CONF-8708202--8
BNL-40871

BNL--40871

DE88 007043

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The Relativistic Heavy Ion Collider Project: A Status Report

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To appear in the Proceedings for Quark-Matter 1987
Schloss Nordkirchen, August 24-28, 1987

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I. Introduction

At this conference we have seen the first results[1] from experiments with high energy nuclear beams at Brookhaven and CERN. These experiments, which began about a year ago, use fixed targets at the AGS and SPS. These programs have begun with relatively light ions ($A \leq 32$ amu) to explore states of compressed nuclear matter in which high energy density is achieved in an environment of high baryon density at energies near the maximum for nuclear stopping.

The widespread interest and excitement which these experiments have generated is due in large part to the fact that they are providing the first glimpse of what is expected to be an entire new regime of physical phenomena, and that these experiments will be followed in the near future by measurements with much higher beam masses and much higher collision energies. This is the mission of the RHIC facility.

Four years ago the concept of a heavy ion collider faciity, reaching center-of-mass collision energies at least 10 times higher than the fixed target experiments, was identified as the highest priority need for a new facility in the Long Range Plan for basic nuclear research in the U.S.[3]. Immediately thereafter a panel was formed which included leading experimentalists and theorists from both high energy and nuclear physics representing

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

the major interested laboratories throughout the U.S. and in Europe, to consider the basic design requirements for such a facility. This group met for three days in August of 1983 and formulated the essential design parameters for a facility which would reach energies high enough to ensure a baryon-free central region in collisions of the heaviest nuclei; incorporate the flexibility to study collisions of all nuclei, from the lightest to the heaviest; and allow experiments to be carried out over the full range of energies, from a few GeV/amu in the c.m. (AGS fixed target) up to the top collider energy, with no inaccessible gaps, and with adequate intensity for sensitive measurements[4]. The technical parameters were developed for an accelerator complex which would utilize the existing facilities already in place for the ISABELLE/CBA project at Brookhaven, with the AGS as injector, thereby saving at least a factor of two in the overall cost of such a collider.

Immediately thereafter, in 1983, these parameters and the basic physics requirements for a heavy ion collider facility were discussed among the community at large as part of the Quark Matter '83 conference at Brookhaven[5]. With this as a starting point, an intensive accelerator physics effort was undertaken at Brookhaven during 1984 to understand the problems of accelerating and storing intense, ultra relativistic beams of highly charged nuclei, and to work out a detailed design for the collider. In January 1985 the RHIC proposal was submitted to the U.S. Department of Energy. The present Conceptual Design Report[6] is an update of that proposal.

One of the most important elements of the RHIC proposal is the design of the superconducting magnets for the accelerator rings. These magnets are the largest component of the cost of the machine, and their fabrication and installation is the major determinant of the construction schedule. The design of these magnets[7] is based on the cosine theta coil structure developed at Brookhaven for the ISABELLE/CBA magnets, which has since been adopted for the Tevatron, HERA and SSC accelerators as well. The RHIC magnets are designed to operate at a relatively low field (3.5 Tesla), and thus the coil can be wound in a single layer of superconductor. This important simplification, along with careful engineering refinement, has resulted in a magnet which is relatively straightforward to fabricate in quantity, either in the existing facilities at Brookhaven or in the facilities of commercial industrial firms. Full-size, "machine-quality" prototypes have been assembled both at Brookhaven and in industry and successfully tested.

Brookhaven has worked together with the Department of Energy to develop a detailed schedule for the project which includes R&D, construction and start-up. This comprehensive plan, which includes R&D and construction for the first round of detectors, would have the first experiments beginning five years after project authorization. This planning, the technical design on which it is based, and the scope of the research which this new facility will make possible, have been the subject of numerous scientific and technical reviews over the past two years. Each has reaffirmed the urgency for getting on with this project. The essential conclusions from two recent reviews are cited here:

- Report of the NSAC Sub-committee on Facility Construction and National Laboratories, June 1986:

  "The recent development of the field of relativistic heavy-ion physics has further strengthened the very high scientific merit for this project...RHIC will provide nuclear science in the United States with a unique world-leading facility with almost unparalleled potential for new discovery."

