Presented at IV All-Union National Conference on Particle Accelerators, Moscow, November 18-20, 1974

BNL 19280
Conf-741112--6

ISABELLE - SUPERCONDUCTING STORAGE ACCELERATOR*

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For some years the Brookhaven staff has studied various possible new accelerators that could make significant contributions to the research capability of the overall high energy physics program. This effort has been split into studies of possible machines and an explicit research and development program on superconducting magnets which are believed desirable for the next generation of machines. In 1970 following suggestions by J.P. Blewett these efforts focused on storage rings having the unique feature that the beams would be stacked at 30 GeV using the BNL AGS as injector then accelerated to a higher energy in the storage rings. By 1972 a preliminary conceptual design of a 200 GeV colliding beam facility had been prepared[1] and a summer study was convened, attended by particle physicists and accelerator experts from many U.S. and European laboratories. Subsequent to this study, the staff has further developed these design concepts so that a formal proposal[2] has been submitted to the USAEC requesting funds for construction. This paper is devoted to a description of some of the interesting parameters of this facility.

The energy must be selected as a compromise between the desires of physicists for highest possible energies and the realities of economics. 200 GeV for each ring has been chosen as high enough to approach unitarity limits, exceed any suspected thresholds, and be far above any energy achievable by fixed target machines. (The equivalent energy would be 86 TeV.) At the same time the size of the resulting machine looks economically feasible.

The magnet program at BNL has had great success in producing model magnets of about 1 meter length, 5 cm diameter warm bore aperture using multifilament NbTi in Cu matrix wires braided into flat conductors. The conductors are arranged in discreet blocks simulating a cos θ current distribution.

*Work performed under the auspices of the U.S. Atomic Energy Commission

The iron shield is closely coupled to the coils within the cryogenic envelope providing magnetic field enhancement and mechanical support. These magnets have achieved fields in excess of 4 T, show virtually no training and have field uniformity approaching the $\frac{\Delta B}{B} \sim 10^{-4}$ required for storage ring applications. Two such models have undergone extensive tests including life tests which include more pulses than the expected total life of ISABELLE. Based on these models a typical ring magnet pair would look like Fig. 1 and a half cell of the bending sections would look like Fig. 2.

The insertions are designed for maximum flexibility based on an extensive study by experimental physicists including conceptual design of numerous experiments. The requirement which most dramatically affects the apearance of the machine is the 40 m long free space around the low beta interaction regions. The overall facility takes on the appearance of Fig. 3. We have chosen four long insertions to make a large number of experimental setups possible and to make the periodicity large to reduce the problems with structure resonances. Hopefully, the identity of the insertions can be relaxed after some experience with the machine. There are also four service insertions in each ring used for beam dumps, injection, rf, etc.

The luminosity of the machine has been set at $10^{33}/\mathrm{cm}^2\,\mathrm{sec}$. Such performance seems to be required by several experiments. Higher luminosities seem to be difficult to achieve and the overall interaction rate might be difficult for experiments to cope with.

Keil[3] has shown that if currents are limited by the beam-beam interaction, the luminosity, L, is given by $L = \frac{4}{3} c\nu \left(\frac{\pi\lambda^3 \Delta Q_x}{E_t \ell \nu_p}\right)^{\frac{1}{2}}$ where λ is the line density of particles in each beam, ΔQ_x is the permissible beam-beam tune shift, E_t the normalized transverse emittance, ℓ the free space in the interaction region, and ν_p is the classical proton radius. Using ISABELLE parameters, and tune shift limit $\Delta Q_x = 0.005$, we find a current of six amperes is required to achieve design luminosity. We have chosen a design current of 10 A giving some margin for later parameter adjustment or even higher luminosity. The low beta values and small crossing angles are compatible with Keil's formulae.

We have chosen a warm vacuum. We believe there are numerous engineering simplifications from this choice. Furthermore, in a cold vacuum if a monolayer or more of gas were cryo-pumped on the surface, the beam current would probably be limited to about an ampere by the pressure bump phenomena.

