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ISABELLE, A PROTON-PROTON COLLIDING BEAM FACILITY AT BROOKHAVEN*

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SUMMARY

ISABELLE, a colliding beam facility to be located at Brookhaven National Laboratory, is designed to study proton-proton collisions at very high energies. With high intensity circulating beams available, it will be possible to extensively explore the structure of the proton and the production of new particles. This paper describes the features of ISABELLE including the planned research facilities. The technical components are briefly described including the status of the respective developmental programs.

High energy physicists have been pushing the available energy of their accelerators higher and higher with every passing year. There are a number of interesting phenomena that lead one to believe that important results will continue to be revealed. The rising total cross section, the possibility of finding the intermediate vector boson, and the production of particles at high transverse momentum all indicate that high energy physics continues to be a fascinating subject. Until recently the only way to achieve higher energies was by building ever larger fixed target particle accelerators. Since the early 1970's, there has been an alternative approach to high energy collisions, namely, colliding beams. Figure 1 shows the energy released from both electron and proton colliding beam facilities as a function of time. As can be seen, the ISR at CERN made a major advance for proton facilities when it began doing physics in 1971. It has never been matched in available energy. This is the challenge that faces those of us at Brookhaven who have been working on the design of ISABELLE, an Intersecting Storage Accelerator.

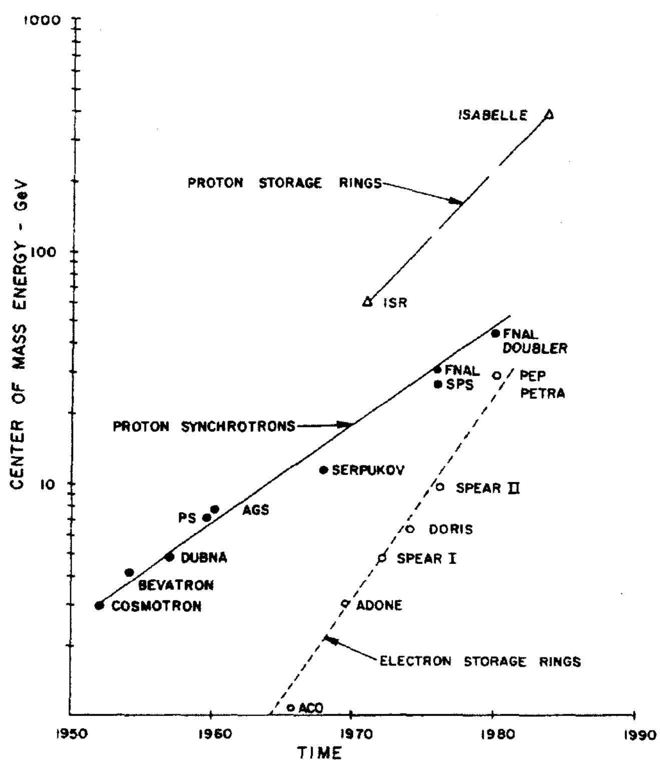

Fig. 1. The energy available from accelerators and storage rings has grown with time as shown.

With the success of the ISR, Brookhaven physicists began to examine the characteristics of an even higher energy proton-proton storage ring. They recognized that in addition to high energy, high collision rates were essential, so that difficult experiments could be attempted in a practical amount of time. An extensive summer study was held in 1975 where the conceptual design for ISABELLE was reviewed by accelerator and particle physicists. The design was found to be sound, and a proposal was prepared for funding by the Energy Research and Development Administration. This proposal is currently being considered by Congress, and we are hopeful that the construction of ISABELLE will get underway later this year or next.

