightly smaller radius than that of the ejection orbit. This method would make it possible to achieve a very good accuracy in position and momentum of the ejected beam without too difficult tolerances on the magnetic field cycle. Details of this beam transfer method are given by Resegotti and Schnell in a report AR/Int. SG/63-43.

The beam transfer problems have been considered by De Read in the report AR/Int. SG/63-14. It is concluded that the beam transfer problems of a 300 GeV proton synchrotron are within the limits of present technology. By a proper choice of the parameters it looks possible to obtain a high degree of standardization in the matter of construction and the electrical characteristics of the various ejector and injector magnets, even if they operate on protons of quite different energy. The best layout of an ejection or injection scheme is the one which minimizes the sum of the errors due to kicker magnets, septum magnets and aberrations in the stray field, the latter depending on the size of the beam. We feel, however, that more experimental work to establish the limits of the precision of kicker and septum magnets is necessary before the final design of the beam transfer schemes can be made.
With the exception of the A.E. system and the beam transfer the problems encountered with the booster are very similar to those one has had to solve in the CEA and DESY electron synchrotrons. Some of these problems are difficult and we plan to put more effort into them during the next year of our design study. However, with the experience gained on the two electron machines mentioned, we are confident that the problems can be solved.

b) Linac

We have for convenience divided the linac into two parts for our study: the part below 200 MeV and the part above 200 MeV. The part below 200 MeV will be needed whichever solution is finally chosen for the injection method. We have so far assumed that this part very likely will be an Alvarez type of linac and it is not expected to constitute severe difficulties. A group at the Rutherford Laboratory has worked out the main parameters for this 200 MeV linac and also made an economic evaluation. A Rutherford Laboratory report by Batchelor and Carne on the subject is in preparation.

Originally it was believed that one would have to change from a drift tube structure to a disc-loaded structure at about 200 MeV. However, during the last year the Rutherford Laboratory has made model studies of two new structures, the so-called cross-bar structure and the clover leaf structure. Both these structures have turned out to be better than the disc-loaded structure for velocities in the neighbourhood of half the velocity of light. The cross-bar structure is particularly suited to our purpose, as it is relatively small, making it possible to use a low frequency. The frequency jump at 200 MeV need not then be more than by a factor of two. It is also a fairly simple structure to manufacture, and has been estimated to give an average shunt impedance of about 20 MOhm/m all in the range from 200 MeV to 3 GeV. For further details on the structure studies reference is made to the report given by Carne to the Dubna conference in August this year. (Rutherford Lab. Rep. FLA ACC.PHY 17178).
Parameter fixing and cost estimating has been done here at CERN. We have concentrated on a linac energy of 3 GeV which would give 150 G injection field in the synchrotron. Further parameters are listed in the following table:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerating length</td>
<td>1500 m</td>
</tr>
<tr>
<td>Total length</td>
<td>1750 m</td>
</tr>
<tr>
<td>No. of tanks</td>
<td>250</td>
</tr>
<tr>
<td>No. of foc. quadrupoles</td>
<td>250</td>
</tr>
<tr>
<td>Frequency</td>
<td>400 MHz</td>
</tr>
<tr>
<td>Structure diameter</td>
<td>0.3 m</td>
</tr>
<tr>
<td>R.F. pulse length</td>
<td>80 μs</td>
</tr>
<tr>
<td>Rep. rate</td>
<td>3 s⁻¹</td>
</tr>
<tr>
<td>Peak power for structure</td>
<td>350 MW</td>
</tr>
<tr>
<td>Peak power for beam</td>
<td>300 MW (I_{beam} = 100 mA)</td>
</tr>
<tr>
<td>Total peak power</td>
<td>650 MW</td>
</tr>
</tbody>
</table>

For further details reference is made to the following reports by Shersby-Harvie and by Paresin: AR/Int. SG/63-12, AR/Int. SG/63-18, and AR/Int. SG/63-38.

The bunches from a linear accelerator of this kind will have an uncomfortably large energy spread and equally uncomfortably small phase spread. Furthermore the central energy and the phase of the bunches must be expected to vary considerably from pulse to pulse. Some kind of debunching will therefore be necessary. The most efficient debunching can probably be obtained by inserting a magnetic debuncher between the linear accelerator and the synchrotron. Another method would be to do the debunching internally in the latter part of the linear accelerator. This would require very little hardware and would therefore be cheap. The main disadvantage of the method is that it would then have to be done in the high frequency part of the linear accelerator, which is 400 MHz, whereas the bunch frequency is in fact 200 MHz, which is the frequency of the 200-MeV part of the linear accelerator. A magnetic debuncher on the other hand could operate on 200 MHz and thus permit twice as
much debunching as the internal method would do. Both methods have been studied by Parain and described in the reports AR/Int. SG/62-3 and AR/Int. SG/62-9.

g) Comparison between the two injection methods

Cost estimates that we have made indicate that the linac solution would be about 100 million Swiss francs more expensive than the booster solution. The difference is only on the injector proper. Added to this comes the extra cost of the synchrotron if one injects at an energy as low as 3 GeV. From this we have concluded that we could only justify using a linear accelerator as an injector if one could show that it had great advantages technically over the booster. The main advantage of the linear accelerator over the booster would be in the injection time required, which for the linear accelerator is negligible compared with the 0.6 seconds required for the booster. This would mean that if the synchrotron were built for 3.3 seconds between pulses at full energy the corresponding time would be 2.7 seconds with a linac as an injector and properly increased magnet power supply and cooling installation. This is not a great difference, but it becomes relatively more important if one considers running the machine at a lower energy than its design energy. For instance at one tenth of the design energy one could make one pulse per second with a booster and two pulses per second with a linear accelerator. Most other technical considerations come out in favour of the booster, in particular the very general point that one applies almost exclusively established techniques with the booster solution, whereas the 3 GeV linear accelerator is a considerable extrapolation beyond today's techniques. The final choice of injection method can still be left open, but we feel sufficiently confident that the booster solution is to be preferred that we have decided from now on not to put any more effort into the linear accelerator above 200 MeV. Our linear accelerator group will spend most of the time on solving the problems envisaged for the 200 MeV linear accelerator.
2.6. Controls

In an accelerator a large number of control signals have to be transmitted from one place to another. The bulk of these signals are very simple on-off signals and it has so far been common in accelerator design to use conventional direct cabling for transmission of such signals. However, on the largest existing accelerators this starts becoming expensive and also technically inconvenient. Since the amount of cabling scales approximately with the square of the energy we have concluded that ordinary cabling should be excluded for the transmission of most control signals.

Brianti and his group (MPS Division) have started a detailed study of other methods. One would have thought that suitable industrially-developed multiplex systems would be available. This, however, turns out not to be the case. Most multiplex systems have concentrated transmitting and receiving regions with large distances in between, and some have distributed transmission but concentrated receiving. We have not found systems with both distributed receiving and transmission and the flexibility required for a large accelerator in the choice of receiving and transmitting points. One must quickly be able to transmit from almost any point to any other point.

We have studied both time division multiplexing and frequency multiplexing. For the time being we favour the latter and are going to install a pilot system for connecting the East Experimental Area of the CERN-FS to the Main Control Room. A laboratory model has already been operating. The idea is to use 200 - 400 kHz as the carrier frequency because simple cables can be used for this frequency and it gives adequate capacity. More details are given in an internal report by Brianti (MPS/Int. CO 63-3). A provisional study of the beam observation system for the large synchrotron has been done by Schnebl and is described in the report AR/Int. SG/63-27.