- Executive Summary of the Department of Energy Review Panel on Technical Design, Cost, Schedule and Management for RHIC, L.E. Temple, Chairman, May, 1987:

  "The review committee found the project ready to proceed with construction funding."

II. RHIC Design

The system of accelerators which comprise the Brookhaven heavy ion program is illustrated in Fig. 1. Ions are injected into the AGS through a long transfer line from the Tandem Van de Graaff accelerator. The commissioning of ion beams accelerated in the AGS took place during this past year, and marks the first step in a long term plan for heavy ion physics at BNL, a summary of which is given in Table I.

Table 1. Heavy Ion Facilities at BNL

1986 Begin AGS Fixed Target Experiments

Beam Energy:	Up to 28 $(\frac{Z}{A})$ GeV/amu
Ion Species:	^{1}H to ^{32}S
Flux:	$\simeq 10^{9}$ ions/pulse
Running Time:	5-10 weeks/year

1990* AGS Experiments with Booster Synchrotron

Extend ion mass to A ≃ 200 (Au)

1993* Begin RHIC Collider Experiments

Beam Energy:	Up to 250 $(\frac{Z}{A})$ GeV/amu per beam in collider mode	
Ion Species:	^{1}H	to ^{197}Au
Total c.m. collision energy:		
	500 GeV (protons)	40,000 GeV (Au)
Luminosity:	$10^{31}cm^{-2}sec^{-1}$	$5\times10^{26}cm^{-2}sec^{-1}$

indicates proposed dates

In 1986 Brookhaven received the first construction funds from the U.S. Department of Energy for the Booster Synchrotron as part of a general program to improve the AGS performance[8]. Present plans foresee completion in 1990. In addition to increased proton intensity for the high energy physics experimental program, the Booster will extend the heavy ion mass range to gold nuclei.

The basic parameters of the RHIC facility are illustrated in Fig. 2. The design calls for a top beam energy of 100 GeV/nucleon for ions of mass A=200, and the acceleration of ion masses spanning the full periodic table. The complete accelerator complex, consisting of Tandem, Booster, AGS and RHIC will provide c.m. collision energies for gold beams ranging from 1.5+1.5 GeV/nucleon to 100+100 GeV/nucleon. This energy range is covered with no inaccessible gaps, and adequate beam intensities throughout. Because operation in the collider mode at very low energy would require very large aperture (and therefore very costly) magnets--much more so than is required at the top energies--the energy range is covered in three segments: As shown in Fig. 2, the range between fixed target AGS experiments and high energy collider operation is spanned by using one of the RHIC beams striking a fixed target. For this operation an internal gas jet target would be used.

The layout of the RHIC collider is shown schematically in Fig. 3. The circumference of the collider is 3833 meters. It consists of two accelerator rings with six crossing regions (insertions) where the counter-rotating beams are brought into collisions and experiments carried out. Particle bunches accelerated in the AGS to top energy (28 GeV for protons; 11 GeV/amu for gold) are transferred to the collider by a magnet system installed in the existing transfer line tunnels. Single bunches of ions are injected 57 times into each ring in boxcar fashion. Filling time per ring will be about one minute. For gold, as an example, there will be ~ 1.1×10^{9} ions/bunch, or 6×10^{10} ions in 57 bunches in each ring. For the lightest ions, hydrogen and deuterium, approximately 10^{11} ions/bunch can be stored in the machine. Acceleration will take approximately 60 seconds. Bending and focussing of the ion beams is achieved with superconducting magnets. Given that the machine will be built in the existing CBA tunnel, a cost optimization is achieved by filling the circumference with relatively low field magnets. The maximum energy of 100 GeV/amu for gold ions (250 GeV for protons) is reached with a magnetic field of 3.4 Tesla. Maximum operational flexibility is obtained with the magnets of each ring in separate vacuum vessels, with the beams in the arcs separated by 90 cm. Figure 3 illustrates a half-cell of the arc magnet lattice, consisting of a dipole, two quadrupoles, and lumped corrector coils.

