200-GeV INTERSECTING STORAGE ACCELERATORS*

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Abstract

Preliminary design data are presented for a pair of 200-GeV intersecting storage accelerators using superconducting magnets. The AGS will be used as the injector for both rings. Methods are proposed for beam transfer and acceleration. Luminosities in excess of 10^{33} cm^{-2} sec^{-1} per meter of collision area should be achievable.

Introduction

During the past decade we at Brookhaven have made a number of studies of accelerators in the energy range from 100 to 2000 GeV and have requested support for their construction. Two recent developments are now leading us to change our direction toward a new goal. The first of these is the fact that two large accelerators in this range are now either under construction or in an advanced planning stage. These machines, it is hoped, will eventually reach energies in the neighborhood of 1000 GeV. The second development is the successful initial operation of the CERN ISR. The fact that circulating currents of a few amperes were reached quickly and with apparent ease dispelled lingering doubts in the minds of many observers about the possibility of slow build-up of unpredicted, impenetrable instabilities. To make a significant step in center-of-mass energy beyond that to be available at Batavia and at CERN II, we have decided to study colliding beams each of energy 200 GeV. This will be equivalent to a single accelerator of 100,000 GeV and will represent a step two orders of magnitude beyond present accelerators.

The machine under consideration consists of two 200-GeV intersecting accelerators using the AGS as injector. Each accelerator is of racetrack configuration, consisting of two semicircular sectors 225 m in radius and two straight sections about 300 m long. In the curved sectors the two accelerator rings will be closely spaced, probably one above the other with their beams not more than 20 cm apart. The apertures in the two rings will be about 5 cm in diameter. The long straight sections will be arranged in such a way that the beams can be made to intersect at small angles or to be collinear.

Several names have emerged for this project but the one that seems to be gaining acceptance follows from the initials of the term "Intersecting Storage Accelerators." To ISA we add a descriptive adjective to arrive at the name ISABELLE.

As a location for ISABELLE the area to the north of the AGS seems ideal. There is ample space for expansion — the area is reasonably level — a beam path from the AGS already emerges to the north on its way to a new experimental area — and accelerated beams can be extracted from one of the rings and brought back for use in 200-GeV experiments in the present AGS experimental areas. A possible machine arrangement is shown in Fig. 1.

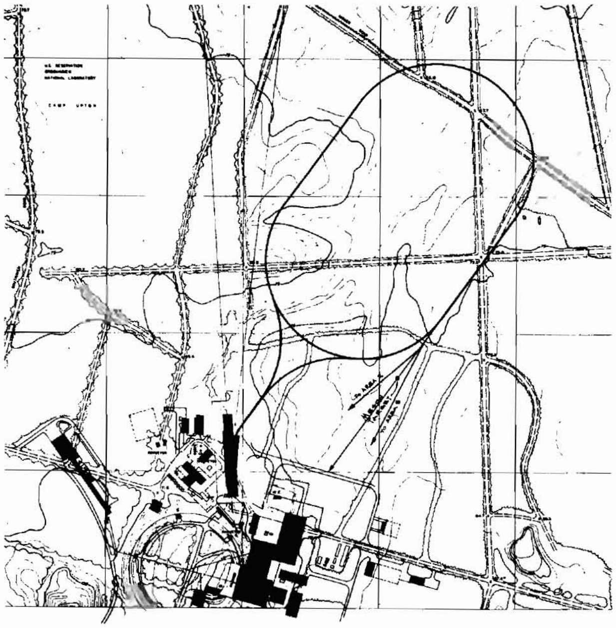

Fig. 1. Location of 200-GeV storage accelerators to the north of the AGS complex.

Magnet System and Lattice

The magnet system will be separated function using superconducting magnets. The bending magnets will operate between an injection field of 6 kG and a final field of 40 kG.