2.7. Expected Performance

The intensity of a 300 GeV machine will be limited either by the number
of particles one is able to inject into the machine or by the space charge limit somewhere, either in the injecting synchrotron or in the 300 GeV synchrotron itself. No linear accelerator exists at present with a sufficiently high intensity to bring one near the space charge limit of the machine with parameters as presented in this report.

It is probably conservative to assume that the 200 MeV linac to inject into the booster synchrotron will be able to deliver 100 mA pulses. If this assumption is made, the synchrotron will deliver about $3 \times 10^{13}$ protons/pulse or about $10^{13}$ protons/second. The space charge limit based on the ordinary simple-minded theory would be at least a factor of three higher, and there is therefore scope for improvement of the linear accelerator intensity. One should probably aim at say 200 mA per pulse for the linac but not at this stage rely on this being possible.

Recently it has been pointed out by several authors that image forces may have similar effects to space charge forces and may constitute a more severe limitation. Symon has studied this problem in our group and the conclusion is that with our parameters this effect is not severely limiting. A more detailed paper has been presented by Laslett to the Dubna Conference. We are continuing the study of this problem and applying Laslett's results to our parameters.

2.8. Experimental Layout and Utilization

A drawing showing the layout of a 300 GeV proton synchrotron is attached to this report. In our plans are incorporated twelve long straight sections, each one being 54 m long, although only two will have experimental areas initially. The possibilities of using internal targets are limited due to the forward collimation of the secondary particles for a 300 GeV accelerator. It is also to be expected that internal targets give rise to an induced radio-activity in the target area which will be about two orders of magnitude larger than in existing machines due to the larger intensity and higher energy of the...
internal beam. It looks therefore more attractive to extract the proton beam with a slow extraction system and to work with external targets. Parameters for ejection schemes have been considered and we believe that a slow extraction with 90 o/o efficiency is feasible. From the point of view of target efficiency and secondary beam optics external targets offer practically the same possibilities as internal targets and have the advantage of accessibility from all sides and flexibility, while at the same time the problem of induced radio-activity will be eased considerably. Both fast and slow ejection must be incorporated in the design from the beginning.

In general, it can be said that the higher the energy the more all primary and secondary beams are pointed forward. This has led to the conclusion that transverse dimensions of beam handling equipment and detectors should not in general increase as compared with 25 GeV equipment, perhaps the contrary.

Longitudinal dimensions, however, scale differently if present-day techniques are going to be used. All beam transport equipment seems to become very long. An R.F. Separator of 100 GeV/c can be taken as an example, where nearly 2 km of length would be required (AR/Int. FSep/62-3). Our tentative conclusion is that one has to think of experimental areas whose lengths range from about a machine radius to a machine diameter. The distance from the point of ejection to the external target at the entrance of the experimental halls should be of the order of 500 m in order to allow sufficient freedom to manipulate the external beam. The size of the experimental halls would then be for example 60 x 400 m². At the downstream end of these halls a 1000 to 2000 m long and 15 m wide extension for an R.F. separated beam, possibly in the open air, is foreseen. Further details may be found in the report AR/Int. SG/63-3.
2.9. Buildings and Services

No detailed studies on buildings have been carried out so far, since they depend very much on the site configurations, and since the main effort was put into the design of the ISR buildings (see 3.9).

Members of the Engineering Division have examined the electricity supply and distribution on the site and the recooling of the machine and the experimental equipment.

Bayard and Reitz have studied possible schemes for the electricity distribution around the machine and experimental areas (AR/Int. SG/63-25). The installed power is estimated to be of the order of 80 MVA for the machine proper, and 80 MVA for the first experimental areas. The total installed capacity may be as high as 300 MVA at a later stage.

Studies are being made by Grütter, Hugi and Perin about a combined electricity and heat generation on site and a recovery of heat from the cooling of the machine and the experimental equipment.

Various methods for cooling the magnets of the machine, and beam transport and experimental magnets have also been studied. A final choice of the system will depend on the quantity and temperature of cooling water available on the future site.

Hugi (Engineering Division) made a study of the airconditioning system for the ring tunnel (AR/Int. SG/63-15). He has assumed meteorological conditions like those of Geneva, and a temperature of 20°C in the tunnel with 55 o/o humidity. He has further estimated the heat dissipation in the tunnel during operation to be 2 MW and the heating requirements during winter 3 MW. The installed power capacity for this plant will then be about 5 MW. The primary cooling can be obtained from either 400 m³/h cooling water at 14°C or by means of cooling towers, but the last system is appreciably more expensive.
2.10. Site Problems and Surveying Techniques

The siting of a 300 GeV proton synchrotron causes some unique problems. On the one hand a free space of about 20 km² area is needed, but on the other hand it should be near a sizeable town in order to provide the necessary facilities for the staff. A flat site is to be preferred, and the ground should be as rigid and stable as possible. Moreover, large amounts of electric power and cooling water are required.

The requirements for a site are listed in the report CERN/485, which was distributed to the CERN delegates in June 1963. In several member states, national geological institutes have searched for possible sites and discussed on an informal basis with the experts in the A.R. Division. Each proposal has been investigated very carefully with possible machine layouts, and in all cases which looked promising visits were paid on the spot in order to clarify some problems which had been left open. Sometimes, this involved a search for cooling water or electric power, sometimes a study of the seismic activities, or of the level of the water table. We are now sure that an acceptable site for a 300 GeV can be found in more than one place in Europe.

In parallel with the search for possible sites, a substantial amount of work was put into the studies of the stability of various types of ground. Survey bases in the form of a triangle of 300 m side have been installed on gravel and limestone and the movements are checked monthly, both in vertical and horizontal directions. The same experiments will shortly be started on sandstone, chalk and possibly slate, whilst information on sand is obtained from DESY and Brookhaven.

Surveying techniques are continually developed. The method of invar wires used so far has been further improved by the development of knife edge bearings integrated with a lever system for the stretching weight. It is also intended to make a study of the possibilities of the use of laser beams for calibration as well as alignment procedures.
2.11. Cost Estimate, Manpower, and Time Schedule

Detailed reports (AR/Int. SG/63-4 and AR/Int. SG/63-5) were written on this subject early this year. Because the parameters have not been changed since then, we believe that the figures given in these reports are still valid. We therefore refer to them for details and give here only a summary.

The time schedule for a 300 GeV P.S. is as follows: Supposing that the official authorization is given by the end of 1965, and that the site is chosen by the middle of 1966, the running-in of the machine could start in 1973. (This schedule is, as a whole, one year later than the one shown in AR/Int. SG/63-4, which was based on an authorization by the end of 1964.)

The total staff build up for the new organization would be as follows:

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</thead>
<tbody>
<tr>
<td>Value</td>
<td>35</td>
<td>150</td>
<td>330</td>
<td>505</td>
<td>790</td>
<td>1075</td>
<td>1390</td>
<td>1615</td>
<td>1860</td>
</tr>
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</table>

The yearly budgets (in MSwfrs) would be:

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</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>3</td>
<td>15</td>
<td>91</td>
<td>193</td>
<td>231</td>
<td>226</td>
<td>229</td>
<td>231</td>
<td>241</td>
</tr>
</tbody>
</table>

The total budget for the construction period will be 1460 MSwfrs, of which 980 M will be spent on the P.S. proper, including its building, and 480 M on the first experimental equipment, beams, data handling, and laboratory services.

We made a detailed analysis of the influence of the machine energy on the cost and time schedule (AR/Int. SG/63-4 is the cost estimate for a 300 GeV P.S., AR/Int. SG/63-5 for a 150 GeV P.S.).

The result can be summarized as follows:
1) The total cost of a 150 GeV P.S. would be more than half of that of a 300 GeV P.S. (942 M$\text{frs}$ as against 1460 M$\text{frs}$).