The six beam crossing regions are designed to accommodate a range of configurations to fulfill the needs of experiments. As illustrated in Fig. 4, these include head-on collisions of beam bunches as well as a range of crossing angles. The free space available for experimental equipment in each crossing region is 9 meters on either side of the intersecting point. For head-on collisions with gold ion beams at top energy, a luminosity of 4.4×10^{26} $cm^{-2}sec^{-1}$ averaged over a 10 hour beam lifetime is expected. For protons the expected luminosity is about 8×10^{30} cm^{-2} sec^{-1}. These maximum values will be decreased by a factor of ~ 4 for a beam crossing angle of 2 mrad. Collisions of unequal species, e.g., protons in one beam and gold ions in the other will be possible as well. The Accelerator Physics Group has considered possible future upgrades of the machine performance, and these ideas are discussed elsewhere in this volume[9].

III. The Present Status

As noted above, a large fraction of the RHIC facility already exists. For the injector complex, the Tandem Van de Graaff, AGS, and heavy ion transfer line are already operational; the Booster Synchrotron is under construction. Most of the conventional construction for the collider is complete, including the ring tunnel, main service building and experimental halls for four of the six intersection regins. In addition, the liquid helium refrigerator, capable of cooling all of the superconducting magnets in the collider has been completed (as part of the CBA project) and successfully tested. The refrigerator has a capacity of 25 kilowatts at a temperature of 4.3K. The estimated heat load for RHIC is ~ 10 kilowatts at 4.6K.

The superconducting magnets for RHIC have been designed. The arc dipole magnet cross section is shown in Fig. 5. The dipole magnets are of cosθ coil geometry with coil i.d. of 8.0 cm and yoke length 9.7 meters. As we discussed in Sec. I, the R&D work on these magnets is well along, and it is planned that a significant fraction of the magnets for the RHIC machine will be industrially fabricated. Figure 6 shows a magnet assembly, consisting of a dipole, quadrupole and corrector coils, mounted in a cryostat.

Four full-length, field-quality dipole magnets have been built during the past year, using coils wound at BNL. Three of these magnets have been assembled by the industrial firm Brown, Boveri Corp. (BBC) of Mannheim, West Germany, using tooling fixtures which are in place for the HERA project at DESY. An agreement has been reached between BNL and DESY whereby this tooling will become available for the manufacture of RHIC magnets in exchange for BNL assistance in the superconducting and cryogenic design for HERA. The first of the full-length magnets, assembled at BNL, was successfully tested in February, 1987. Since then the remaining, industrially built magents in this series have been tested. All of these magnets reached fields of approximately 4.6 Tesla, or 35% higher than the operating field for RHIC, with virtually no training.

The magnet R&D program is continuing, with work now in progress on quadrupoles, corrector coils and the specialized magnets needed for the beam crossing reigons. A full cell of arc magnets, consisting of two dipoles, two quadrupoles and lumped corrector package, will be installed and tested prior to the production of final magnets.

The Project has been reviewed and validated by the U.S. Department of Energy, and construction could begin in fiscal year 1989 if funds are made available. A five-year construction schedule is planned. The accelerator construction cost is roughly 200 million dollars, with an additional 70 million dollars budgeted for detectors (these figures are in FY 1988 dollars).

IV. Experiments and Detectors

Of the six crossing regions built into the RHIC rings, those at the 2, 4, 6 and 8 o'clock positions have completed experimental halls, including support buildings and (except in the 4 o'clock "open area") crane coverage. The RHIC plan calls for mounting experiments initially in these four areas, leaving the remaining two unfinished until some later time.