Several satisfactory magnet designs are available. A number of cosine wound dipoles of circular cross section have been tested at Brookhaven during the past several years1) and a design has been evolved which is relatively simple to construct. For operation at 40 kG the cosine winding about 15 mm thick would be surrounded by an iron pipe about 7 cm thick. Two such units would lie parallel to each other in the same Dewar. This would result in a unit of a height of about 50 cm and a horizontal extent of about 25 cm. The magnets would be about 3 m long; several would be enclosed in the same Dewar system.

Rectangular picture frame magnets also can be made to perform reasonably well up to fields of 40 kG.2) Minor corrections will probably be necessary in either type of magnet to remove unwanted

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sextupole components due to saturation of iron.

If, as seems improbable, the future users of the colliding beam system could be persuaded to accept beams that were identical in energy, some saving could be made by construction of the magnets side by side with coil configurations such that one serves as the flux return for the other as shown in Fig. 2. We have derived the current distribution to give the field pattern shown and find that the over-all ampere-turns required are materially lower than for the case where the two magnets are isolated from each other. For the case shown the reduction was about 40%.

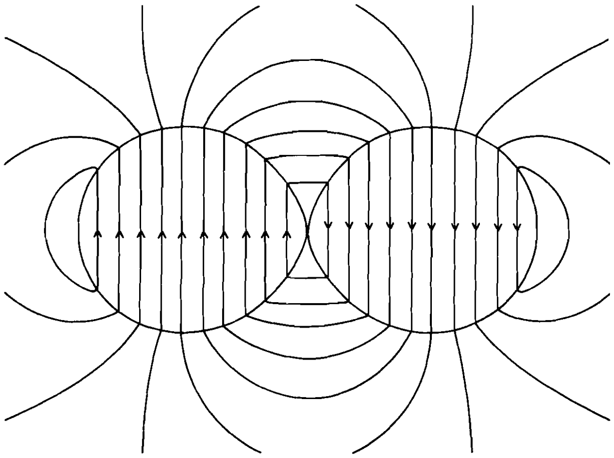

Fig. 2. Arrangement of magnet coils to allow one coil to use the return flux from the other.

This problem has been solved with greater elegance by R.A. Beth for the case shown in Fig. 3 of a circular opening divided into two apertures by a current septum. He believes that the case of an elliptic cylinder divided by a current septum also is soluble. A circular cosine winding surrounding either of these structures would make it possible to increase one field and decrease the other.

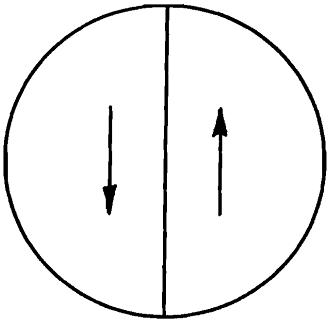

Fig. 3. Configuration of storage ring coils studied by R.A. Beth.

The stored energy in the dipoles will be about 15 MJ at full field. The acceleration period will be about two minutes during which the magnet power supply will be required to supply energy at a 250 kVA rate. For comparison the AGS magnet power supply is rated to supply energy at 360 times this rate.

Quadrupoles can be built with essentially the same pole strength as is used in the 40 kG dipoles. Quadrupole lengths will be less than 1 m.

The presently proposed lattice is made up of cells about 25 m long, each cell including about 10 m of dipoles, a horizontally focusing quadrupole, another 10 m of dipoles and a vertically focusing quadrupole. Maxima of the horizontal and vertical β functions would be about 45 m. The ν (or Q) values would be about 17 so that the phase transition energy would be well below the 30-GeV injection energy.

Injection

The intensity of the converted AGS is expected to be above 10^{13} protons per pulse. At 1.7×10^{13} protons per pulse, the average circulating current will be 1 A. In the proton bunches which occupy only about one tenth of the AGS circumference the circulating current is about 10 A, a current which could give a satisfactory luminosity in a colliding beam system.

Since we have not been able to devise a workable method of depositing the 12 AGS bunches in the storage accelerators in a closely spaced azimuthal sequence, we propose to debunch the AGS beam, decreasing its energy spread in the process and to rebunch at the fundamental frequency into a single bunch. To preserve phase space the rebunching would be done with a sawtooth wave rather than a sine wave. At the low frequency of about 400 kHz generation of sawtooth waves should present no serious problems. Methods for producing nonsinusoidal waveforms were discussed at the Frascati Conference by Kerns3).

