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ISABELLE[*]

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INTRODUCTION

Brookhaven National Laboratory on Long Island has been the site of two major particle accelerators, the Cosmotron and the Alternating Gradient Synchrotron. A further development in high energy physics is now being made with the construction by the Department of Energy of a new facility called ISABELLE. It is located in the northwest corner of the Brookhaven site which is shown in Fig. 1. Two rings

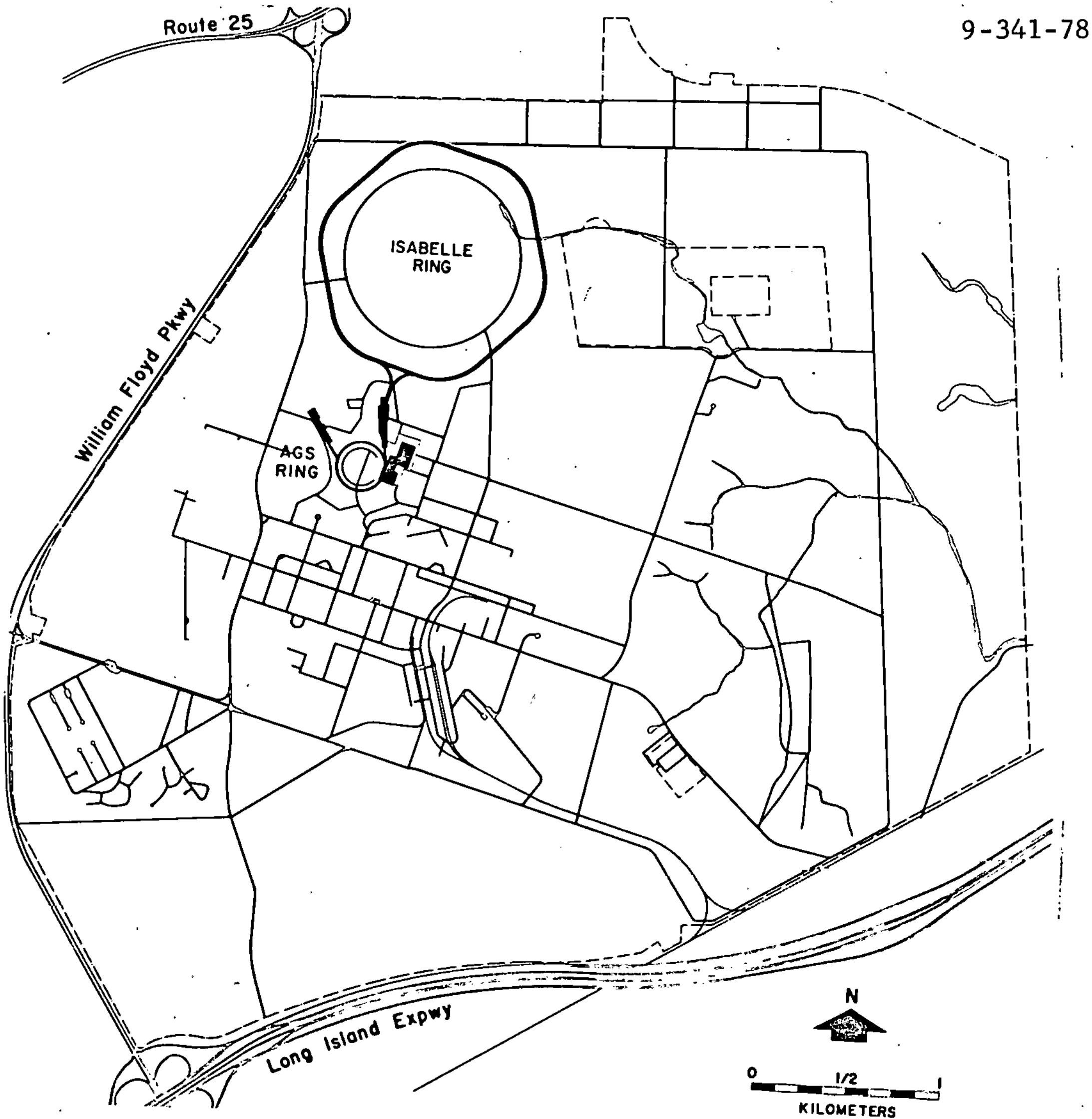

Fig. 1. ISABELLE Placement

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[*] Work performed under the auspices of the U.S. Department of Energy.

DISCLAIMER

of superconducting magnets will guide protons circulating both clockwise and anticlockwise crisscrossing at six points on the periphery. These rings are located in a common tunnel with special areas around the crossing points designed to facilitate the performance of experiments on the colliding particles. Each proton beam will be accelerated at energies up to 400 GeV, and the head-on collisions at the intersecting regions give a center-of-mass energy of 800 GeV. At the present time construction has begun and we summarize here the general features of the design and the status of the project.

Figure 2 shows a schematic of the ISABELLE-AGS layout. The AGS is a conventional proton accelerator that has been in operation since 1961. Injection of the beam to the AGS is accomplished with a 200 MeV linac and then protons are accelerated to an energy of 30 GeV. These protons are used to sustain a vigorous high energy experimental program, and will also be utilized as a source of injected beam for ISABELLE. The AGS is a very well understood accelerator, and it lends itself very well to the delicate task of injecting protons into a pair of superconducting rings. The extracted beam branch to the North Area is presently used for neutrino physics and this beam has operated in a very clean manner over a five year period in a configuration close to that required to inject into ISABELLE.

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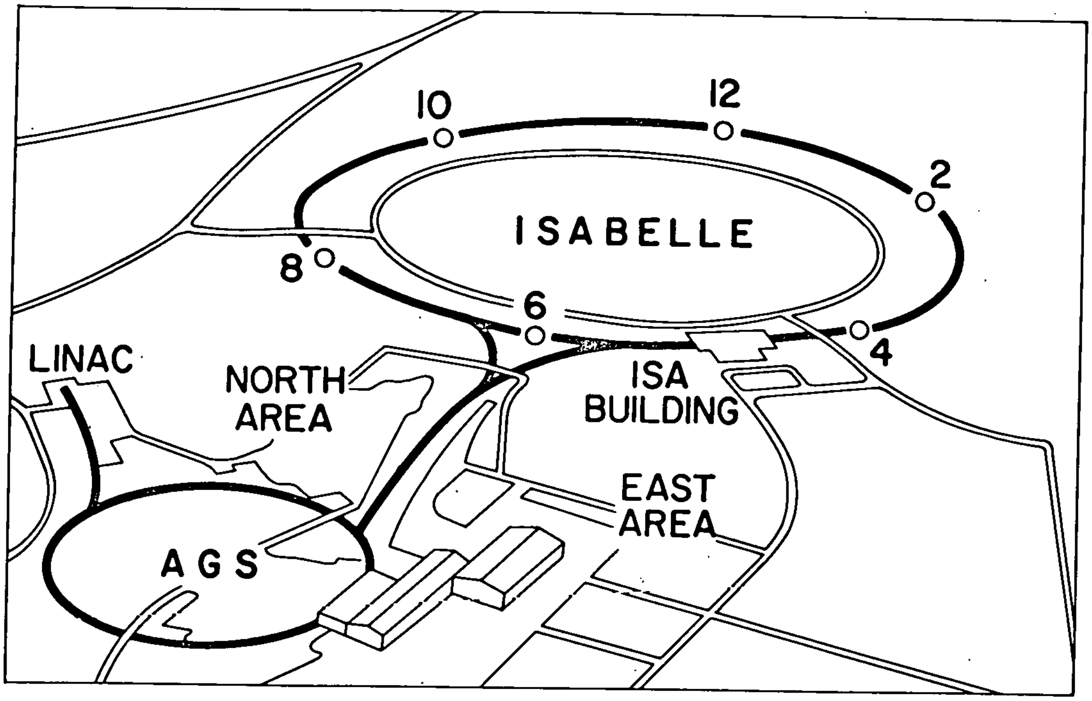

Fig. 2. ISABELLE Schematic

Figure 2 also shows the layout of the experimental areas, six in number. The design of each of these areas is being varied so as to exploit the experimental opportunities of ISABELLE. We will discuss this in more detail below. Each of the areas is designated by the appropriate clock face number 2,4,6,8,10,12. Injection of the 30 GeV beams and ejection at all energies takes place near area 6; this puts some constraints on the design of area number 6, the Wide Angle Hall.