For a warm vacuum, the requirements imposed by the pressure bump considerations are summarized in Fig. 4. Here η is the surface desorption coefficient. We have chosen aluminum as the material for the vacuum pipe. This material is cheap and easy to fabricate. Its high electrical conductivity is advantageous for all types of coherent instabilities. With proper surface cleaning and bakeout at 200° a vacuum better than 10^{-10} torr can be achieved with an η value of about 2. Thus an 8 cm bore should conservatively permit the design current of 10 A.

Given this aperture, a current of 10 A is readily stored in each ring using the momentum stacking scheme currently in use at the CERN ISR. No extrapolation above current AGS performance is implied. In fact, we anticipate injecting about 2×10^{12} protons per pulse whereas the AGS is capable of operating at 10^{13}. Once the stack is formed, it would be rebunched on the second harmonic. The choice of this low harmonic along with a low impedance for the rf system should prevent bunched beam longitudinal instabilities of the type studied by Sacherer.[4]

All types of instabilities must be examined at 30 GeV, during acceleration, and in the final 200 GeV stack. So far no cases of instabilities have been found which imply any particular difficulty.

A variety of options can be considered for addition to such a facility. We have considered, for example, the addition of a 15 GeV electron ring permitting e-p interactions with maximum center-of-mass energies greater than 100 GeV and with luminosities $\sim 10^{33}/cm^2 sec$ at $E_{cm} = 75$ GeV. Another interesting suggestion consists of using one ring as an ordinary accelerator producing large numbers of anti-proton at energies $\sim$ 30 GeV which would be injected and stacked in the other ring. After stacking the anti-protons would be accelerated to 200 GeV and made to collide with a 200 GeV proton beam in the first ring. It is believed that luminosities of $\sim 7.7 \times 10^{28}/cm^2 sec$ can be achieved.

This proposed facility has attracted favorable attention from a large fraction of the high energy physics community. Because of this interest and simultaneous interest in the PEP proposal submitted by SLAC-LBL and possible new facilities at the Fermi National Accelerator Laboratory, the USAEC Research Division appointed a panel of distinguished physicists chaired by Professor V.F. Weisskopf to examine the physics and technical arguments for the various machines and to recommend a course of action for the next few years. This panel recommended[5] a substantial increase in funds to Brookhaven starting in 1976 to improve the rate of progress in superconducting magnet development with particular interest in the problems in mass producing suitable magnets on an industrial base. This research and development effort would be followed by construction funding at an early date.

The Brookhaven staff and a large community of users are encouraged by these recommendations and hope that the funds will be forthcoming. Meanwhile, research and design efforts will continue on many aspects of the ISABELLE concept with particular emphasis on the superconducting magnets and technology of large cryogenic systems. By next summer we hope to have operational a beam line in the AGS experimental hall using four very large dipole magnets (8 cm warm bore, 2 m length, 4 T field) and, in addition, a single 4 m full size model of an ISABELLE dipole.

A full parameter list of the current ISABELLE design is given in the table.

GENERAL PURPOSE EXPERIMENTAL INSERTIONS	
(Horizontal crossing, adjustable parameters)	
- β^*_v	2-6 m
- β^*_h	5-10 m
- Maximum β	1000 - 300 m
- Total Free space around crossing point	40 m
- Crossing angle	0-6 mrad
- Interaction length	<1 m
MAGNET SYSTEM	
- Bending field at 200 GeV	40 kG
- at 28.5 GeV	5.9 kG
- Number of normal dipoles/ring	256
- Dipole length magnetic	4.11 m
- physical (iron-iron)	4.25 m
- Peak current in dipole	3.3 kA
- Stored energy @ 40 kG/dipole	465 kJ
- Vacuum chamber aperture (warm bore)	8 cm
- Main coil i.d.	12 cm
- Operating temperature (pool boiling)	<4.5 K
- Number of normal quadrupoles/ring	88