The energy spread at the end of acceleration in the AGS is about ± 0.07%. Debunching can reduce this to less than ± 0.02%. Rebunching on the fundamental with a sawtooth wave of amplitude 10,000 V will increase the energy spread to about 0.3%. The bunch will have a total length of 16° (or 36 m) and the current in the bunch will have been increased to over 20 A. The rebunching process will require about 50 ms.

The single bunch will now be transferred to one of the storage accelerators where it will be held in a bucket having about twice the azimuthal extent of the bunch. This means that the frequency of the acceleration system in the storage accelerators would be at the thirtieth harmonic of the revolution frequency, or about 4.5 MHz. The transfer process would be repeated on the 59 succeeding AGS pulses until all of the buckets in both rings are filled. Kicker magnets for depositing the bunches would be required to turn on and off within 60 ns, a requirement that is well within the present state of the art4).

Acceleration to 200 GeV

Since the beams will be expected to circulate in the storage accelerators for periods of hours, it seems unnecessary to complicate the acceleration process by attempts at rapid acceleration. A reasonable acceleration period is 2 min during which the beams circulate almost 20 million times. The necessary energy gain per turn will be less than 10 keV; peak energy gains of 30 keV will be quite sufficient to contain the energy spread of the beam and to provide acceleration. The energy spread after acceleration will be ± 0.05%.

Since the frequency swing during acceleration is only one part in 2000 and since the energy gain per turn is only one seventh that in the AGS, it is evident that the RF system will be simple and inexpensive.

Long Straight Sections

The design of the long straight sections will take into account the fact that they will be torn down and rebuilt many times during the life of the accelerators, as the demands of the experimental program change. Focusing magnets and bending magnets used to control the angle of intersection of the beams will be movable and demountable and vacuum chamber sections will be easily removable. Lenses will be included for reduction of the β-functions of the beams at the point of collision in order to increase luminosity in these areas.

The specific initial straight section design and the design of experimental buildings will remain under study for some time by ISABELLE's future users. Possible experimental buildings now proposed would be about 10 m high, 16 m wide and 80 to 100 m long. Outside of this building 100 m would be kept clear in both directions for future experimental expansions.

Some future users would like to increase the length of the two straight sections to 400 m; on the other hand, those responsible for orbit design would prefer a straight section length shorter than 300 m.

Luminosity

Preliminary estimates of luminosity indicate that, for collinear collisions of beams of average currents of 10 A, luminosities should be higher than 10^{33} cm^{-2} sec^{-1} per meter of length in the collision region. This figure is two orders of magnitude higher than the luminosity now available at the ISR. The reasons for this are as follows:

a) The radial extent of the beam due to betatron oscillations is reduced in inverse proportion to the square root of the beam energy. This gives a factor of 7 in luminosity.

b) The β-function can be reduced at the point of collision, from an average value of about 24 m in the normal cells, to a value of about 3 m. This corresponds to a factor of 8 in luminosity.

c) The beam will be bunched during acceleration and can be kept bunched by continuing to apply RF power. The bunching factor at 200 GeV is about 0.4 corresponding to an increase in luminosity of a factor of 2.5.

In combination these factors give an increase in luminosity of a factor of 140.

Future Expansion

It is expected that provision will be included during construction for extraction of one or both accelerated beams to make possible studies of conventional 200-GeV physics. A future possibility for increasing the energy of the accelerated beam would be to lower the temperature of the superconducting magnets. By changing the operating temperature from 4.2°K to 1.4°K, magnets wound with niobium-titanium superconductors could be made to operate at fields higher by 30%, making it possible to reach energies about 250 GeV.

Considerable enthusiasm has been expressed about a suggestion of Dr. M. Schwartz of SLAC that an electron ring of about 10 GeV be included to make possible studies of collisions between electrons and protons. He points out that about 90 GeV should be available in the center-of-mass system and a whole new realm of electron-proton physics would become accessible. Other possible subjects for study in the new rings would be collisions between protons and antiprotons, provided the Budker method of electron cooling is tested with success, collisions between protons and deuterons, and between deuterons and deuterons.