2) The construction time of a 150 GeV P.S. will be shorter than that of a 300 GeV P.S. (7 and 8/2 years respectively).

3) The laboratory staff for a 150 GeV P.S. would not be much smaller than that for a 300 GeV P.S. (total staff at the end of the construction period 1545 and 1860 respectively).

4) A 300 GeV and a 150 GeV P.S. of which the construction is started in the same year, and which are both built to a comparably tight programme, will have yearly budgets which are very much the same for both machines until several years after the operation of the machines is started. Eventually the yearly budget of the 300 GeV will rise to a higher figure than that of the 150 GeV, but the first machine will have a longer useful life and will enable one to do better physics from the beginning.

3. Intersecting Storage Rings for the CERN Proton Synchrotron

3.1. Working Principle and Expected Performance

Since the theory of intersecting storage rings is less known than that of a conventional accelerator, we shall give a summary of the working principle:

The particles are accelerated in the synchrotron to their final energy. A fast ejection system then takes out all the particles in one revolution and puts them into a beam transport system. A fast injection system then puts the particles into one or the other of the two storage rings, where they are picked up by the radio-frequency system of the rings and brought into the stacking region (near the middle of the vacuum chamber). Each time the
synchrotron has brought a new pulse up to full energy the process is repeated, and the pulses are stacked side by side in the longitudinal phase plane of the storage rings.

Each pulse occupies a very small fraction of the longitudinal phase space available. One can therefore build up very high intensities (in ordinary space) near the middle of the vacuum chambers.

The two storage rings may have several common straight sections in which colliding beam experiments can be performed. Originally the Study Group considered a pair of excentric storage rings with only two interaction regions, but a more detailed study has made us adopt the concentric design proposed by Woods and O'Neill. With this design one can have more than two intersection regions. We are at the moment considering eight such regions which make it possible to carry out a number of experiments simultaneously. This is important because some experiments may have low counting rates and require long running times, while in general only one experiment at a time per intersection region will be possible.

In proton storage rings where there is only negligible radiation loss, the intensity to which one can build up a beam is limited by the phase space available in the storage ring compared with the phase space occupied by the beam in the synchrotron. Since the stacking process is in the longitudinal phase plane ($\Delta p, \psi$) and since coupling between transverse and longitudinal oscillations can be neglected, we only have to consider the $\Delta p, \psi$ phase plane where for convenience we measure $\psi$ in the R.F. system. We then afterwards have to add the space needed for betatron oscillations.

The particles ejected from the synchrotron have a certain phase space density in the bunches. We have made calculations to find how efficiently one can transfer these bunches into the storage rings. (Details of these computations were presented by Swenson to the Brookhaven Accelerator Conference
in 1961 and more information can therefore be found in the Proceedings of this conference.) The main conclusion to be drawn from these computations is that we can assume being able to transfer the beam with very little reduction in phase space density. If the total number of stacked pulses is large, say of the order of 100 or more, we can therefore assume, for performance estimates, that the phase space density is nearly the same in the storage rings as within the bunches at the output end of the synchrotron. If the momentum width that can be accomodated within the space available for the stack in the storage ring is $\Delta p_s$, the maximum number of stacked particles can be written

$$N_s = \eta \rho_o \pi \frac{H_{SR}}{\Delta p_s}$$

where $\eta$ is the stacking efficiency (which from the remarks above can be put equal to unity with good approximation), $\rho_o$ is the phase space density in the synchrotron bunches and $H_{SR}$ is the ratio between the R.F. frequency and the revolution frequency in the storage ring.

The CERN-PS now delivers $5 \times 10^{11}$ p/p in 20 bunches each of a shape $\Delta p = \pm 6.7$ MeV/c, $\Delta \lambda = \pm \frac{\lambda}{4}$ radian, which gives a $\rho_o = 5 \times 10^3$ protons/MeV/c. In the storage rings $H_{SR} = 30$ and $\Delta p/p = \pm 1$ o/o (these figures are the results of parameter choices which will be discussed later in this report). With these results we find that the estimated number of stacked particles of momentum 25 GeV/c $\pm 1$ o/o in the storage ring is

$$N_s \approx 4 \times 10^{14}$$

which is equivalent to $\sim 20$ A circulating current.

We shall assume that the cross section of the beam in the interaction region is rectangular with a width $b$ and a height $h$ and that the angle between the two beams is $\alpha$. The interaction volume in each intersection region is then
\[ V = b^2 \frac{h}{\sin \alpha} \]

The height of the beam is given by the properties of the beam coming from the synchrotron and to some extent by the parameters of the storage ring. We assume here \( h = 1 \text{ cm} \). The width of the beam for a given \( \Delta p \) is largely given by the momentum compaction factor and will in the interaction region be about \( b = 6 \text{ cm} \) for \( \Delta p/p \approx 1 \text{ o/o} \) with storage ring parameters as presented later in this report. The crossing angle will be \( 15^\circ \). With these figures the interaction volume becomes \( V = 140 \text{ cm}^3 \). Within this volume one knows the momentum distribution of the two beams, which reduces the disadvantage of the large momentum spread.

It is possible to incorporate in the design provision for making a localised contraction of the beam as proposed by Terwilliger. When maximum use is being made of this possibility, the beam width is mainly determined by the betatron oscillations. In this case one can assume \( b = 1 \text{ cm} \) and one gets the interaction volume \( V = 4 \text{ cm}^3 \), which is about the minimum interaction volume one can expect. There is in this case a random distribution of the momentum within this volume and the Terwilliger scheme can therefore not be used if better knowledge of the momentum of the interacting particles is required. The interaction rate from each interaction volume is

\[
N_{IR} = \frac{c}{h \tan \alpha/2} \left( \frac{N_s}{2 \pi R} \right)^2
\]

where we have assumed that there are \( N_s \) particles in each ring, \( c \) is the particle velocity, \( R \) is the average radius of each ring and \( \alpha \) is the cross section of the reaction under consideration. It is interesting to notice that this formula does not contain the width of the beam, which means that the application of the Terwilliger scheme does not change the interaction rate in the interaction volume.
We are at present thinking of having an average radius of the storage rings of 150 m. This together with the figures arrived at above gives the following interaction rate per intersection region

\[ N_{IR} \sim 4 \times 10^{30} \delta \text{ interactions/sec.} \]

where \( \delta \) is the cross section in cm\(^2\) of the interaction to be studied. The total cross section of p-p collision is \( 4 \times 10^{-26} \text{ cm}^2 \) and the expected total interaction rate in an interaction region is therefore

\[ N_{IR \text{ total}} \sim 1.6 \times 10^5 \text{ interactions/sec.} \]

It is believed that the numerical results arrived at in this chapter are conservative, as they are based on present performance of the CERN-PS. Improvements can be expected in two ways: i) the present development work carried out around the P.S. will probably lead to an intensity near the space charge limit, that is a few times \( 10^{12} \) protons/pulse, ii) it is probably possible to improve the phase space density by concentrating the beam injected into the P.S. nearer the centre of the R.F. bucket. An order of magnitude increase in stacked current may be possible, but should not be relied upon at this stage.

3.2. Basic Parameters

No proton storage rings have so far been built. In fixing parameters we have therefore not been able to extrapolate from any earlier construction. The parameters have had to be evaluated more from basic principles although the general accelerator experience gained on the CERN-PS has been of great help. Several sets of parameters have been worked out and presented in various internal reports. We shall here only sum up the situation as arrived at by now. (For more details see the internal report: AR/Int. SG/63-30 by De Raad).
The most important parameter to choose is the maximum energy which the storage rings must be able to take. The CERN-PS is able to deliver protons of a total energy of up to 26 GeV. We have therefore based the design of the storage rings on this energy.