The major features of ISABELLE are summarized in Table I. As we have indicated, there are two interlaced accelerator storage rings with a circumference of 3.8 km. The bending radius of 400 GeV protons by a 5 T magnetic field is ∿ 270 m, with the extra perimeter being taken up with straight sections for experimental areas and the space for quadrupoles and instrumentation. The AGS is capable of accelerating more than 10^{13} particles per pulse; we expect to restrict the injection pulses to about 2.7×10^{12} particles thereby providing a clean beam of low emittance. As we will see below, some of the physics goals of ISABELLE can only be met with a high luminosity 10^{32} - 10^{33} cm^{-2} sec^{-1}. This will require approximately 7×10^{14} protons in each ring, a current of 8 A. The center-of-mass energy is just the sum of the energy of the two beams in a symmetric collision of the type envisaged at ISABELLE; this c.m. energy can be attained with protons of 3.4×10^{14} eV (340 TeV) on a stationary proton target.

Table I. Major Features of ISABELLE

Two Interlaced Accelerator/Storage Rings
    Circumference = 3.8 km

Injection From the AGS at 30 GeV
    2.7×10^{12} p/p for ∿ 300 pulses

High Intensity of Protons - Luminosity
    $8\ \mathrm{A} \rightarrow L$ of $10^{32} - 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$

High Center-of-Mass Energy
    60 - 80 GeV

Equivalent Fixed Target Energy
    2 - 340 TeV

732 Superconducting Dipole Magnets
    50 kG

352 Superconducting Quadrupole Magnets
    6.1 kG/cm

Large Scale Cryogenic System
    20,000 watts at 3.8 K

Demanding System Performance
    Vacuum ∿ 3×10^{-11} Torr, Current Regulation ∿ 10^{-4}

Six Experimental Areas
    1 Wide Angle Area
    2 Major Facility Areas
    1 Small Angle Area
    2 Open Areas

The magnets needed to provide the 5 T guide field are superconducting dipoles, 732 in all each 4.5 m long. In addition, there are 352 superconducting quadrupoles to provide a satisfactory strong focusing lattice with a peak gradient capability of 6.1 kG/cm. These magnets are cooled by 3.8 K helium at 5 atm in the gaseous phase. This cooling requires a refrigerator power of 20 kW at the low temperature. The compressors needed to provide this power are rated at 15 MW. Two levels of vacuum are necessary for the machine, the insulating vacuum at 10^{-5} Torr and the main vacuum for particle transport at 3×10^{-11} Torr.

A cross section of the tunnel with magnets in place is shown in Fig. 3. The superconducting magnet enclosures are shown with the beam pipe center 1.27 m above the floor. Each dipole vessel is 5 m long and about 60 cm in diameter. The beam lines are nearly 1 m apart in the tunnel region away from the crossovers and the whole assembly is enclosed by the 2.3 m radius tunnel. The utilities both cryogenic and electrical are mounted at the top of the enclosure which is 3.1 m from the floor.

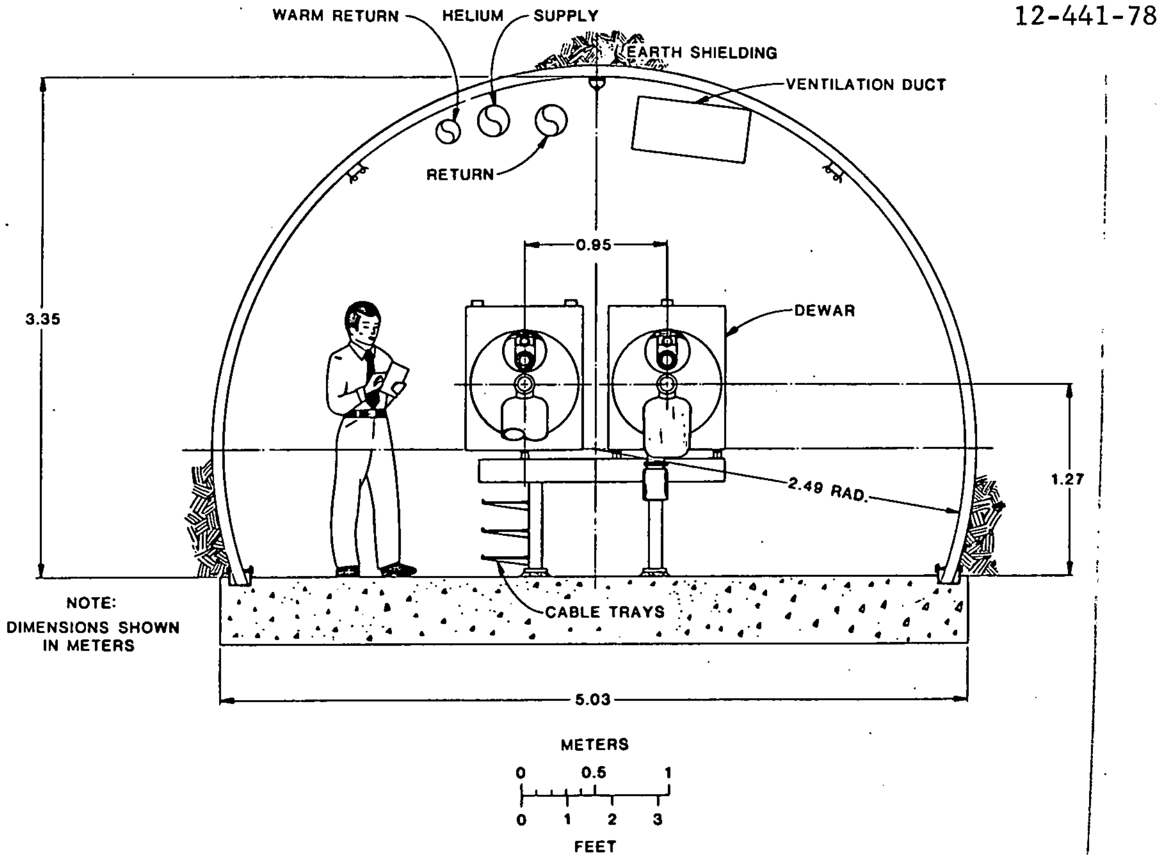

Fig. 3. Section of Tunnel

The space between the legs of the magnet stand has been set aside for magnets for a possible electron option in the future. Figure 4 is an isometric drawing of a dipole pair, but with an earlier design of the support frame.