Acknowledgements

Many members of Brookhaven's Accelerator and Physics Departments have contributed and continue to contribute to this study. We are indebted for much further help to many University users of the AGS who have shown unanimous enthusiasm for this project. Particular mention should be made of the work of D. Berley, E.D. Courant, M.L. Good, G.K. Green, L.M. Lederman, T.D. Lee, S.J. Lindenbaum, F.E. Mills, R.B. Palmer, R.R. Rau, R.P. Shutt, A. van Steenbergen, W.J. Willis, and C.N. Yang.

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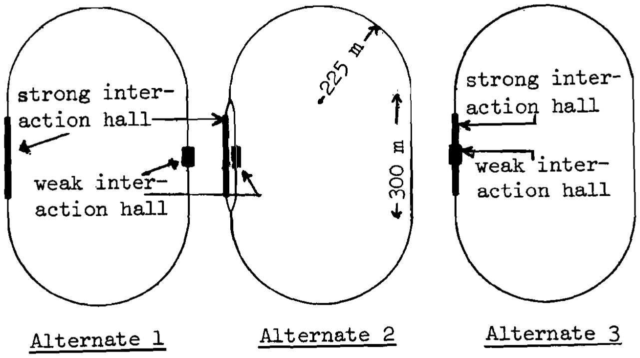
DISCUSSION

L. C. TENG: Do you think it is better to string all the beam crossings together in a very long straight section rather than distributing the crossings around the ring as in the CERN-ISR?

J. P. BLEWETT: We have considered possible arrangements of experimental areas as shown in a slide not in my paper.



Alternate 1 Alternate 2 Alternate 3

Figure: Experimental areas for Isabelle

The final solution, I think, will be determined to a certain extent by the cost of the operation.

F. MILLS: The main advice we have obtained from experimental physicists is that the most desirable parameters of the ISR are (1) high luminosity and (2) straight-section length, that is, accessibility to the beam and flexibility in experimental set-up. Different classes of experiments require different straight-section configurations. For example, for elastic scattering, "high-beta" regions are needed in order to achieve the 10 μrad precision desired. Other experiments require different parameters, for example, high energy resolution, but at lower luminosity. Primarily, the weak and electro-magnetic interaction experiments require the highest luminosities quoted by Blewett.

K. JOHNSEN: It is not obvious that experimentalists would prefer a given total straight-section length to be more concentrated than it is at present in the ISR, particularly if one takes into account how many experiments want to have access to the crossing region. Only experiments looking at very small angles profit from having longer and fewer straight sections and such experiments are at present in the minority. Experience on the ISR may throw more light on this question of straight-section length as time goes on.

J. P. BLEWETT: Yes, we plan to follow closely the developing experience at the ISR.

J. REES: What is the betatron frequency shift corresponding to the quoted luminosity of 10^{13} cm^{-2} sec^{-1}?

E. COURANT: A rough calculation indicates that with 10^{15} protons, an emittance of $\pi \times 10^{-6}$ rad-m, one obtains $\Delta Q \simeq 10^{-3}$ per meter of collision length.

J. REES: Would it not be advantageous to bunch the stored protons tightly in order to increase the luminosity, or to decrease the number of stored protons for given luminosity?

E. COURANT: I agree that much tighter bunching would enable us to increase luminosity further, as long as it is permitted by the Q shift. But this would requite a much more ambitious RF system than that described by Blewett.

K. JOHNSEN: Very fine field adjustments are needed on the ISR to set up proper working lines. Will the same requirements apply to the BNL project and, if so, will this not pose a serious tracking problem during the acceleration?

J. P. BLEWETT: It is possible that such tracking must be done during acceleration and we are considering methods for deriving the necessary information to control the corrections. Correcting coils will probably require rather small currents; they will, no doubt, be wound directly on the dipoles.