As already mentioned, we now favour a concentric arrangement because of the greater possibilities this gives for physics experiments. From the physics point of view six interaction regions would probably be sufficient. However, eight turn out to be more convenient from the point of view of beam dynamics, as this gives comfortable distance from the working point to the nearest stopbands. We have therefore confined ourselves in the further studies to this number of interaction regions.

At one stage we seriously considered choosing a magnet arrangement with split focusing and bending as this would give more flexibility to the operation of the rings. An economical study, however, indicated that this would be a more expensive magnet than one with combined focusing and bending. Furthermore, considerable flexibility for experimentation can still be obtained with the latter design by having special magnets at the ends of the long straight sections. We have therefore recently gone back to this arrangement. The magnet structure of the ISR is nevertheless somewhat different from that of the CPS because the ISR must have much longer field free sections for experimental purposes and its mean radius will vary along the circumference. This is a consequence of a concentric arrangement. Another difference from the CPS is that in an accelerator, the energy spread of the protons is small and the aperture requirements are mainly determined by the injected beam size and closed orbit deviations due to magnet imperfections. In the storage rings, however, the beam is injected with a high energy and small diameter. Most of the horizontal aperture, which is a few times larger than the vertical aperture, is required for the energy spread in the stacked beam and for the injector itself.
For the magnet units we have chosen the so-called FOFOX structure which has certain important advantages. However, it has the disadvantages of requiring rather high magnetic field gradients and complicating the construction of the vacuum chamber. The choice of structure is therefore not finally settled and detailed computations are in progress to determine the relative merits of the two alternatives.

Each storage ring has four outer arcs where the magnet units are placed as close as possible, leaving only some space for correcting elements and four inner arcs, with about 13 m long mid-F straight sections and about 5 m long mid-D straight sections. The number of colliding beam events is inversely proportional to the beam height and therefore the interaction regions have been chosen to be in mid-F straight sections. In half the interaction regions the beams go towards the outside of the ISR and in the other half they go towards the inside. The latter interaction regions are most suitable for small-angle experiments on account of the longer field free sections.

Concerning the general layout, the main parameters to choose are the angle of intersection $\alpha$ and the number of magnet periods $M$. The former should be reasonably large to avoid mutual interference of the magnets of the two intersecting storage rings, but this is limited by the fact that the ISR mean radius $R$ increases with increasing $\alpha$. This increases the cost and reduces the interaction rate. $M$ should be divisible by four since there are four superperiods and preferably by some other numbers to allow a reasonable subdivision of the number of magnet units between inner and outer arc and a convenient distribution of correcting elements. To reduce the gradient of the magnetic field and make the straight sections long $M$ should be as small as possible. The most convenient choice appears to be $\alpha = 15^{\circ}$, and $M = 48$. Each outer arc then has 16 magnet units and each inner arc has 8 magnet units. The distance between the middle of the inner and outer arc is 9.1 m.

The maximum value of the magnetic field is subject to serious limitations. Whereas in an accelerator like the CFS a few centimetres of good field at
top energy is sufficient, in the ISR the field shape must remain correct over the whole aperture so that a much better correction is required. The fact that the magnet operates at d.c. is of no help, on the contrary, heating of the pole face windings limits the possibility of corrections. We have therefore chosen a maximum magnetic field on the central orbit of 12 kGauss.

The following table gives a summary of the main parameters that we have arrived at. For further justification of the various choices reference is made to the above mentioned report by De Head.

<table>
<thead>
<tr>
<th>Main Parameters of Concentric Storage Rings for the CPS</th>
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<tbody>
<tr>
<td>Maximum energy (total) 23 GeV</td>
</tr>
<tr>
<td>Peak field on central orbit 12 kGauss</td>
</tr>
<tr>
<td>Magnetic radius 79 m</td>
</tr>
<tr>
<td>Mean radius 150 m</td>
</tr>
<tr>
<td>Number of intersections 8</td>
</tr>
<tr>
<td>Angle of intersection 15°</td>
</tr>
<tr>
<td>Number of magnet periods 48</td>
</tr>
<tr>
<td>Length of long straight sections 13 m</td>
</tr>
<tr>
<td>( \delta r ) for ( \frac{s_p}{p} = 1 ) c/o mid-F 2.3 cm</td>
</tr>
<tr>
<td>Aperture of vacuum chamber 5 cm x 15 cm</td>
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</tbody>
</table>

3.3. Magnet, Power Supply and Cooling

The detailed magnet design is waiting for some results from the structure calculations. However, preliminary design is in progress and model work is being prepared.

It will be easier to obtain the extreme precision required throughout the delivery (± 0.01 mm in the gap) by stamping laminations rather than by
machining blocks. Steel sheets have better magnetic properties than solid steel and laminations can be mixed to get a better uniformity of the steel properties in all magnets. Although the magnet is going to be run d.c. it has therefore been concluded that it should be constructed from laminated steel.

The two rings will contain 384 magnet blocks of outside dimensions 140 cm x 103 cm x 245 cm. The total amount of steel to be purchased will be 11,500 tons. With the parameters as given in the previous section the magnet gap will be 10 cm x 40 cm. The coils will contain 1100 tons of copper. Pole face windings will be necessary for the field correction. Because of the d.c. operation at top field they will have to be water cooled. In addition to the normal magnet units, the magnet system will contain 128 quadrupole lenses, 64 skew quadrupoles and 32 sextupole lenses.

The steel measuring equipment has been constructed and steel samples from several European firms are being measured with encouraging results. A d.c. generator has been ordered for powering the magnet models.

The power supply for the storage rings is being studied by Mosig and GodENZI (Engineering Division). Three different methods have been considered:

a) Series connected d.c. generators.
b) Synchronous generator with rectifiers.
c) Stepping transformer with rectifiers.

The stepping transformer solution offers some advantages over the others: lower price, negligible maintenance, higher reliability and a minimum of space.

The discontinuity in the regulation of the stepping transformer will be eliminated by a booster power supply which consists of silicon controlled rectifiers.
A small scale model will be built to investigate the problem in more details.

Cooling and ventilation problems are being studied by Hugi. The magnet cooling capacity required is 18,000 kW and the system considered would require approx. 100 m³/h raw water. In addition to the cooling system for the storage ring magnets we shall provide a cooling capacity of maximum 12,000 kW for experimental equipment in the 25 GeV experimental halls and a maximum of 7000 kW for equipment in each intersection region.

The air conditioning system must serve both the circular tunnel sections and the experimental halls. It will consist of 8 air treatment plants, the air distribution and return ducts with the necessary outlets and return air grills, the necessary piping for hot and chilled water between the cooling room and the air treatment plants, and a water chiller consisting of centrifugal compressor, condenser with cooling tower and evaporator. More details are given in the internal report EBG/Int. 63-20.

3.4. The R.F. System

It is advantageous to transfer the P.S. beam while it is still bunched, and to inject the bunches directly into R.F. buckets in the storage rings. The R.F. system of the storage rings must therefore work on the same frequency as that of the P.S. The harmonic number will be higher in the storage rings because of their larger mean radius, and the radii have to be in a rational ratio.

The requirements on the R.F. system have been studied by Schnell and are detailed in the reports A4/Int. SG/62-5 and A4/Int. SG/63-24. In the following is given a short review of the principal conclusions.