Figure 2 shows an "aerial view" of ISABELLE on the Brookhaven site. In the foreground the AGS is shown with an extracted proton beam to the North Area providing protons to the storage rings. The ISABELLE magnets are contained in a common tunnel with a circumference of 2620 meters. A number of the major features of ISABELLE are outlined in Table I. Returning to the description of the facility, the extracted beam would be injected first into one ring of magnets and then the other. During injection the current of protons would be accumulated slowly, building up to a current of 10 A at which time acceleration in that ring would take place. The rate of acceleration might be something like 100 GeV per minute without putting an undue burden on the refrigeration system or the superconducting magnets. Each ring would contain 444 bending and focusing magnets with superconducting coils operating at 4 K. Each dipole is nearly 4½ meters long and 70 centimeters in diameter. The magnetic field is produced by superconducting braid formed into a coil with a cos θ configuration. Before discussing the measured properties of the ISABELLE magnets, I would like to review the supporting development programs underway at the Laboratory.

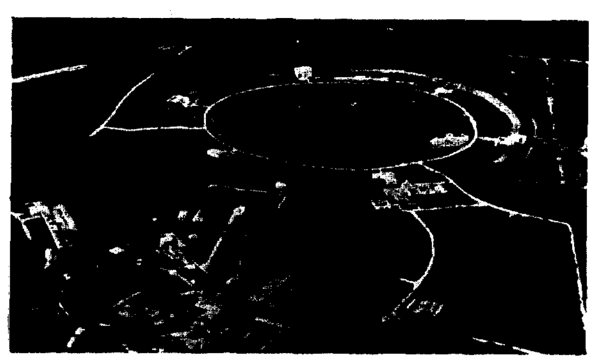

Fig. 2. An architectural rendering of ISABELLE on the BNL site north of the AGS.

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TABLE I. Major Features of ISABELLE

Two interlaced accelerator/storage rings
Circumference = 2640 m
Injection from the AGS at 30 GeV
3×10^{12} protons/pulse
High intensity of protons - luminosity
10^{32} - 10^{33} $cm^{-2}sec^{-1}$
High center-of-mass energy
60 - 400 GeV
516 Superconducting dipole magnets
40 kG
372 Superconducting quadrupole magnets
5 kG/cm
Large-scale cryogenic system
25 000 W
Demanding system performance
3×10^{-11} Torr
Flexible interaction regions
± 20 m free space
Six experimental areas
a fully scoped facility

Table II shows the current R&D activities that have a major impact on the design of ISABELLE. Although not listed, the number one strength is that of the staff who have formulated our current proposal. The planning for ISABELLE has gone on for a number of years, and all of the individuals are eager and ready to get on with building it. Although the 200 upon 200 GeV design has been explored most thoroughly, higher energy possibilities are also being considered by the staff. Backing them up is the magnet program. Here there are three series of magnets: one meter long R&D units used for extending the field properties and reliability of the units; full-size ISABELLE-type magnets prepared to demonstrate the magnetic field characteristics of dipoles and quadrupoles suitable for ISABELLE; and magnets for immediate beam line applications at the AGS. Good results have been achieved on all fronts. The next item concerns the cryogenic system developed for ISABELLE. It is envisioned that the magnets will be cooled by high pressure, subcooled helium gas. This is an effective fluid that can be readily prepared by the refrigeration system. The principles of forced flow cooling have now been verified with several magnets.

TABLE II. Supporting Development Programs

MAGNETS
1 m long R&D units
4½ m long ISA dipoles and
1½ m long ISA quad
2½ m long HEUB dipoles
OTHER DEVELOPMENTS
Cryogenics - forced flow of He
Vacuum system ($\sim 10^{-11}$ Torr)
Power supply and control systems
Industrial participation
APPLICATIONS
Half-cell (2 dipoles, 1 quad)
Full-cell (4 dipoles, 2 quads)
Experimental apparatus
ISABELLE

All circulating beams require a low vacuum in the beam tube. As seen, the requirements are for a below 3×10^{-11} Torr; a vacuum that has been exceeded in the full-size development tests at the Laboratory. During these tests, a 12 m aluminum vacuum chamber reached below 10^{-11} Torr after three days of pumping. The power supply is ready to go and has been tested on a room temperature magnet. Finally, a prototype computer network has been installed in the former Cosmotron control room and will be used for the half-cell. It will later be extended to other development activities, such as the new refrigerator and vacuum system to be put into operation.