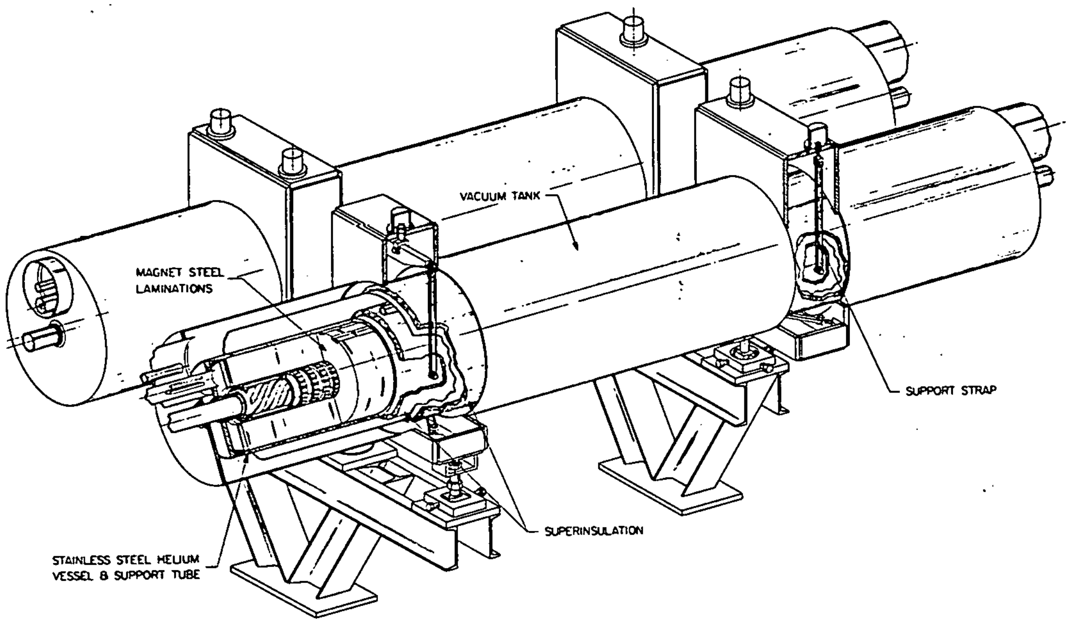

Fig. 4. ISABELLE Magnets

SUPERCONDUCTING MAGNETS

Conventional magnets utilize the boundary conditions at the steel as a dominant influence on the field configuration. At the elevated fields (5 T) that will be used at ISABELLE the saturation of the steel makes this technique inapplicable. The desired dipole field can be achieved by careful attention to the distribution of current density in the windings. In particular, if the current density depends on the azimuthal angle θ as $\cos\theta$ then a uniform B field results inside the coil. The ISABELLE coils represent an approximation to this ideal. In Fig. 5 we show a schematic of the coil structure. The conductor that is used to fabricate these coils is made of a multifilament strand of NbTi in copper, braided so as to reduce eddy current effects in the conductor. The conductor is wound with spacers between the layers so that an approximation to the $\cos\theta$ distribution is achieved. The wedge-shaped insulating pieces then hold the component coils rigidly under the magnetic forces. The coil is cooled by He gas at 5 atm passing through the helical cooling passages that are shown. Inside the main coil are correction coils which carry relatively modest current ($\sim$ 200 A) which make the higher multipole terms appropriate for a storage accelerator.

The beam will circulate in a tube at room temperature for reasons we discuss below and so this tube of 8.09 cm i.d. is insulated from the inside of the magnet tube by superinsulation in insulating vacuum. A cold bore would act as an effective cryopump and it is expected that a circulating beam of the magnitude to be used in ISABELLE would cause emission of the adsorbed molecules raising the pressure to an intolerable level. This effect is sufficiently serious to warrant the addition of a warm bore with the necessary insulation. The coils that we are using in production are fabricated by industry and are inserted into the laminations shown in Fig. 5. The laminations contain the return flux and provide mechanical support for the coil. The laminations are held in place by a thick-wall stainless steel tube. The major difficulty in fabricating high field superconducting magnets rests with the need to prevent any motion of the coil under the magnetic forces. Motion of the coil induces eddy currents chich causes heating and makes the magnet quench (go normal locally). ISABELLE magnets are designed to tolerate quenching without difficulty although the B field goes to zero and the heat must be extracted from the magnet before the B field can be reestablished.

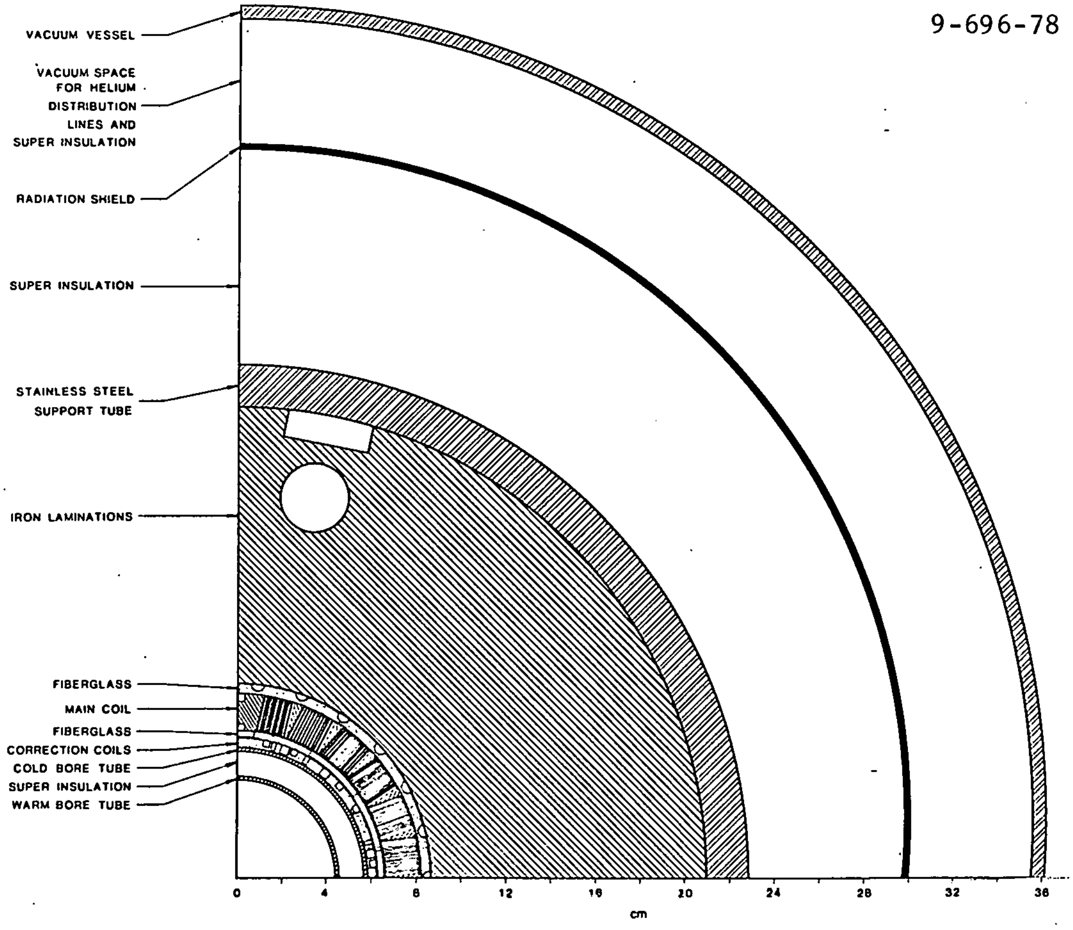

Fig. 5. Section of Coil

The assembly process is designed so that the coil is positively held in place after the magnet is cooled to operating temperature. This process is sufficiently well understood that magnets have now been produced that have an acceptable peak field after a few quenches to firmly set the coil in the laminations. Figure 6 shows the end of the dipole magnet where the coils form a saddle to return current on the opposite side of the bore tube. The cooling passages are also shown which run continuously throughout an entire sextant of the machine. The coil and laminations in the cast tube are mounted in the dewar with fiberglass straps as shown in Fig. 4. The total heat load from conduction and radiation at 3.8 K is close to 4 W, which is significantly below the design figure, giving confidence that the refrigeration is adequate.