At the instant a beam pulse is deposited after displacement by R.F. modulation from the injection orbit to the storage orbit, the R.F. buckets
must fit the bunches tightly in order to avoid dilution of particle density in phase space. The time required for doing the full displacement to the top of the stack with a tightly fitting bucket is, however, too long compared with the period between consecutive P.S.-pulses, except for \( \sin \varphi_s \) (\( \varphi_s \) = stable phase angle) close to unity. Stacking with \( \sin \varphi_s \) close to unity presents some difficulties because the tolerances on the R.F. programme become rather tight and because the stacking efficiency tends to become worse with large values of \( \sin \varphi_s \). Nevertheless, it appears to be possible to find a compromise (\( \sin \varphi_s \approx 0.8 \)) where a reasonable efficiency can be achieved, provided the number of stacked pulses is not much smaller than the maximum number.

On the other hand, stacking with \( \sin \varphi_s \approx 0.5 \) is certainly possible also, and probably safer, provided the R.F. programme is made up of the following three steps: The P.S. bunches are injected into large R.F. buckets which move the bunches most of the way to the stack in a convenient time \( T_1 \); the phase area of a bucket is much larger than that of a bunch during this step. Thereafter, a time \( T_2 \) is required to reduce the bucket area to fit the bunch before approaching the stack; this has to be done adiabatically in order to avoid deterioration of stacking efficiency. The tightly held bunch is dropped at the bottom of the stack, but some time \( T_3 \) is necessary to move through the diluted tail of the stack, and to readjust for energy deviations due to R.F. programme errors. With a maximum R.F. voltage of 20 kV and \( \sin \varphi_s = 0.5 \) as a reasonable compromise, Schnell finds for the contemplated storage ring parameters, certain assumptions on tolerances, and \( E = 25 \) GeV,

\[
T_1 + T_2 + T_3 \approx 0.3 + 0.4 + 0.8 = 1.5 \text{ s}
\]

leaving still a good reserve, since one P.S. cycle takes 3s at 25 GeV. Below 25 GeV the stacking time first decreases with energy, to rise again if transition energy is approached. Stacking would, however, be possible as close as 5 o/o to transition energy.
The effect of R.F. noise on the stacking process is a serious concern. Fortunately, the frequency modulation required covers a very narrow band. In order to confine phase blow-up by R.F. noise to less than 10 o/o of the half-length of the bunch, a tolerance of about 0.1 Hz r.m.s. frequency deviation within 100 Hz of band width results. Measurements are in progress for checking whether this noise tolerance can be met. So far only the basic FM oscillator has been built and tested. Its frequency noise has been found to be well below tolerance. In addition, it might be possible to use automatic phase-lock of the R.F. system to the injected beam, despite the presence of the stored beam, at least during part of the stacking cycle.

The maximum accelerating voltage which might conceivably be required is of the order of 10-20 kV, and the total maximum R.F. power consumption has been estimated at about 10 kW.

On the other hand it must be possible to turn the R.F. voltage down to values below 100 V in a well-controlled fashion. In this connection beam loading represents a rather serious problem. It seems possible, however, to reduce the beam-induced cavity voltage to a tolerable amount by driving the cavity from an amplifier with a very low source impedance. The amplifier which has strong negative feedback and operates in a class A condition must be expected to have a rather low efficiency, but this is acceptable, because the total required power is not very large.

Alternatively, or in addition, one may have to rely on servo systems for phase and amplitude to tie the voltage across the gap to the input voltage of the amplifier regardless of the voltage induced by the beam.

3.5. Vacuum

De Raad has shown (AR/Int. SG/62-12) that the pressure of the residual gas in the vicinity of the interaction region should be $10^{-10}$ Torr or less in
order to reduce the flux of background particles to the level which is desirable for experiments. The average pressure around the ring can be somewhat higher. At an average pressure of $10^{-9}$ Torr the storage rings must be filled at least once per day at 25 GeV and twice per day at 10 GeV. At a pressure of $10^{-8}$ Torr the stacked beams would have to be renewed ten times more often (for details see AR/Int. 3G/63-30). From these data we conclude that an average pressure of $10^{-9}$ Torr is necessary for satisfactory operation of the storage rings.

The A.R. Division has for several years developed ultra-high vacuum systems in connection with the storage ring model work. Sections of the vacuum chamber for the storage ring model have been operated at a slightly better vacuum than $10^{-10}$ Torr. This has been achieved by careful design, avoiding all organic material and using gold wire O-rings for seals. All welds are argon-arc welded without additional electrode material. The walls of the vacuum chamber are electrolytically polished on the inside and the whole system is baked out at about $300^\circ$. Getter-Ion pumps have been used for pumping, and molecular pumps (Pfeiffer) for roughing. The report AR/Int. SR/63-13 gives more details.

Recently we have also taken up the development of cryogenic pumping using liquid helium. A vacuum of a few times $10^{-12}$ Torr has been reached for short periods in a volume of about 10 litres.

From these results we have concluded that it is possible to obtain the rather stringent vacuum requirements of the intersecting storage rings by a careful design of the vacuum system. Model work of sections of the vacuum chamber is being planned.
3.6. Extraction, Beam Transport and Inflection

The beam must be transferred from the CPS to the ISR in such a way that the maximum number of protons can be stacked in the energy band determined by the 6 cm stack width of the ISR. At the moment of beam transfer the frequencies of the R.F. systems in the CPS and ISR must be the same. The mean radii of the CPS and the ISR are 100 m and 150 m respectively and therefore the harmonic numbers are 20 and 30. After a pulse from the CPS has been injected there are 20 full and 10 empty buckets circulating in the ISR. For maximum intensity the last 10 empty buckets must also be filled before the beam is accelerated towards the stack.

To avoid any loss of protons we propose to place in the beam path between the CPS and ISR a fast switching magnet followed at a distance $\lambda/4$ by a septum magnet. This combination operates in the same way as the fast ejection system of the CPS. The sequence is then as follows. First a pulse from the CPS is transferred to ISRa. The second pulse from the CPS is timed in such a way that it fills the empty buckets of ISRa, but after the first ten bunches have passed the switching magnet the latter is energised and sends the second half of the pulse into ISRb, which then has 10 full and 20 empty buckets. The 20 empty buckets are filled with a third pulse from the CPS. Meanwhile the injected beams are accelerated towards the stack and at the fourth pulse from the CPS the sequence starts to repeat itself.

As is well known a fast ejection system is now operating successfully on the CPS. The tolerances are tighter if one wants to stack the beam afterwards, but the encouraging results on the CPS have made us conclude that a satisfactory ejection system can be constructed. De Raad has considered an arrangement in some detail in the above mentioned report AR/Int. SG/63-30. In this report is also given an analysis of the beam transport system between the CPS and the ISR and of the injection system into the ISR. The kicker needed for the injection is different from the one needed for ejection from
the CPS. The injection kicker should only occupy a very small fraction of
the aperture and its stray field must not reach the already stacked particles.
We intend therefore to place a movable screen between the septum magnet and
the stack at the moment of injection. In addition to what is required for
ejection the decay time of its magnetic field must also be shorter than the
time in between the two bunches (80 ns) since the protons continue to
circulate through the kicker magnet. Model work on this kicker is in progress.