It is not feasible to pursue all the development programs in isolation, and it is hoped that combining these elements into the half-cell test will rapidly bring together the different disciplines required in a storage ring. Figure 3 shows the three magnets comprising the half-cell assembled on the Cosmotron floor. Off the picture to the right is the refrigerator system that provides the low temperature helium gas for the three magnets. At the left can be seen the beginning of a simulated beam tunnel that will eventually enclose all the magnets. The half-cell is composed of MK-II, MK-V, and the quadrupole, all previously tested. The two dipoles each reached nearly 50 kG during their tests, and the quadrupole over 7 kG/cm when it was tested. It is expected that each of these magnets will repeat their prior performance when connected in series. The purpose of the half-cell is to face the problems created when the magnets are hooked together. In particular the process of quench propagation along the units when a magnet goes normal will be studied. Figure 4 is a cut-away illustration of a typical dipole magnet. The superconducting coil is tightly held within the unsplit iron laminations that complete the magnetic circuit. The entire magnet is suspended within a vacuum vessel after having been surrounded with superinsulation. Within the center tube upon which the coils have been placed is a warm bore vacuum system. With the use of additional superinsulation, it is possible for

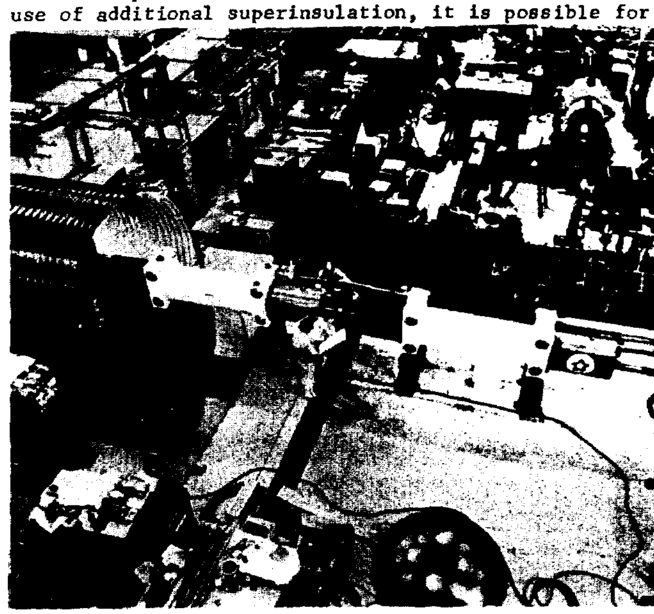

Fig. 3. The half-cell being assembled on the Cosmotron floor.

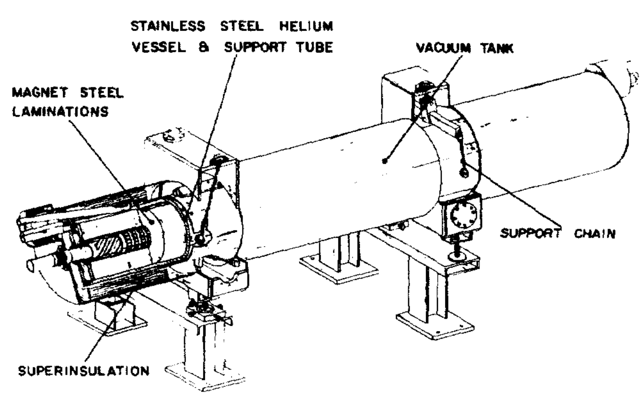

Fig. 4. A cut-away drawing of an ISABELLE dipole showing the support system.

this vacuum system to be serviced and pumped out repeatedly.

Although we do not have data on the half-cell, it is possible to talk at this time about the performance of the individual dipole magnet. Figure 5 shows the magnetization curve for MK-V. As can be seen, the magnet after nine quenches reached 49 kG. This was nearly 97% of the ultimate field capability for the braid at the temperature of 4.6 K. The magnetic field properties are shown in Table III.