The nature of these experiments, and specific designs for detectors have been studied by a number of groups at workshops and conferences over the past several years[2,10,11,12,13]. The measurement capability required for such experiments is similar to that which exists in spectrometers for high energy elementary particle experiments, but there are important differences. The most striking is the extraordinary level of particle multiplicities which experiments must deal with in high energy nucleus-nucleus collisions: Estimates for RHIC reach up to ~ 10,000 particles per event. In addition, most of the essential measurements involve soft particles, with transverse momenta and pair masses characteristic of the kinetic energies in a thermalized plasma of quarks and gluons. This is in contrast with the elementary particle case where the focus is largely on rare processes produced in the high P_T tails of momentum distributions. In April 1985 a workshop involving about 100 nuclear and high energy physicists provided preliminary designs and cost estimates for a first-round suite of detectors for RHIC. The proceedings[2] from the workshop are available, and provide a detailed discussion of physics goals and conceptual designs for detector systems.

The second RHIC workshop was held this past May at Lawrence Berkeley Laboratory. This week-long meeting culminated a year of effort carried out by individual working groups holding meetings at BNL, CERN and elsewhere. The experiments which have now taken data with ion beams at the AGS and SPS have produced many new insights into the requirements for detectors and detector development as well as sharpening the physics focus as we prepare for the higher energy regime of RHIC. The results of this latest workshop, proceedings of which will be available soon[13], represent a first step in the planning for the initial round of experiments at RHIC.

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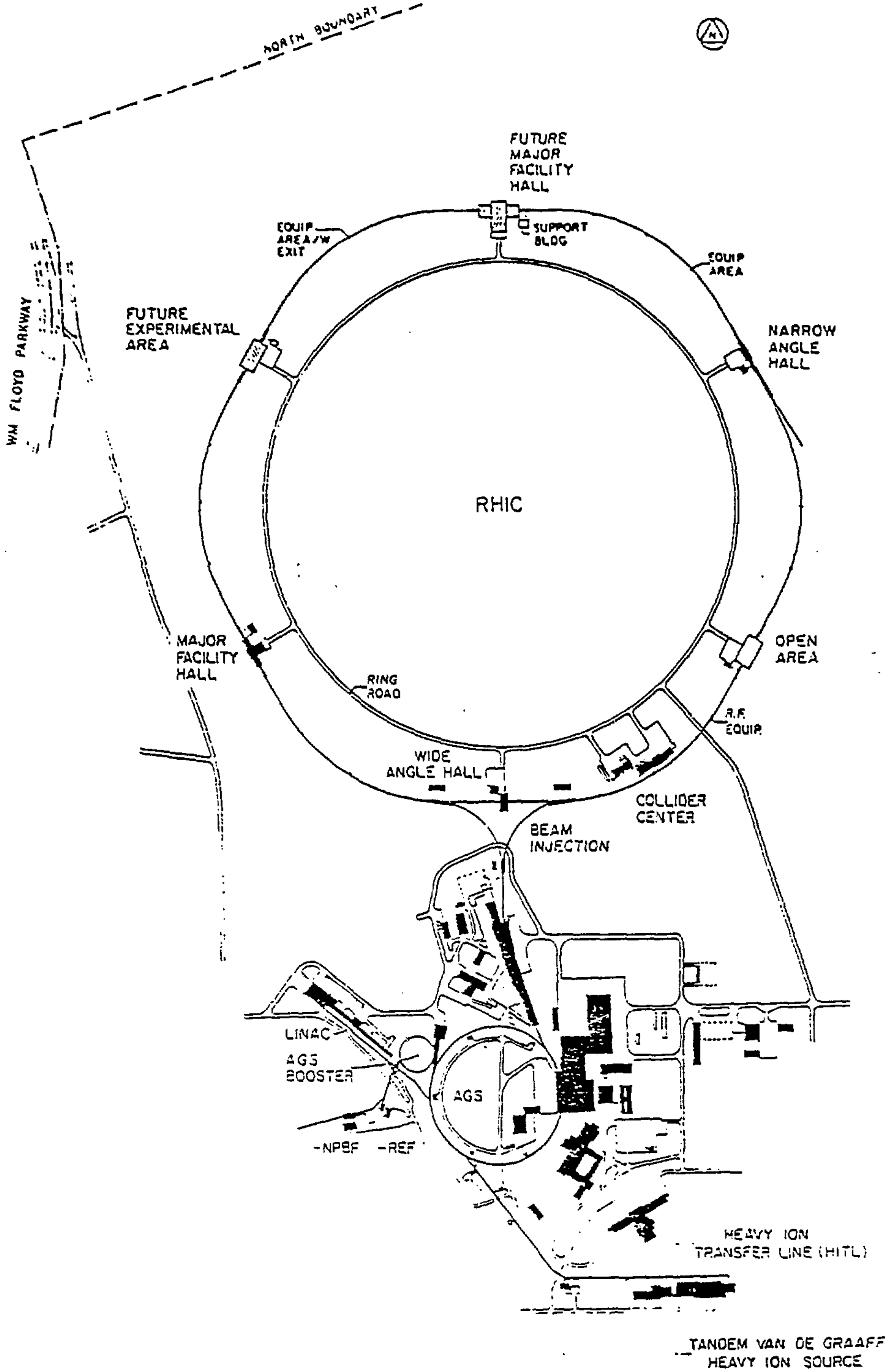