3.7. Experimental Considerations

The experimental problems connected with the utilization of ISR are
quite different from those which are familiar from stationary target experiments
with existing accelerators. Collisions between protons take place inside the
ISR vacuum chamber and must be studied by analysing their reaction products
in detectors placed around the vacuum chamber near the interaction region.
This restricts the freedom in the choice of the experimental conditions. It
also makes it essential to take into account the experimental requirements in
the design of the storage rings proper and special features should be in-
corporated in the ISR design in order to increase its flexibility for the
experiments. Several such features have already been mentioned in this
progress report, e.g. the vacuum requirement is mainly governed by the
experimental requirements. The length of the straight sections is to some
extent thus governed, as well as the design of the magnets at both ends of
the long straight sections. The implications connected with several interesting
experiments have been analysed by Burhop, Jones, O'Neill, De Raad and others.
For more details reference is made to the report AR/Int. SG/63-31, and also
to the report of the working party on the European High Energy Accelerator
Programme (PA/HE/23 rev. 3).
3.8. Shielding

The radiation level in the vicinity of the ISR vacuum chamber will exceed the maximum permissible dose by at least two orders of magnitude, even if collisions with the residual gas at a pressure of $10^{-10}$ Torr were the only source of background. This means that even under these ideal conditions the detectors, for instance spark chambers, are never accessible in the presence of a stacked beam. If access to the detectors is required the only possibility is to dump the stacked beams and it takes about one hour of CERN-FS operation to fill both ISR again. The electronic triggering circuits must be close to such detectors as spark chambers to avoid delays in the cables but on the other hand they must be shielded from the ISR to make them continuously accessible.

When the vacuum is less good than the value assumed above the background increases correspondingly. During the filling of the ISR the background due to protons which are lost from the stack is much larger. The stacked beams themselves are potentially dangerous sources of radiation since they may contain as much as $10^{15}$ protons and it is always possible that the beams would be lost near an interaction region due to faulty operation of an experimental magnet, vacuum troubles etc. Although in principle one can design a fast kicker magnet which dumps the beam in a well-shielded place in case of accidents, such a system could not in our opinion be absolutely safe. Finally the ISR may quite often be used as beam stretchers for the CERN-FS. All these arguments taken together lead to the conclusion that the shielding thickness of the ISR must be comparable with that of the CERN-FS. More details on our shielding estimates appear in the internal report AR/Int. SG/62-10 rev., by Middelkoop and De Raad.

3.9. Building Studies

The general layout of the principal buildings (ring tunnel, colliding beam halls, 25 GeV experimental hall) was studied by De Raad and Middelkoop (AR/Int. SG/63-23) and is shown in a drawing attached to the present paper.
The ring tunnel is 15 m wide and 6 m high, the colliding beam halls are 25 m wide, 70 m long and 13 m high; the 25 GeV experimental hall is 40 x 120 m and 18 m high. Initially there will be only 2 colliding beam halls and one 25 GeV hall, but this number can be increased as the need arises. There will be a laboratory building, a divisional workshop and a power, cooling and control building.

Mallet and Bianchi (Site and Buildings Division) have started a study of the buildings, especially of the ring tunnel and halls.

The first point to study was the quality of the ground of the new French site. This turned out to be disappointing. The quality and inhomogeneity are even worse than at the location of the P.S. Also the homogeneous molasse is in many places further down than we had expected from the layers under the P.S. It became clear that our original hope to fix the magnets immediately on to this molasse, could not be realized.

The most economical level for the machine was found to be 443 m for the floor of the tunnel (as against 432 m for the CPS). At the point with the highest ground level the machine is about 20 m below the surface.

The actual construction details for the tunnel and the experimental halls are still under study, but at the moment a solution for the tunnel is favoured where we would first dig a trench, then construct the tunnel without its floor in it, cover it with earth and only then start to make (inside the tunnel) the magnet foundation which would be a slab separate from the building itself, resting on the homogeneous molasse where possible, on concrete filling where needed. In this way the greater part of the sag under the load of the earth covering would take place before the foundation were constructed.

The colliding beam halls, with possibly very heavy experimental equipment and shielding to be expected around the interaction regions, form also a
difficult problem of civil engineering. Various solutions are still under consideration, the most probable one now being to make completely separate foundations around the interaction regions, which foundations would rest on the molasses but not be connected to the rest of the building or the magnet foundation. Thus a possible sag under the heavy loads would not influence the position of the nearby magnets.

Another subject of discussion was how to make the shielding around the colliding beam halls. The use of movable shielding blocks wherever possible would of course give a maximum flexibility, but is at the same time expensive. Earth will have to be used in most places.

Because the building studies are still in progress, and no definite conclusions have been arrived at, we shall not go into any details about such things as: general layout in the tunnel, position of cables and pipes in the tunnel and colliding beam halls, special requirements for physicists at the interaction regions, survey requirements, cranes and other transport equipment etc.

So far it has become clear, however, that the civil engineering work on this machine will be considerably more difficult than on the P.S., but not impossible to realize.

3.16. Cost Estimate, Manpower and Time Schedule

On this subject a report (A/Int. 30/63-11) was written early this year. The total cost, at that time, was estimated to be 252 Mfrs.

A revision of this estimate has become necessary for the following reasons:
1) The early estimate was made for a storage ring of 25 GeV design energy, whereas all our subsequent studies have been made on 28 GeV design energy. This meant increasing the diameter from 270 m to 300 m.

2) A further study of the ultra high vacuum and beam neutralization problems had shown that it was necessary to increase the magnet aperture appreciably.

3) This increased aperture lead us for economical reasons to use alternating gradient magnets instead of split focusing and bending.

4) The Site and Buildings Division has made a more detailed study of the building requirements. It turned out in particular that the quality of the ground on the new site is worse than we had hoped, so that the magnet foundations will be more difficult.

5) The cost of bringing cooling water and electricity to the new site has been taken into account now.

6) We now foresee from the beginning two colliding beam experimental halls instead of one, and one 25 GeV experimental hall.

7) For calculating the staff expenses the present (increased) average expenses per staff member have been taken into account.

A revised estimate is given in AR/Int. SG/53-11 Rev. 1.

The proposed time schedule is as follows: supposing that the official authorization is given by the beginning of 1965, the running in of the machine could start in 1971.
The staff build-up for this project would be as follows:

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<td>ISR Division</td>
<td>40</td>
<td>80</td>
<td>120</td>
<td>150</td>
<td>165</td>
<td>170</td>
</tr>
<tr>
<td>Other Divisions</td>
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<td>40</td>
<td>80</td>
<td>130</td>
<td>210</td>
<td>300</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>120</td>
<td>200</td>
<td>280</td>
<td>375</td>
<td>470</td>
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("Other Divisions" means Nuclear Physics and Data Handling Divisions, Site and Buildings Division and Administration and Finance Divisions)

The yearly budgets would be (in Mfrs):

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<td>27</td>
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<td>68</td>
<td>56</td>
</tr>
</tbody>
</table>

As seen from this Table this latest estimate gives a total budget for the construction period of 290 Mfrs, of which 245 Mfrs will be spent on the ISR proper, including its buildings, and 45 Mfrs on the first experimental equipment, data handling and laboratory services. The increase from the previous estimate is 38 Mfrs. About half of this comes from the increase in machine diameter from the previous design (point 1 on p. 37).

4. Prospects for High Energy Physics

Although the main activity of the Study Group has been concentrated on the design study of the two projects mentioned the group has also considered as one of its tasks to stimulate an evaluation of the need of these projects in terms of their physics programmes. We have tried to do this partly by detailed studies of some relevant experiments, in particular colliding beam experiments, but mainly by trying to coordinate the interest in these programmes among experimental and theoretical physicists, both inside CERN and in the member states.

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By the end of March and beginning of April 1962 physicists interested in colliding beam experiments were invited to CERN for a two weeks informal discussion. The main contributions to these discussions have been collected in the report AR/Int. SG/62-11. Some of the problems discussed during this meeting were evaluated in much more detail by Jones, who was a visitor to the Nuclear Physics Division at that time, by De Raad and later by Burhop who joined the Study Group in the autumn 1962 for one year on leave from University College London (AR/Int. SG/62-7, AR/Int. SG/62-12, and AR/Int. SG/63-29).