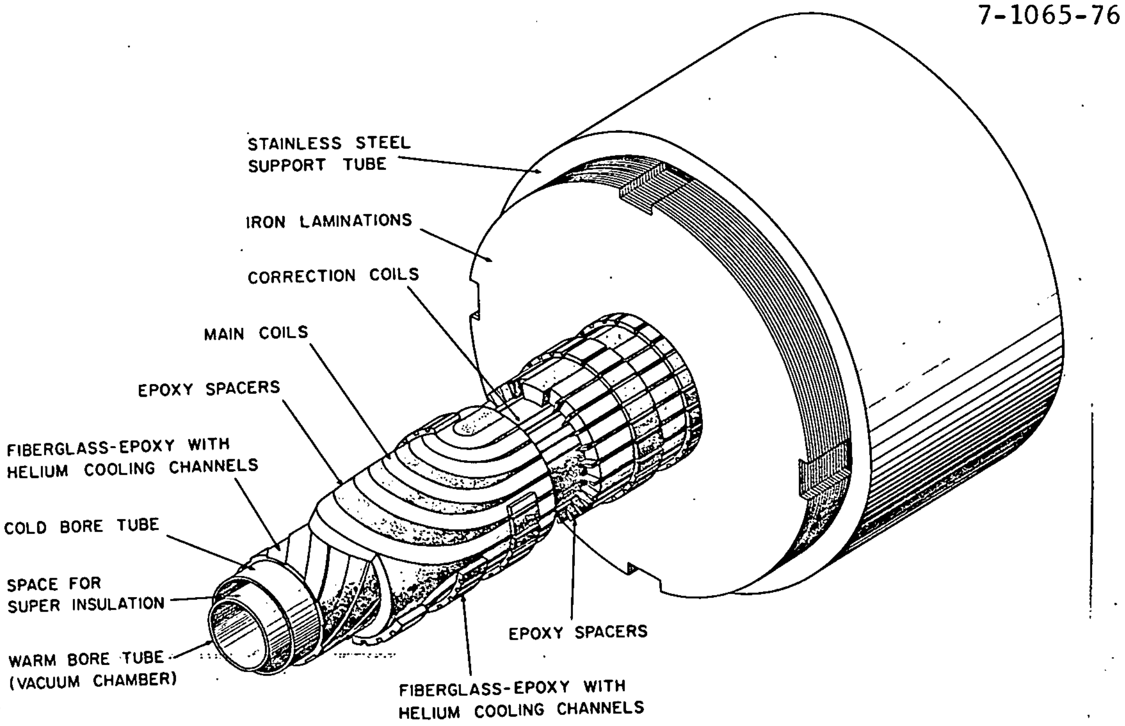

Fig. 6. End of Coil

THE ACCELERATOR

ISABELLE is a separated function machine with the basic cell structure shown in Fig. 7. The cell consists of 6 dipoles and 2 quadrupoles and is repeated nine times per sextant. At the end of each sextant a transition section is required to provide a crossing point at the center of the experimental areas. The "outside" ring is designed to give additional bend to make the beams cross. This diagram contains a standard matching section which is expected to produce the luminosity of 2×10^{32} with the nominal peak circulating current. Although the space between the quadrupoles Q_1 marks the easily accessible area available to experimenters, clearly for small angle scattering experiments detectors will be placed outboard of Q_1 towards the bending sextant itself.

Table II shows the operational sequence that is expected for ISABELLE. At injection 30 GeV pulses of $\sim 2.5 \times 10^{12}$ protons from the AGS will be injected into ISABELLE. The AGS normally accelerates 13 bunches of protons and two of them will be removed to allow for clean single turn ejection. These 11 bunches will be used to fill one quarter of the ISABELLE and this operation repeated four times to fill the ISABELLE circumference. This will be repeated for a total of 300 AGS pulses to fill ISABELLE to design current, taking about 10 minutes/ring. The beams will then be accelerated from 30 to 400 GeV in a few minutes to keep the heat load on the magnets to an acceptable level.

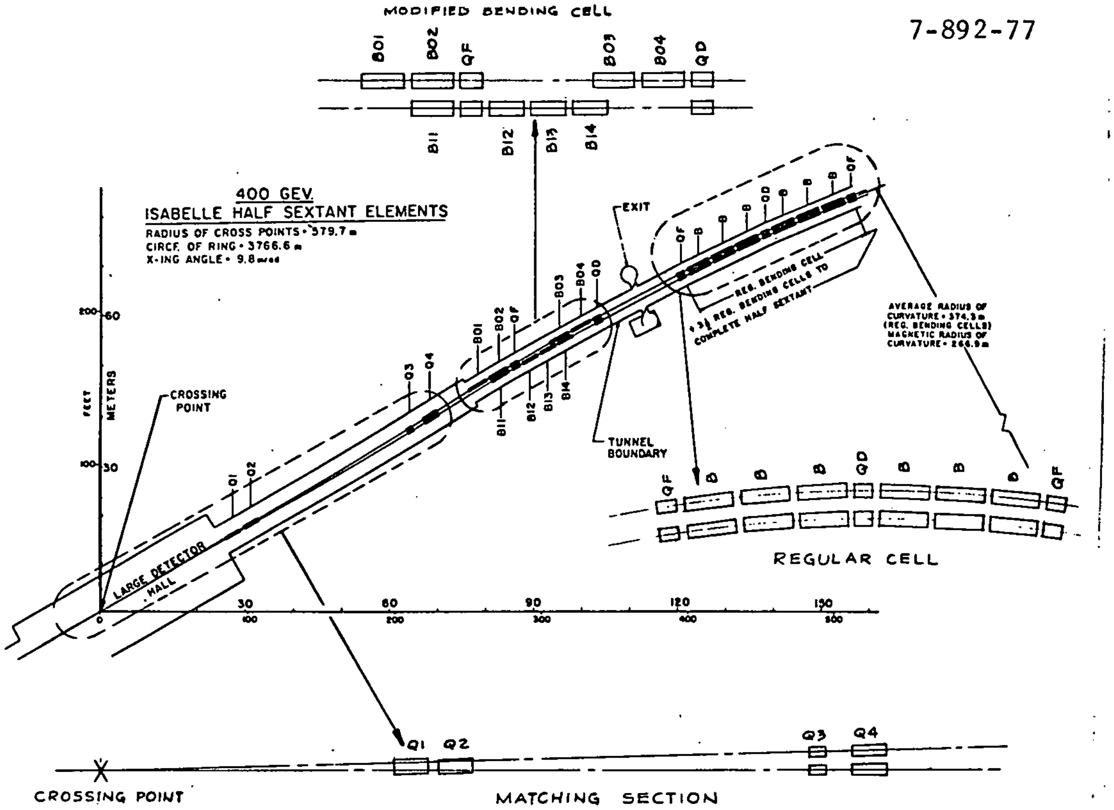

Fig. 7. 400 GeV ISABELLE Half Sextant Elements

Table II. ISABELLE Operational Sequence

Injection
- 30 GeV protons from the AGS
- 2.5×10^{12} p/pulse
- 11 bunches

Stacking
- Each pulse fills ¼ of ISABELLE
- Move into holding pattern
- Repeat 300 times/ring during 20 minutes
- $\rightarrow 7.5 \times 10^{14}$ protons/ring or 8 A

Acceleration
- Accelerate at 239 KHz
- $\langle dB/dt \rangle \sim 300$ G/sec
- 30 to 400 GeV in a few minutes

The lifetime of the beams is expected to be many days, the limitation on the use of the beam coming from gradual deterioration of the beam quality rather than outright loss of particles. The loss of energy of the beam from synchrotron radiation is noticeable; it is about 1% per day and will probably be compensated for by lowering the magnetic field.