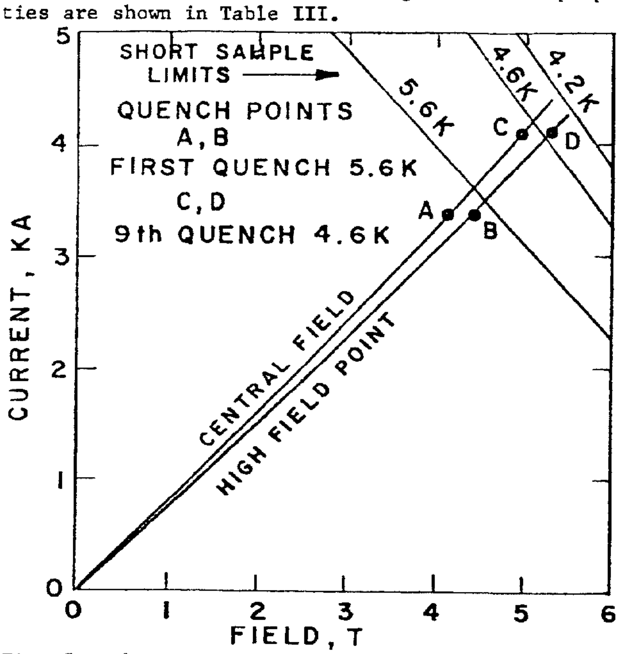

Fig. 5. The magnetization curve for the MK-V dipole showing the quench history.

TABLE III. Magnet Field Data

B_o T	Radial Distance cm	$\Delta B/B_o$ Without Correction Coils	With Correction Coils
1.8	1.25[a]	1.6×10^{-4}	4.2×10^{-6}
3.25	1.25	3.0×10^{-6}	2.0×10^{-7}
1.8	4[b]	1.9×10^{-3}	5.0×10^{-5}
3.25	4	0.4×10^{-3}	2.7×10^{-5}

[a]Typical beam position
[b]Edge of warm bore.

As can be seen, the uniformity of the magnetic field across the aperture is better than one part in 10^4 when the correction coils are energized. In addition, this magnet has shaped end turns so that the integral of the magnetic field is very uniform from side to side.

Returning to the proposal, Fig. 6 shows the way the dipoles and quadrupoles would be used in a portion of a sextant. Although it is too small to identify clearly, one can at least get a feeling for how the magnets are closely spaced together within the beam tunnel as it conveys the beam to a very narrow crossing at the insertion region. Here the beams cross at about 13 mrad using quadrupoles that are placed ± 20 meters away from the interaction point. This means that at least 40 m will be available for installing experimental equipment in such a research area. Figure 7 shows a perspective view of what one of the experimental areas might look like. Here the detectors are installed near the center of a large experimental hall. This perspective drawing shows a spectrometer that was designed during one of the workshops last summer. In fact, an example of a possible research program has been worked out for ISABELLE. As currently conceived, six interaction regions would be used for experiments with at least three of them ready when the facility turns on. There is a considerable interest in the beam properties at a standard intersection region, and these are displayed in Table IV.

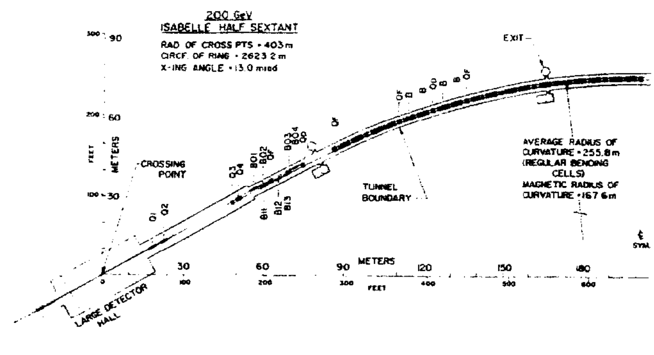

Fig. 6. A segment of an ISABELLE sextant.