It was felt to be important to get even more collaboration from outside CERN in order to make sure that the CERN plans were properly coordinated with plans in the member states. After consultations between the Scientific Policy Committee and the Directorate, a meeting of senior European physicists was called in January to form the "European Committee for Future Accelerators".

The first meeting discussed the present status of the field (Proceedings were issued in the document FA/EC/2) and then created a Working Party under the chairmanship of Professor Amaldi and with Professor Burhop as secretary. The other members of the Working Party were Professor Cassels from U.K., Professor Ekspong from Scandinavia, Professor Gregory from France, Professor Paul from Germany, Professor Wouthuysen from Belgium and the Netherlands and Professors Puppi and Johnsen from CERN, but many other physicists attended one or more of the meetings.

This Working Party was asked to provide an answer to the following question:

"What is a desirable programme of high energy accelerator construction for the European Nations in CERN taking account of the following factors:

FS/4141
a) European physicists should be provided with facilities to enable them to continue during the 1970's to make significant and topical contributions to high energy physics and to provide the necessary training facilities.

b) The programme of high energy accelerator construction should be related to a reasonable growth in the number of physicists engaged in high energy research.

c) The financial contributions required from Member States should be realistic bearing in mind the scale of support needed for significant scientific research in fields where large scale effort is essential, and the need for adequate support for existing high energy programmes.

d) The programme of construction should be within the capabilities of the likely supply of accelerator physicists and engineers.

e) The programme should envisage a balance between national, regional and international accelerators so that all Member States should benefit from it.

Much effort of the Study Group went into providing background material for this working Party during the spring of this year. We shall not give a detailed account of this work, as this is contained in the widely circulated report from the working Party issued last June (FA/WP/23 Rev. 3). For convenience, however, we shall reproduce the conclusions arrived at by the working Party with regard to the summit programme:

"I. In the region of highest energies the programme of accelerator construction ("the summit programme") should include both

(a) the construction of a pair of storage rings for operation in association with the existing CERN-PS

(b) the construction of a new proton accelerator of very high energy."
Both these projects should have high priority. Provided authorisation could be obtained by the end of 1964 the storage rings could be completed by 1970 and would make possible at a comparatively early date a programme of highly significant physics in an energy region not accessible by any other means in the foreseeable future. Owing however to the reasons set out below the storage rings while representing a very important part of the programme could never in themselves form an acceptable alternative to a high energy proton synchrotron.

II. The energy of the proton accelerator should be about 300 GeV provided that the necessary authorisation for its construction can be obtained by the end of 1965 so that the machine could be completed between 1973 and 1975. Its design should provide for injection at a comparatively high energy (6-10 GeV) from an intermediate high repetition rate proton synchrotron ("booster") in order greatly to increase the proton current. In comparison with a 150 GeV machine which was also considered it would be a better and more versatile machine and have a longer potential life while for the first ten years after the commencement of construction the annual budgets of the two machines would be almost the same. The Working Party considered that these advantages outweighed the disadvantage that the time when useful physics could commence would be delayed (by at most 2 years assuming the same date of starting construction.) The choice of energy should be reconsidered however if for any reason the likely delay in starting physics should turn out to be substantially longer."

The physics considerations on which this conclusion was based are summed up in the first chapter of Appendix III of the Amaldi Working Party Report. This chapter reads as follows:

"Need for a new High Energy Accelerator Programme.

On general grounds a new high energy accelerator programme is needed to enable a deeper probe of nature at very small distances. This and the
study of phenomena at very great distances constitute the two fundamental frontiers of knowledge in the field of physics today. As physicists it is our duty to promote the study of the exciting new worlds that lie outside our present knowledge in these two directions. As high energy physicists we are particularly concerned with the former.

More specifically, problems of great physical interest are accumulating, the solution or further exploration of which will require the availability of particles of higher energy than those that can be obtained from any existing accelerator. The physics that can be done with the CERN-PS turns out to be far more significant and richer in content than was predicted in the most imaginative justifications written for it during the planning period. It will continue to provide an indispensable tool for European high energy physics for a decade at least. But all the time the list of problems that can only be elucidated by going to higher energy is likely to grow longer.

By 1970 we can therefore anticipate a tremendous demand among European physicists for access to a higher energy machine if they are to continue to make significant contributions in this field. It will not be possible to provide them with a suitable machine in the 1970's unless decisions are taken about its design and construction in the near future."

Then comes a paragraph on electron machines and thereafter the report continues as follows:

"Problems which even today are acquiring great importance and which cannot be solved without the use of particles of higher energy include the following:

i) The high energy asymptotic behaviour of total cross-sections for interactions between fundamental particles (and antiparticles) of all
kinds: \( \pi, K, N, Y \) and protons and neutrons. How particle and antiparticle cross-sections approach the same limit as predicted? If so, how rapidly do they approach this limit as the energy increases?

ii) **The elastic scattering of fundamental particles by protons and neutrons** at very high energies. Does the diffraction peak shrink for all particles at sufficiently high energies? What is the nature of the difference between the particles in this respect?

iii) **Multiple production of mesons in high energy collisions.** Are the mesons produced through the intermediary of some highly excited object or "fireball", as is suggested by some cosmic ray investigations? Does this represent some new "pionic" state of matter and, if so, what are its properties?

iv) **Existence of further mesonic or baryonic isobars.** Will the production of more and more excited states of mesons and baryons persist at higher energies? Are we on the threshold of a new spectroscopy, the lower states only of which are accessible at existing machine energies?

v) **Persistence of conservation laws at very high energies.** Do the conservation laws of strangeness, isotopic spin, baryon number, etc. continue to dominate physics at very high energies? Do some of them break down? Are new invariants and symmetries important at such energies?

vi) **Weak interaction processes at high energies.** Does the intermediate boson exist and, if so, what is its mass and lifetime? At what energy, if any, does the distinction between "weak" and "strong" processes disappear?

vii) **Neutrino physics at high energies.** How do neutrino reaction cross-sections vary with the energy? What new neutrino interaction processes occur at very high energies?
viii) "Structure" of fundamental particles. Are the form factors of nucleons, pions, etc. the same when probed by neutrinos as when probed by electrons?

This list of problems is by no means complete even today. It is bound to grow longer during the years before a new accelerator programme comes into operation. Most important, however, is the consideration that all previous experience suggests that, owing to the rapid advance of the subject and the clarification of our ideas about it, the actual experimental programme is likely to be far richer, deeper and more exciting than any predicted in advance."

Much of the work in evaluating the future prospects of research was done in the early part of 1963 and was taken into account by the Amaldi Working Party in their report from which the above quotations have been taken. More special studies have also been made, particularly on possible uses of storage rings, and a number of individual reports have been made (see list at the end). The present state of opinion of the physics programme of the future and on how they can be handled by the two machines considered by the Study Group is summarised in a report by Burhop (AR/Int. SG/63-42).
5. Chronological List of Reports resulting from the Study Group work
   up to December 1963.

   PS/Int. AR/60-33
   H.G. Hereward
   18.11.60
   Some Thoughts on the Stacking Efficiency of the Storage
   Ring.

   PS/Int. AR/60-34
   H.G. Hereward
   2.12.60
   The Possibilities of Local Superposition of Equilibrium
   Orbits in a Storage Ring, with Little Increase of the
   Aperture Requirements.