It is interesting to compare the expected performance of ISABELLE with that of high energy machines that are presently in operation and those planned for the near future. Figure 8 is a plot of the available energy ($\sqrt{s}$) vs the luminosity. It is clear that the highest energy is available only with colliding beam machines and that although much has been said on problems of high luminosity at ISABELLE, these problems are not as severe as those encountered at fixed target accelerators. This is not to minimize the difficulties but to indicate that they are clearly not unmanageable.

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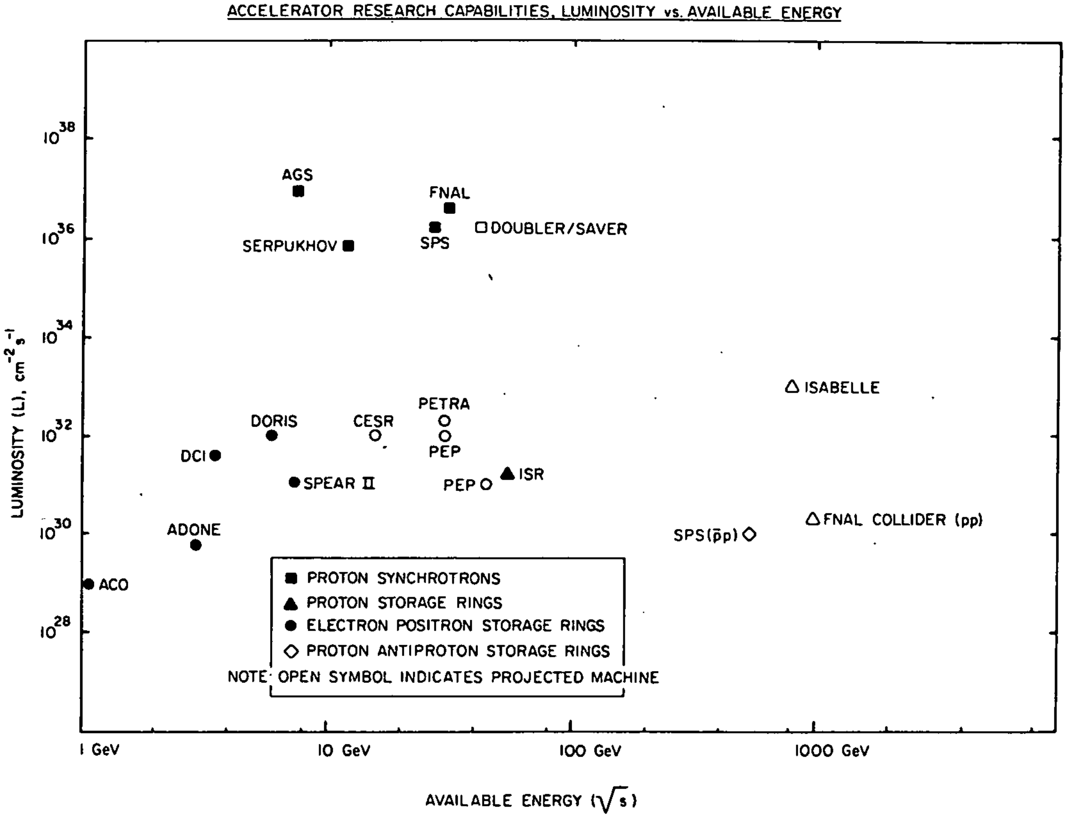

Fig. 8. Accelerator Research Capabilities

RESEARCH POSSIBILITIES AT ISABELLE

Table III shows a sample of the research possibilities to be expected at ISABELLE. The most spectacular goal for the new generation of high energy machines is the search for the intermediate vector bosons $W^{\pm}$ and Z^{o}. The assurance with which the gauge theories are now regarded leaves the experiments with unusually precise predictions for the masses of these objects whose importance is hard to overemphasize. The cross section for their production is also predicted and it is small $\sim 10^{-33}$ cm^2. A model in which the W is produced by the annihilation of quarks and antiquarks from the sea yields the production cross section in p+p collisions shown in Fig. 9. The arrow is the point where ISABELLE sits for a W mass of about 70 GeV/c^2. It is clear both that high energy is needed to investigate this mass region and high luminosity is needed to get many events.

Table III. Research Possibilities at ISABELLE

Search for W and Z	$M \sim 75$ GeV/c	$\alpha \sim 10^{-33}$ cm^2
Search for massive hadrons and leptons		
Measure high p_T phenomena (see cosmic rays)		
Look for particle correlations (jets)		
Elastic scattering, total cross sections and measure the real part		

The success of the Υ discovery in pp collisions through the observation of μ pairs leads to the belief that the study of lepton pairs and even single leptons will be a major industry at ISABELLE. Again, the cross sections are low but there is little in the way of prediction in terms of what masses to expect, except that the quark masses so far go up by factors of 3 for each flavor.

This is a cosmic ray conference and many tantalizing hints have been seen of dramatic phenomena at ISABELLE energies. The existence of a change in the p_T behavior from the Tien Shan data leads us to put this item high on the list of initial experiments. We list also here the work-horse experiments that have yielded surprises and understanding in the past, namely elastic scattering, total cross sections and the forward scattering amplitude. Finally, this conference has made it clear that we do not understand high energy phenomena and there is a store of the unexpected at high energies.

EXPERIMENTAL FACILITIES

We show the layout of ISABELLE again in Fig. 10 with the disposition of the experimental halls. These halls have been designed so that a diversity of facilities is available to the experimenter. We shall discuss in general terms the expected function of each area and return to two of the areas whose detailed design is quite advanced.

The wide angle area has been designed so that there is sufficient lateral distance that particle identification at high p_T is possible. We have taken it as self-evident that this kind of study is likely to be interesting and that also the correlations between particles produced near 90° should also be accessible at ISABELLE. The constraints put upon this area by the nearby injection and ejection have made it convenient to put a wide angle/high p_T area in this location.