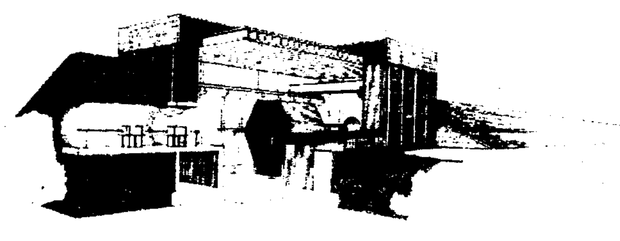

Fig. 7. The 11 o'clock experimental hall containing a large spectrometer.

TABLE IV. Beam Properties at Insertion Region

Center-of-mass energy	400 GeV
Luminosity	2×10^{32} cm^{-2}sec^{-1}
Beam size	1 mm
Crossing angle	13 mrad
Crossing area	30 cm

As can be seen, the desirable feature of high interaction energy and luminosity is achieved. Here the 400 GeV corresponds to 40 kG in the magnets. Already it is apparent that higher fields will be possible with the same magnet design. Because of this it is hoped, and indeed expected, that by the time ISABELLE is built energies as high as 250 GeV against 250 GeV may be possible. The standard insertion regions should provide luminosities somewhat more than 10^{32} cm^{-2}sec^{-1}, while high luminosity areas could go as high as 10^{33} cm^{-2} sec^{-1}. The latter is achieved by inserting special magnets in the experimental region, thus reducing the crossing angle to some 6 mrad. The entire design of ISABELLE has recently been reconfigured for the six-fold geometry. The circumference has shrunk, and due to the use of somewhat longer magnets, the overal number of magnets has been reduced.

Table V shows the current state of the project. The present cost estimate for the project is $125 million with an additional $17 million for contingency and $31 million for escalation. It is expected that this project can be constructed in a five-year time span, and we are seeking authorization in FY 78 or FY 79. Brookhaven has enjoyed good financial support from ERDA for the building of this research facility. Nearly $10 million of advanced accelerator R&D has been spent over the last few years to develop magnets and other devices that will be used in ISABELLE. In addition, two allocations of CP&D funds have come from ERDA. These monies are being used to review the characteristics of the proposal, including a cost evaluation of the technical components and conventional construction. With respect to the conventional construction, we have been aided by the enormous help of the architectural/engineering firm selected on this project. Ammann & Whitney, a New York-based firm, has been at Brookhaven since late November studying the design of the storage rings and the features of the Brookhaven site. They are now contributing original ideas to the project, for example, in the design of the experimental areas. They have suggested the use of sand-filled containers to form the walls of the experimental halls while at the same time providing shielding around the interaction region. Needless to say, we have a considerable amount of sand at the Laboratory, and it is a natural material to use.

Industrial firms have become interested in making the magnet coils. Grumman Aerospace produced two coils for a magnet during this last winter. These are some of the best coils that have been turned out and will be tested in another few months. At present, orders have been placed for the manufacture of braid for four more magnets, and recently a contract was placed with Airco for winding the braid into coils for the four magnets. The magnets when completed will be used for a full-cell or, who knows, put right into the ISABELLE tunnel.

We are trying to couple the interest of the high energy community in this project with support by ERDA and Congress. Recent hearings have been held where the Director of the Laboratory testified about the readiness of ISABELLE and the need for a new high energy physics facility at Brookhaven as part of a broad national initiative for our field. It is expected that ISABELLE, along with the Doubler and PEP, will provide new resources in high energy physics for the United States in the 1980's.

TABLE V. Status of the ISABELLE Project

Summer study in 1975, Workshops in 1976 and 1977.
Proposals prepared in 1975, 1976, and soon for 1977.
ERDA provided funds for increased accelerator R&D in FY 75, 76 and 77.
Construction, planning, and design (CP&D) funds have been available for proposal evaluation
Brookhaven is ready to initiate construction in FY 78 or FY 79.
In the meantime, the following developments are underway:

- Study of higher field magnets
- Perfection of prototype units
- Involvement of industry

We are currently seeking ERDA and Congressional support.