   PS/Int. AR/60-35/
   Modif.
   H.G. Hereward,
   K. Johnsen, A. Schoch, C.J. Zilverschoon
   22.12.60
   Present Ideas on 25-GeV Proton Storage Rings.
   (A revised version of this paper is in the Proceedings
   of the 1961 International Conference on High-Energy
   Accelerators in Brookhaven)

   AR/Int. SR/61-15
   H.G. Hereward
   20.6.61
   Some Effects of Radiation-damping for Electrons in the
   C.P.S. or in Storage Rings of Similar Properties.
   (A revised version of this paper is in the Proceedings
   of the 1961 International Conference on High-Energy
   Accelerators in Brookhaven)

   AR/Int. SR/61-25
   K. Johnsen
   3.11.61
   Some Intensity Considerations for High Energy Machines.

   AR/Int. 3R/61-19
   D.A. Swenson
   8.11.61
   A Study of the Beam Stacking Process.
   (Published in the Proceedings of the 1961 International
   Conference on High-Energy Accelerators in Brookhaven)

   AR/Int. Sr/61-29
   K. Johnsen
   27.11.61
   Proposed Programme for a CERN Study Group on High Energy
   Projects.

   AR/Int. Sr/61-32
   J. Parain
   1.12.61
   Accumulation à l'énergie d'injection dans les accélérateurs
   à gradient alterné de 50 à 100 GeV.

   AR/Int. SG/62-1
   C.J. Zilverschoon
   19.1.62
   Preliminary Considerations on a Site for a 300-GeV
   Proton Synchrotron.
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<tr>
<td>AR/Int. SG/62-2</td>
<td>Experimental Utilization of Colliding Beams.</td>
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<td>L.W. Jones</td>
<td>12.3.62</td>
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<td>AR/Int. SG/62-3</td>
<td>Dégroupeur à prisms magnétiques pour accélérateurs</td>
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<td>J. Parain</td>
<td>linéaires de protons quasi relativistes.</td>
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<td>AR/Int. SG/62-4</td>
<td>The Displaced Closed Orbits in a Structure with Achromatic</td>
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<td>K. Johnsen</td>
<td>Insertions.</td>
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<td>25.4.62</td>
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<td>W. Schnell</td>
<td>Storage Rings.</td>
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<td>1.6.62</td>
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<td>AR/Int. SG/62-6</td>
<td>Some Aspects of Concentric Storage Rings.</td>
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<td>B. de Raad</td>
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<td>AR/Int. SG/62-7</td>
<td>Experimental Utilisation of Proton Storage Rings.</td>
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<td>L.W. Jones</td>
<td>(Published in the Proceedings of the International Conference</td>
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<td>B. de Raad</td>
<td>on Instrumentation for High Energy Physics in CERN,</td>
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<td>11.7.62</td>
<td>Nuclear Inst. and Methods, 20, 477 (1962))</td>
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<td>AR/Int. SG/62-8</td>
<td>Considerations about the Choice of Basic Parameters for</td>
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<td>L. Resegotti</td>
<td>a 300 GeV A.G.S.</td>
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<td>AR/Int. SG/62-9</td>
<td>Dégroupeage des particules dans un accélérateur linéaire</td>
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<td>J. Parain</td>
<td>à protons, en utilisant l'oscillation de phase.</td>
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<td>AR/Int. SG/62-11</td>
<td>Experimental Use of Proton Storage Rings.</td>
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<td>AR/Study Group</td>
<td>Report of a Working Party Meeting from March 26 to</td>
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<td>AR/Int. SG/62-12</td>
<td>Design of some Experiments with Proton Storage Rings.</td>
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<td>B. de Raad</td>
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<td>AR/Int. PSep/62-3</td>
<td>Parameters for M.F. Separation of π and K at 100 GeV/c</td>
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<td>E. Keil</td>
<td>Design momentum.</td>
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Design Study for a Large-orbit Electron Synchrotron.


Matched Straight Sections, Secondary Beams and Ejection in a 300-GeV Proton Synchrotron.


Tentative Parameters for a 150-GeV A.G.S. Revision 1.

Preliminary Cost and Performance Estimates for R.F. Particle Separation up to 250 GeV/c.

Draft Cost Estimate for a 300-GeV Proton Synchrotron.

Draft Cost Estimate for a 150-GeV Proton Synchrotron.

Experimental Areas, Shielding and Beams of a 150 GeV and 300 GeV Proton Synchrotron.

Le synchrotron injecteur de la machine 300 GeV.

Le synchrotron injecteur de la machine 150 GeV. First Draft.
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<td>AR/Int. SG/63-9</td>
<td>Comparison of various Accelerators in the Range 120 - 300 GeV.</td>
<td>K. Johnsen</td>
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<td>AR/Int. SG/63-10</td>
<td>The Desirable Energy of a Future Accelerator - Considerations of the Physics Programme and its Realisation.</td>
<td>E.H.S. Burhop</td>
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<td>AR/Int. SG/63-11</td>
<td>Draft Cost Estimate for a Set of Concentric Storage Rings (CSR) for the CERN-PS.</td>
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<td>AR/Int. SG/63-12</td>
<td>Focalisation radiale dans un accélérateur linéaire à protons entre 200 MeV et 3 GeV.</td>
<td>J. Parain</td>
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<td>AR/Int. SG/63-13</td>
<td>A Cosmic Ray Experiment Design to Explore Strong Interactions at 300 GeV.</td>
<td>L.W. Jones</td>
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<td>AR/Int. SG/63-14</td>
<td>Some Beam Transfer Problems in a 300-GeV Proton Synchrotron.</td>
<td>B. de Raad</td>
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<td>AR/Int. SG/63-15</td>
<td>Preliminary Study of Air Conditioning - Requirements for Large Accelerators.</td>
<td>E. Hugi</td>
<td>20.4.63</td>
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<td>AR/Int. SG/63-16</td>
<td>Data Handling and Related Activities around the New Accelerator (An estimate of trends and requirements).</td>
<td>L. Kowarski</td>
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<td>AR/Int. SG/63-17</td>
<td>Optimum Current Density in the Magnet Conductors of a 300 GeV Proton Synchrotron.</td>
<td>L. Resegotti, F. Grütter, J. Noble</td>
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<td>CERN/465</td>
<td>Information on Site Requirements for a 300 GeV Proton Synchrotron. (24th Session of the Council)</td>
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<td>AR/Int. SG/63-18</td>
<td>Erreurs de phase dans les accélérateurs linéaires à protons de 1 GeV et de 3 GeV.</td>
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An R.F. System for a 300-GeV Proton Synchrotron with Mechancially Tuned Cavities. (Presented to the International Accelerator Conference in Dubna - August 1963)

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AR/Int. SG/63-21  AR/Study Group  27.6.63
Injection into a 300-GeV Proton Synchrotron. (Presented to the International Accelerator Conference in Dubna - August 1963)

AR/Int. SG/63-22  AR/Study Group  23.6.63
The CERN Design Study for a 300-GeV Proton Synchrotron. (Presented to the International Accelerator Conference in Dubna - August 1963)

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Some Problems connected with the Use of Intersecting Proton Storage Rings. (Presented to the International Accelerator Conference in Dubna - August 1963)

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Le nombre d'ondes $Q$ de l'oscillation synchrotron
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Synchronization between a 300 GeV Synchrotron and its
Booster Injector.
CERN 25 GeV PROTON SYNCHROTRON (TO SCALE)

POSSIBLE EXTENSION FOR SEPARATED BEAMS
LONG SEPARATED BEAMS
EXTERNAL TARGET HALL

LONG STRAIGHT SECTION
NEUTRINO AREA
BOOSTER INJECTOR

LAYOUT OF A 300 GeV PROTON - SYNCHROTRON