Fig. 1. Site map of present and proposed accelerators at Brookhaven. The Tandem Van de Graaff and the AGS with its linac injector are existing machines. The Booster Synchrotron for pre-injector to the AGS is currently under construction. The RHIC colliding beams accelerator to the north of the AGS complex is a proposed construction project.

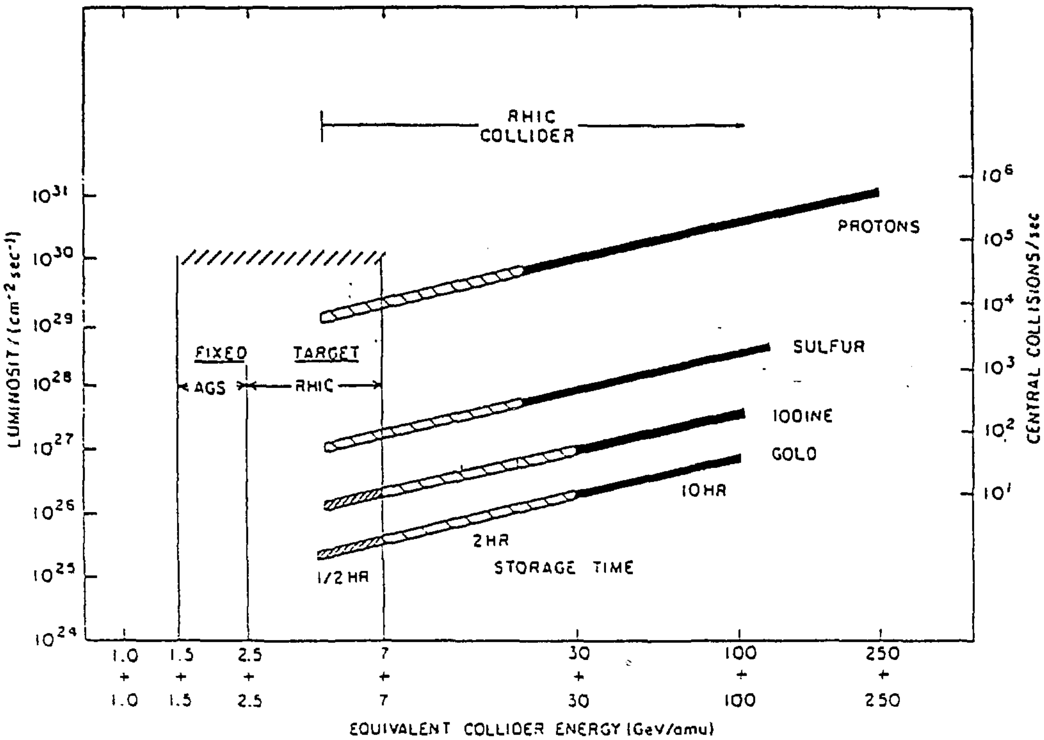

Fig. 2. The design luminosity, for various ion masses, as a function of collision energy over the full range accessible with AGS and RHIC. On the left-hand scale, central collisions correspond to impact parameter less than 1 fermi.