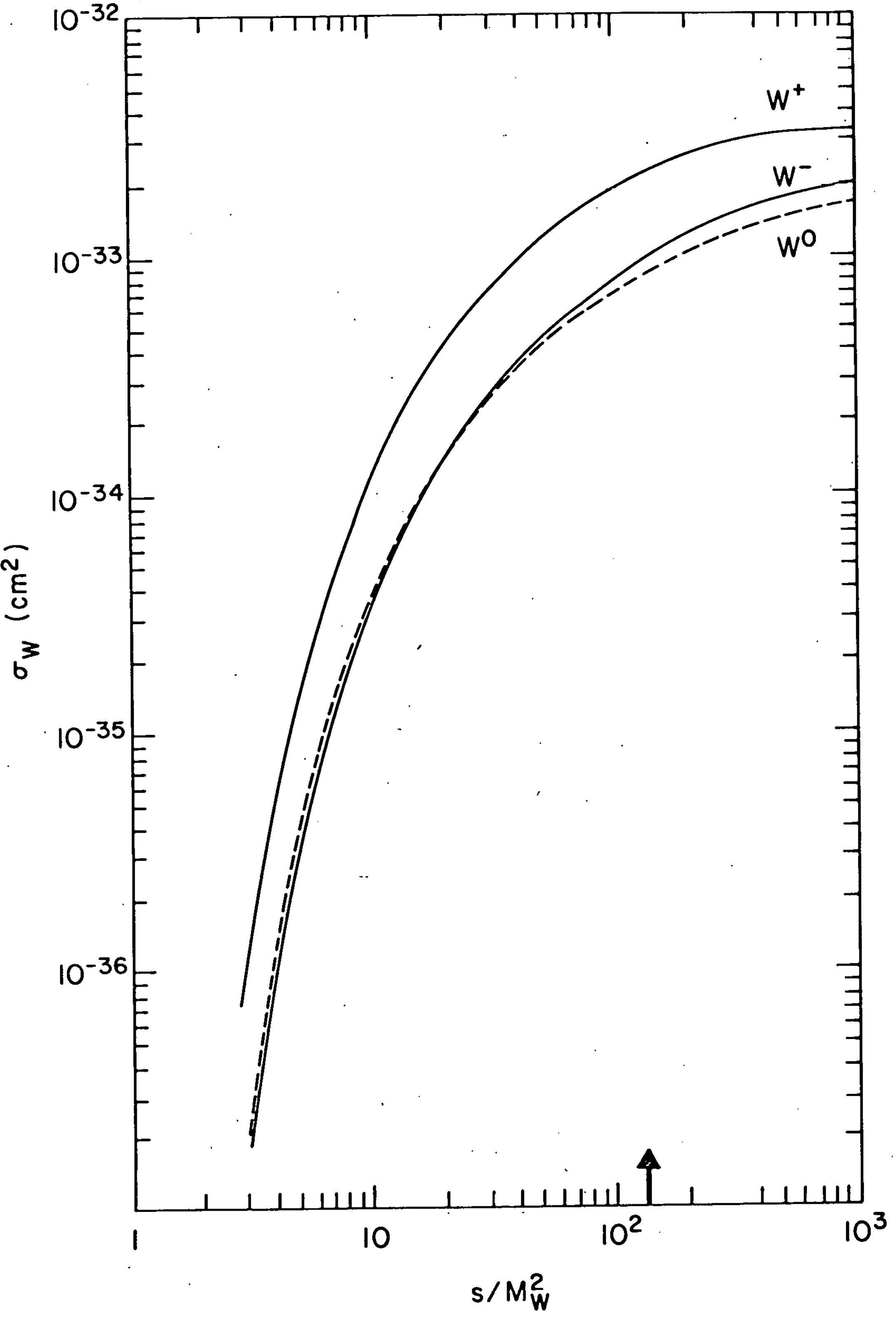

Fig. 9. W Production Cross Sections

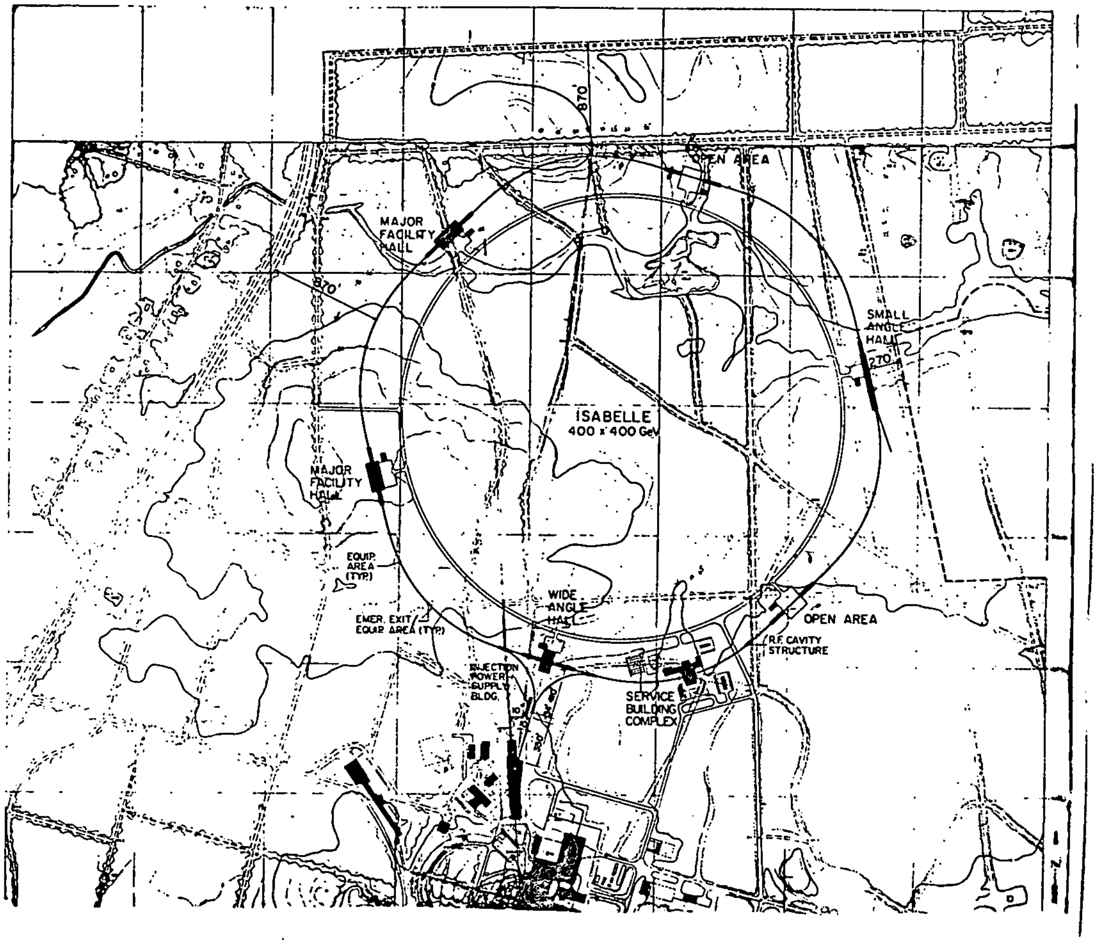

Fig. 10. ISABELLE Outline with Experimental Areas

The 4 o'clock open area is designed so that maximum flexibility for small experiments is preserved. In the initial operation of ISABELLE it is expected that there will be a need for a series of relatively modest experiments, modest in size and also in the requirements for beam time. This area is then planned to be convenient for short duration small size experiments to be installed and run.

The small angle hall at 2 o'clock reflects the demands of low p_T physics. The total cross section and forward scattering amplitude measurements as well as particle production at all x (Feynman) and low p_T can be serviced in this area. The spur that is visible in the diagram is a feature which the single arm spectrometer physics finds imperative.

The remaining three areas are presently in a fluid conceptual state. The history of recent particle physics has led to an emphasis on the power of the large and complicated electronic detector as a source of major physics discoveries. Detector development and conceptual design has occupied the attention of many people and these areas must reflect the demands of the large devices that are appropriate for ISABELLE. The need, however, for flexibility as well as restricting the cost of these areas themselves causes the design of these areas to be a delicate question. Delicate enough so that we have left the area at 12 o'clock as an open area for the time being, leaving a wide spectrum of options.