- Quadrupole gradient	6.6 kG/cm
- Peak current in quadrupole	500 A
- Stored energy/quadrupole	30 kJ
- Quadrupole length magnetic	1.16 m
physical (iron-iron)	1.30 m

CRYOGENIC SYSTEM

- Total heat load at 4.5 K	≈ 20 kW
- Total refrigeration capacity	8 x 2.9 (23.2) kW
- Power requirement of compressors	7.5 MW
- Total liquid helium	136 000 liter

INJECTION

- AGS energy	28.5 GeV
- Number protons/AGS pulse (10 bunches)*	2.3×10^{12}
- AGS emittance $\epsilon_h = \epsilon_v$	0.4×10^{-6} m.rad
- Longitudinal phase space per bunch, A	0.36 eV.sec
- ISA current/ring	10 A
- Number protons/ring	5.6×10^{14}
- Number AGS pulses stacked	≈ 250
- Stacked beam size	2.0 cm x 0.8 cm
- Momentum spread	0.7 %
- rf frequency stacking system	4.45 MHz
- rf voltage	12 kV
- Impedance (with feedback)	400 (40) Ω

ACCELERATION

- Duration	2 min
- rf frequency (h = 2)	223 kHz
- Energy gain/turn	12.5 kV
- Peak rf voltage	40 kV
- Momentum spread at 200 GeV	0.3 %

LUMINOSITY

L_{pp} (200 GeV, unbunched, $\beta_v^* = 2$ m, $\Delta\nu_{max} = 5 \times 10^{-3}$)	10^{33} $cm^{-2}sec^{-1}$
- pp option, $L_{p\bar{p}}/L_{pp}$	$\approx 10^{-4}$ $cm^{-2}sec^{-1}$
- dp option, L_{dp}/L_{pp}	≈ 0.7
- dd option, L_{dd}/L_{pp}	≈ 0.7
- ep option	
Maximum e-energy	15 GeV
Number of electrons	8.2×10^{12}
Maximum luminosity @ 7 GeV-electrons	10^{33} $cm^{-2}sec^{-1}$
Luminosity @ 15 GeV-electrons	5×10^{31} $cm^{-2}sec^{-1}$

*The AGS beam intensity is reduced, for ISA injection, from its normal value of nominally 10^{13} protons per pulse.

R E F E R E N C E S

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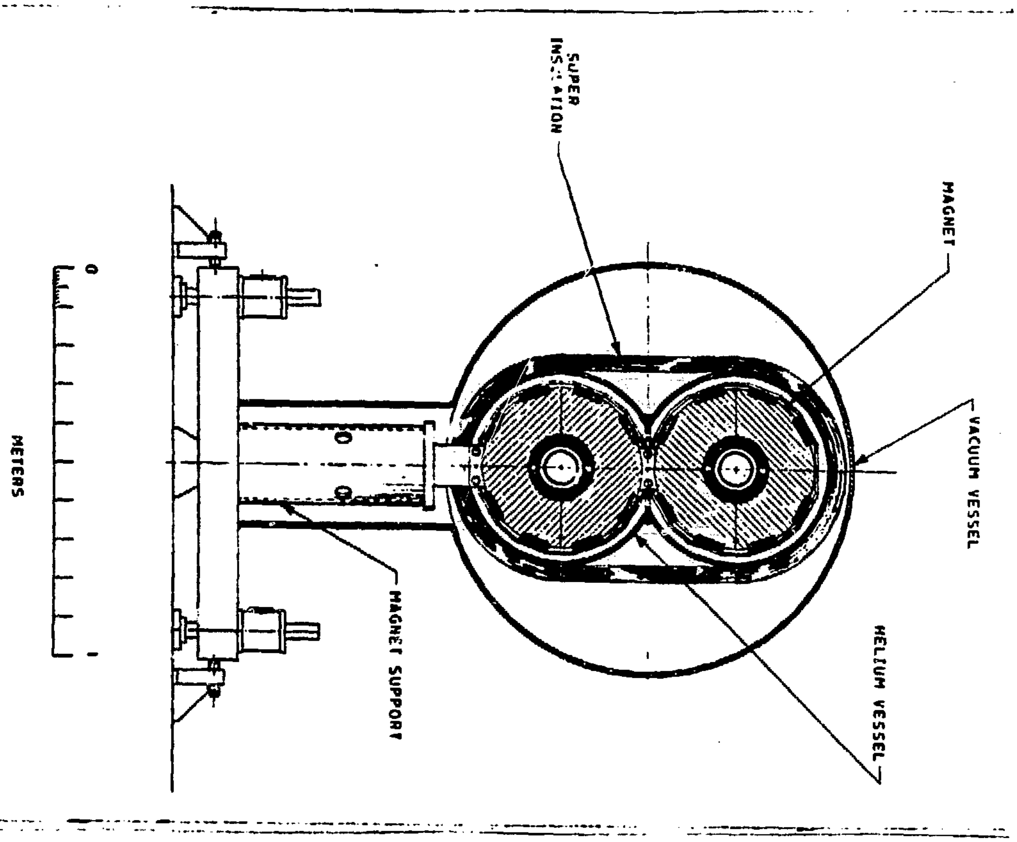