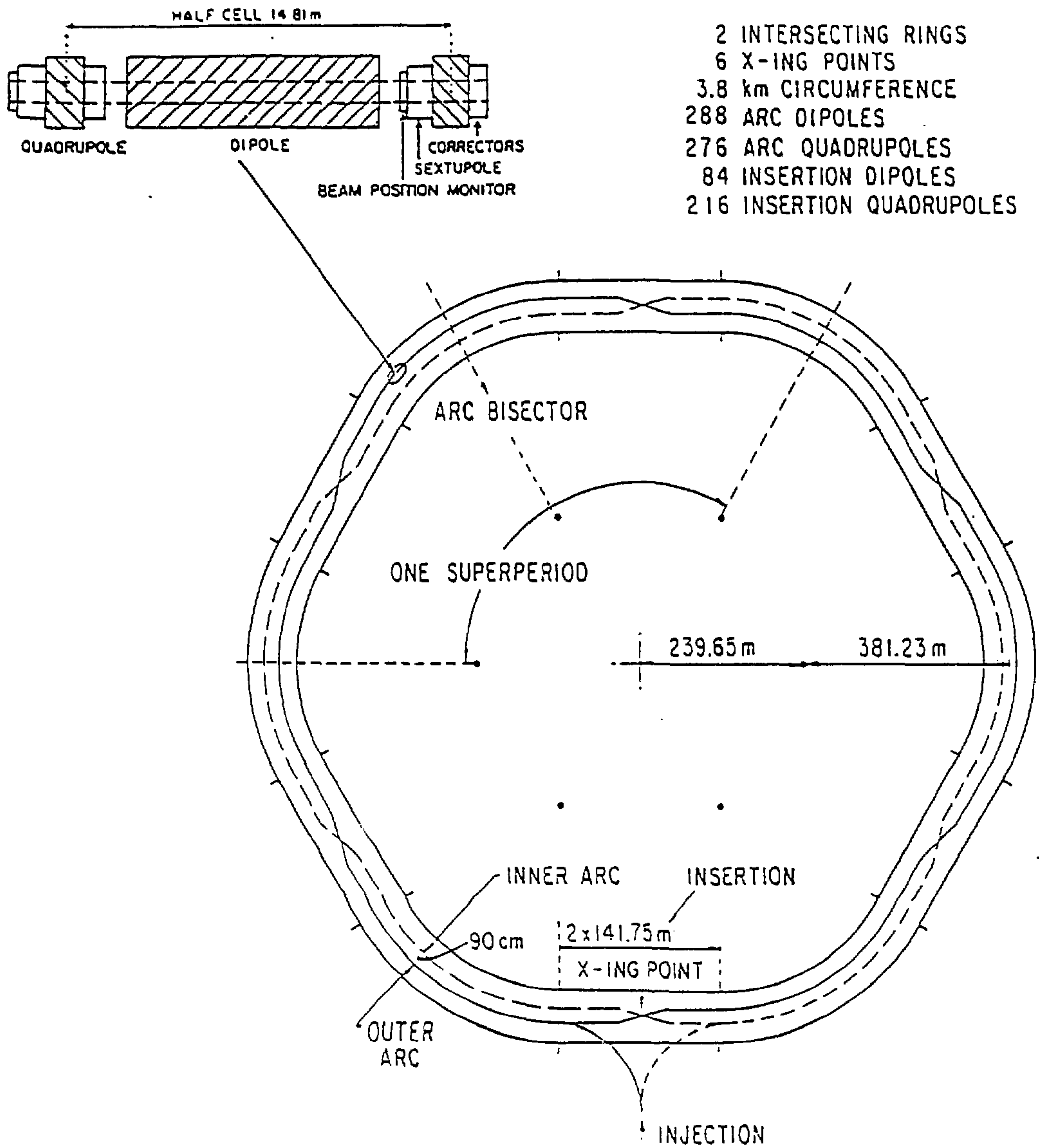

Fig. 3. Layout of the storage rings for the RHIC collider.

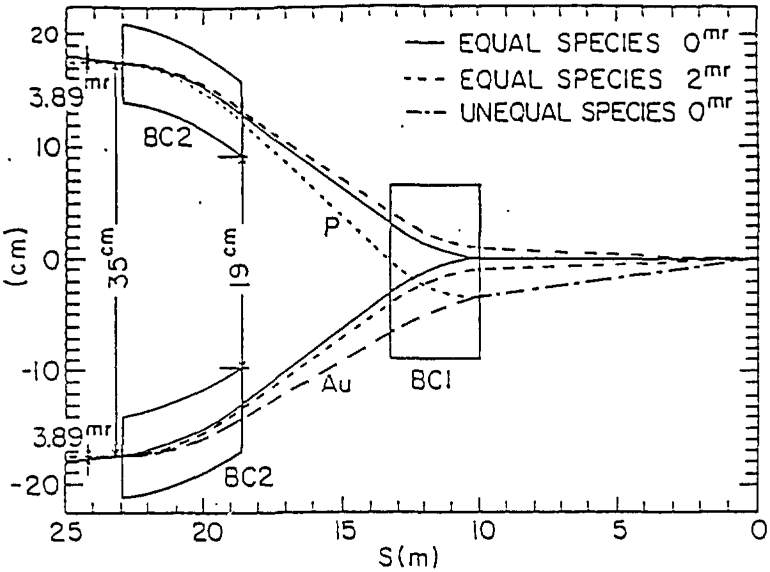

Fig. 4. Beam crossing