We return now to the Wide Angle Hall #6. We show in Fig. 11 this hall together with the injection lines from the AGS to ISABELLE. Ejection of the beams also takes place in this area into two dumps close to the outside of the ring. Figure 12 shows a plan of the Wide Angle Hall. The main part of the hall is a shielded enclosure; we show a piece of apparatus that we have used as a model in place in this area. This apparatus is a symmetrical pair of spectrometers with a wide angle and momentum aperture. The momentum aperture is made especially wide so that particles with low p_T can be correlated with particles at high p_T retaining a precise measurement of the momentum of the high momentum particles. The intersection diamond of the particles at ISABELLE is less than 1 mm in the vertical direction and about 25 cm in the horizontal direction. The large size of the diamond in the horizontal direction is influenced mainly by the small crossing angle of 11.2 mrad. The apparent horizontal size of the diamond is then about 100 times the beam size in the horizontal plane. If the particle source position is to be used as a constraint in momentum determination then bending must take place in a vertical plane. The combination of vertical bending and a wide momentum acceptance means that there must be an adequate clearance between the beams and the floor height. In this area the clearance is 4.3 m.

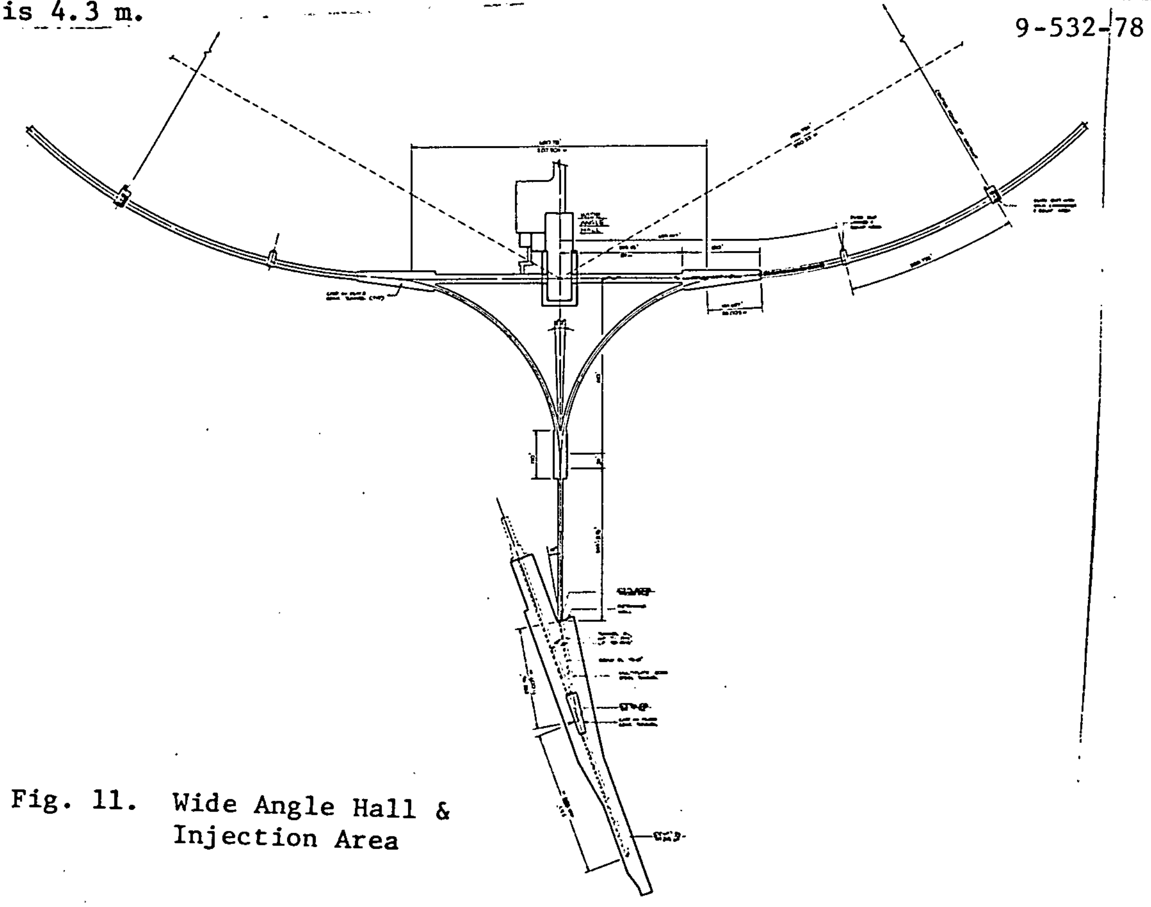

Fig. 11. Wide Angle Hall & Injection Area

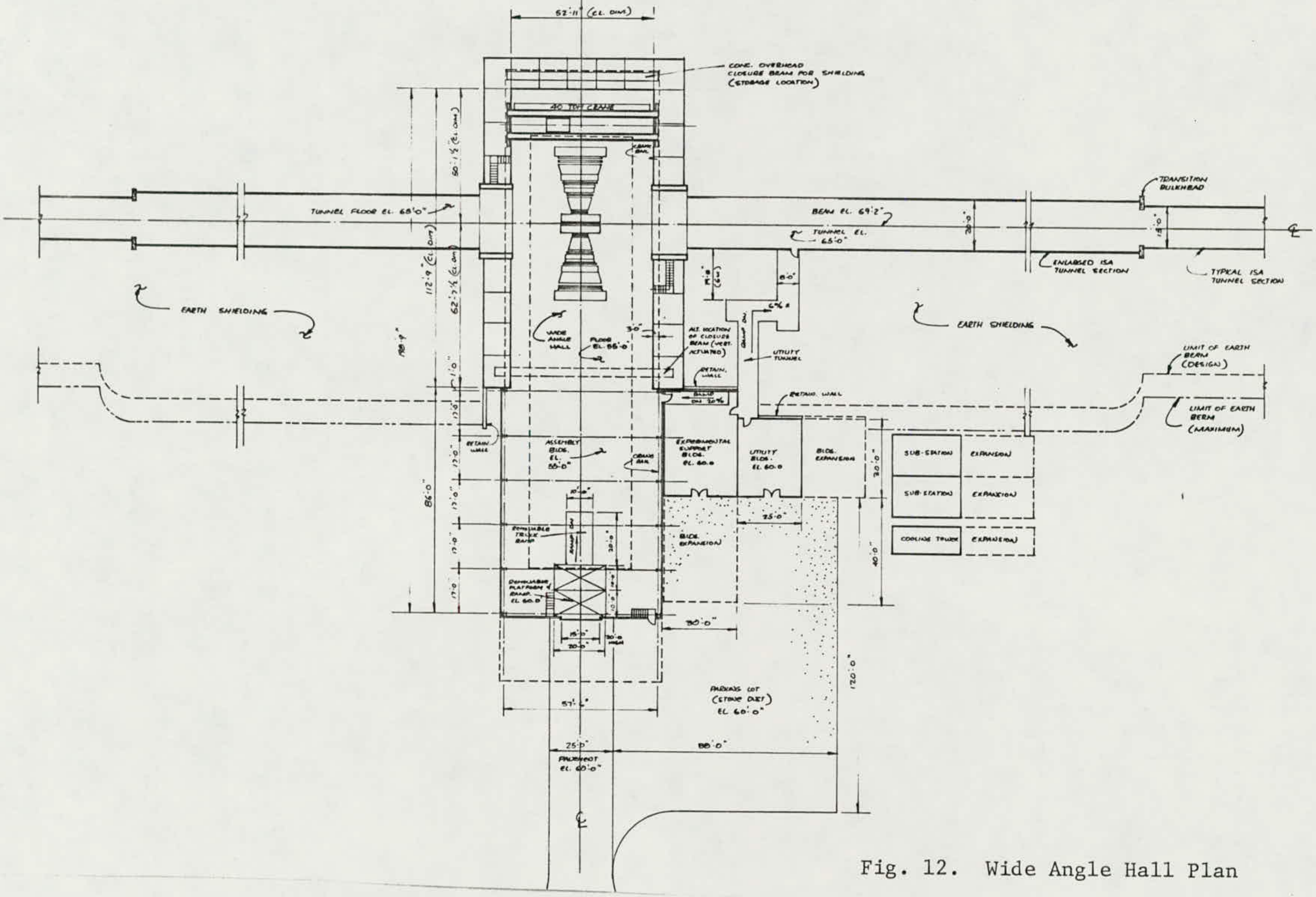

Fig. 12. Wide Angle Hall Plan

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The shielding considerations in designing an area such as this divide into two parts. The muon flux that accompanies the decays of pions and kaons from the high energy interactions of the beams is primarily in the forward direction so that the earth berm over the machine tunnel is the major contributor to the shielding effect. The limit of the berm is shown in the diagram. If this were the only consideration, transverse slots could be cut in this berm for closer access to the accelerator. However, the second consideration, namely, the slow neutrons which eventually absorb much of the interaction energy represent a limit to the minimum transverse extent that can be tolerated. In Fig. 12 the shielding walls are shown together with a shielding door that allows easy access when the accelerator is not operating. An assembly area is shown adjacent to the shielded enclosure with both floors at the same level. The same 40 ton crane can be used in either area. The experimental support building and utility enclosure is also shown adjacent to these areas.

It is anticipated that apparatus will move between the shielded and nonshielded enclosures in spite of the large sizes of equipment that have been discussed. It appears that the management of a program of many experimental areas served by a single storage ring requires this kind of flexibility and this area reflects our attempts to build this in at an early stage.