Fig. 1. Dipole transverse cross section

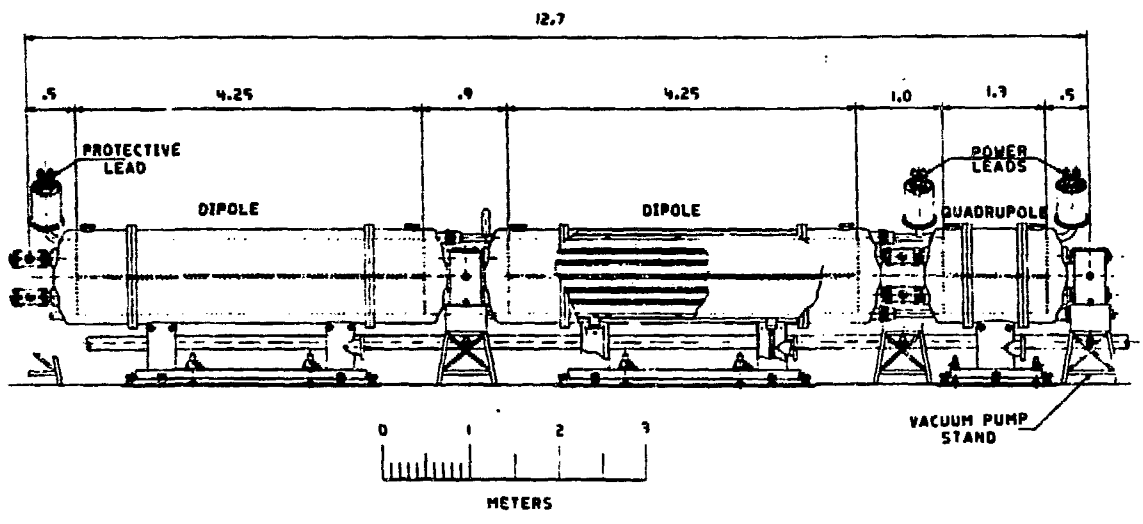

Fig. 2. Typical half cell

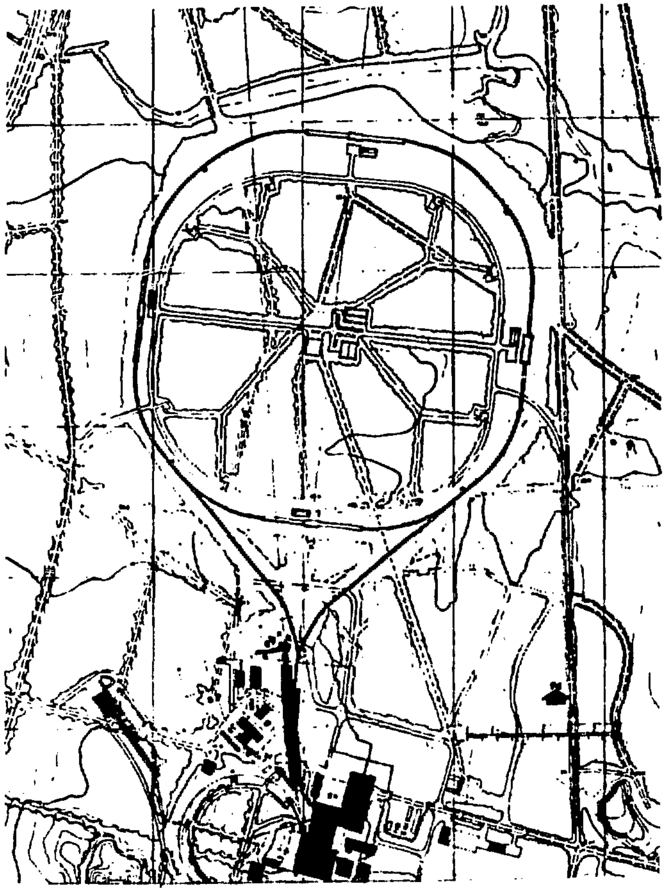

Fig. 3. ISABELLE Site Layout