geometry. BC1, BC2 are dipole magnets. The distance from the crossing point is denoted by S.

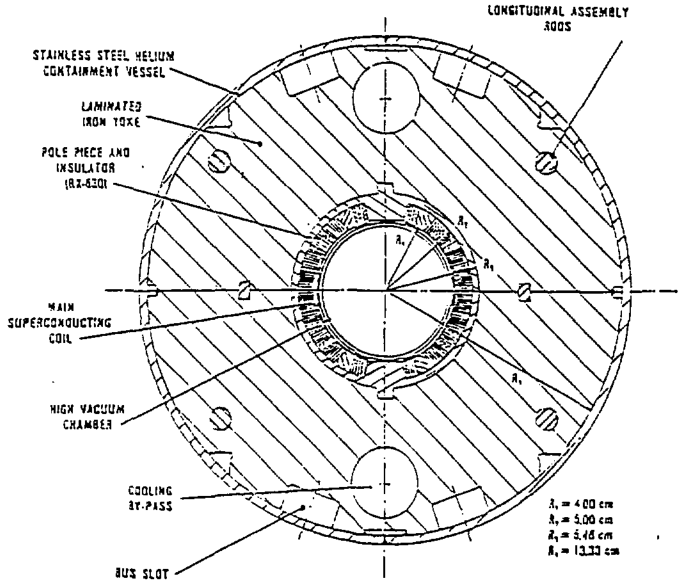

Fig. 5. Cross section of RHIC dipole magnet.