A second hall which has been designed to exploit a specific field of physics is shown in Fig. 13. This hall is at 2 o'clock and exhibits one very different aspect ratio to the 6 o'clock hall. We feel confident that the forward scattering amplitude, both real and imaginary parts, will be of interest at ISABELLE energies together with a determination of the total cross section using the optical theorem.Particle production at small p_T ($\sim$ 1 GeV/c) can be studied here up to the full energy of the beam. Theshold Cerenkov counters at these energies become very long so it has been necessary to incorporate a spur to the area, a small diameter tunnel approximately tangent to the beam. The actual angle subtended is made very small by the use of Lambertson septa that bend the scattered particles away from the beam and down the spur for experimental use. It is also expected that measurements of particle production in coincidence with the high momentum secondary production will be made and the experimental area proper is built to cope with this.

COST ESTIMATE

Table IV shows a cost estimate of ISABELLE including the experimental areas but not including any of the apparatus that we expect to install for the experiments themselves. The costs are in 1978 dollars with the escalation added at the bottom of the table. The major part of the cost of the installation is in the accelerator components themselves and especially in the magnets. The time limitation on the construction schedule is determined entirely by the rate of funding. Although many scenarios for the rate of funding are made, the data at which ISABELLE will begin doing physics varies from early 1985 to mid 1986 depending on the fiscal assumptions.

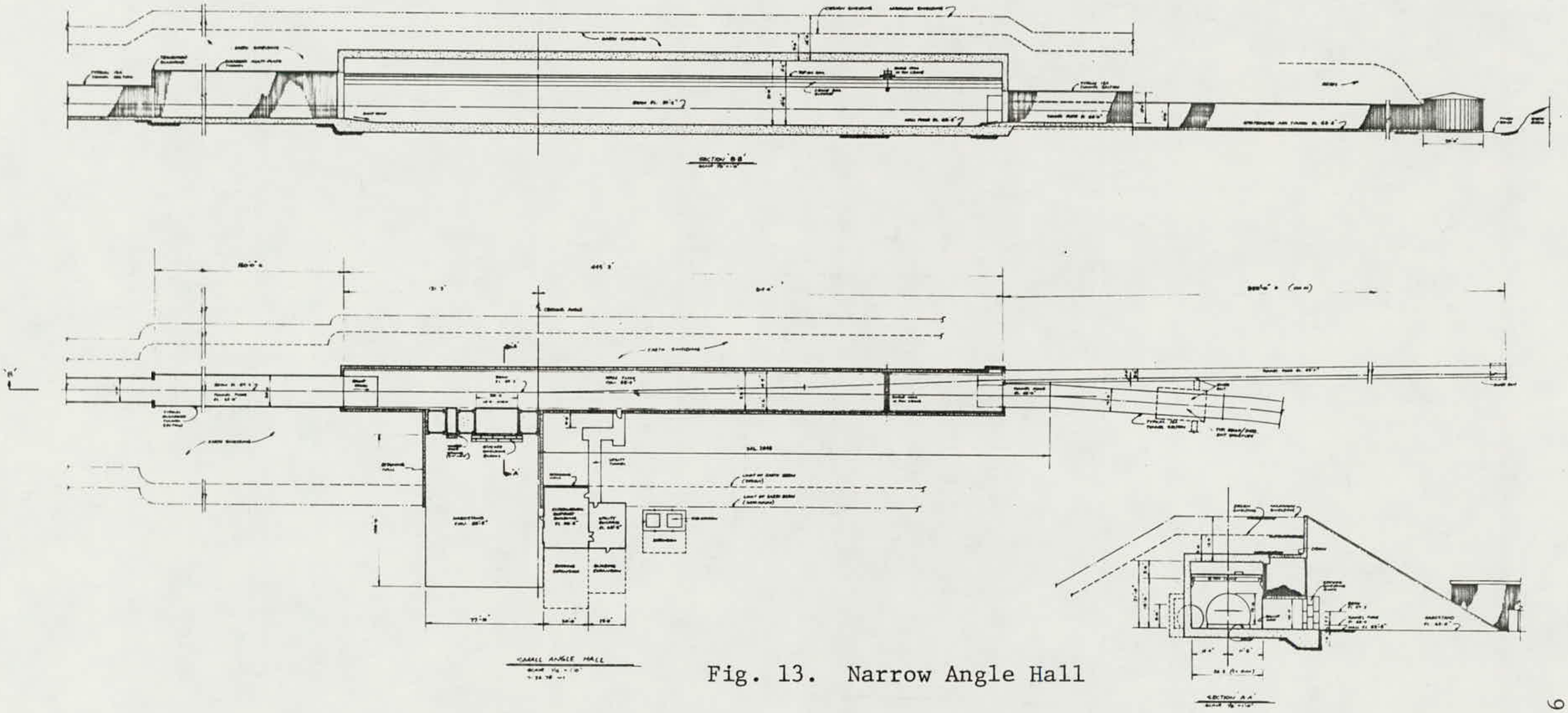

Fig. 13. Narrow Angle Hall

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Although even earlier dates can be mentioned they are almost certainly unrealistic at this time.

Table IV. ISABELLE Cost Estimate (April 1978, 400 × 400 GeV, in Thousands of Dollars)

Accelerator Components		128,570
Ring Magnets and Power Supplies	72,740	
Refrigeration System	19,860	
Control System	7,810	
Vacuum System	9,570	
Injection System	6,840	
rf System	6,020	
Other Items	5,730	
Conventional Construction		31,450
Beam Enclosures	12,950	
Experimental Areas	8,010	
Service Buildings	4,180	
Site and Utilities	6,310	
Architect/Engineer		4,330
EDIA		27,170
	Subtotal	191,520
Contingency		36,890
Escalation		46,590
	TOTAL	275,000

We have here described some of the components of ISABELLE, a high energy physics resource that we expect to make available to enjoy understanding the tantalizing hints of new phenomena we have heard from the cosmic ray physics of the present.