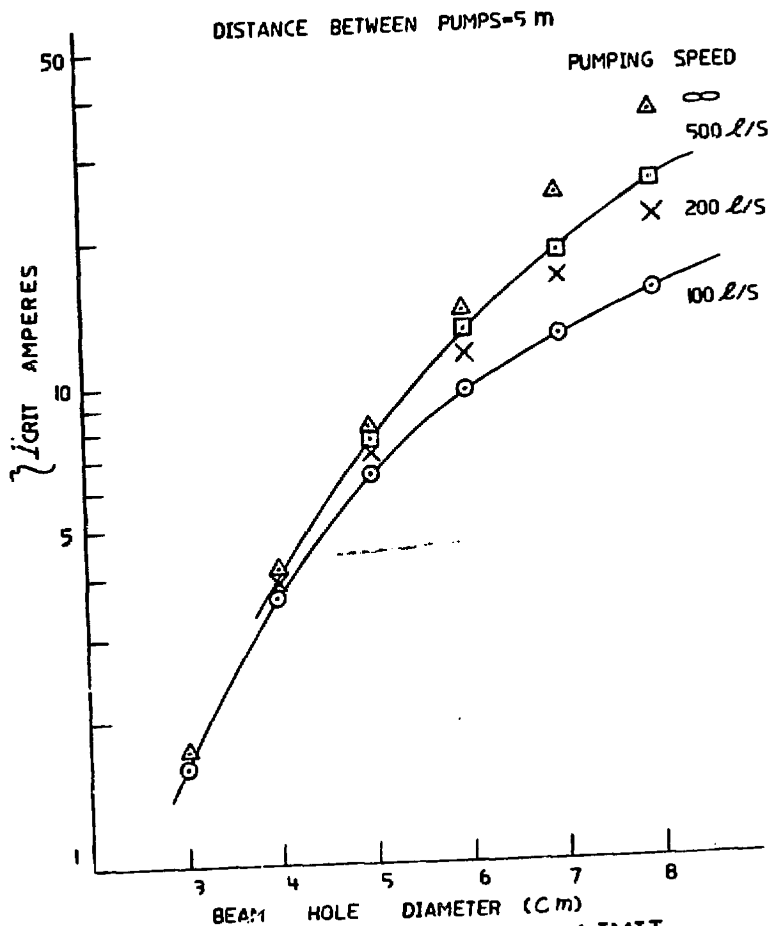

FIG. 4 CRITICAL CURRENT LIMIT

FIGURE CAPTIONS

Fig. 1. Dipole transverse cross section.

Fig. 2. Typical half cell.

Fig. 3. ISABELLE site layout.

Fig. 4. Critical current limit.