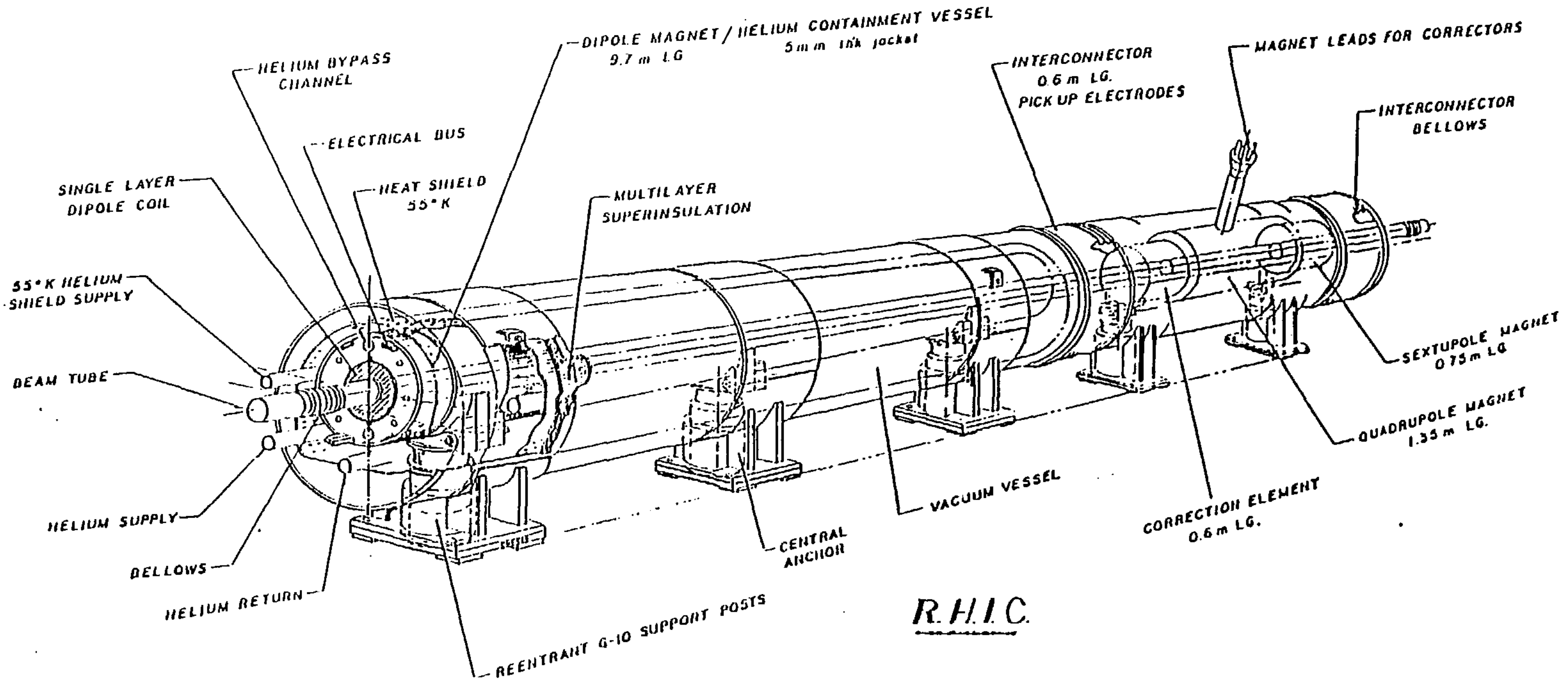

Fig. 6. RHIC magnet assembly: The drawing shows a half-cell of the arc magnet lattice, including a dipole, corrector package, quadrupole and sextupole magnets enclosed in their cryostat.