RHIC PROJECT*

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Abstract

With funding in place and governmental approval to begin the detailed design, as well as to proceed with the procurement of long lead-time items, the RHIC Project is now a *bona fide* construction project at Brookhaven National Laboratory. This paper will present an overview of the RHIC accelerator configuration, the collider design, and the present status of the Project.

I. INTRODUCTION

The scope of the RHIC Project at Brookhaven National Laboratory is to design, construct, and bring into operation a colliding beam facility and an initial complement of detectors dedicated to studies of nuclear phenomena in relativistic energy heavy ion collisions. Performance objectives call for the acceleration and storage of beams of ions as heavy as gold with a top energy of 100 GeV/u. The lower end of the energy is limited by the speed of emittance growth due to the intra-beam scattering and is envisaged to be about 30 GeV/u. The collider, which consists of two concentric accelerator/storage rings of superconducting magnets, will be constructed in the existing 3.8 km circumference ring tunnel in the northwest section of the BNL site. The operational flexibility derived from having two independent rings for the counter rotating beams allows collisions of unequal species of ions. The wide energy range available at the collider is expected to cover the transition from confined phase to plasma phase of the nuclear matter. These unique features meet experimental requirements which will be vital for the understanding of complex heavy ion collision phenomena, particularly those pertaining to the study of the on-set of a new phenomenon such as quark-gluon plasma formation.

The performance objectives for the collider were initially formulated in 1983 by a Task Force for Relativistic Heavy Ion Physics, and was endorsed by the DOE/NSF Nuclear Science Advisory Committee as early as December 1983. The present scope of the project was finalized with input from scientific and technical review committees. The funding for the RHIC construction was proposed by the President and approved by the U.S. Congress for a Project start in FY 1991. Subsequently, after a review by the DOE Energy Systems Acquisition Advisory Board (ESAAB) in January 1991, the Project received approval to begin the detailed design and procurement of long lead-time items (e.g., superconducting cables). $11.3 million of the FY 1991 construction funds was released at that time, and the remaining $2.2 million is to be released after ESAAB approval for the full construction, anticipated in the July-August time frame. The construction funding for FY 1992 is expected to be $50 million. The total estimated cost (TEC) for construction is $397 million, to be distributed over six years. Approximately $97 million of the TEC is earmarked for the initial complement of detectors. The total project cost (TPC), which includes R&D and pre-operations cost, is estimated to be $499 million. With the funding in place, construction of RHIC began in full swing with the target date of completion in the spring of 1997.

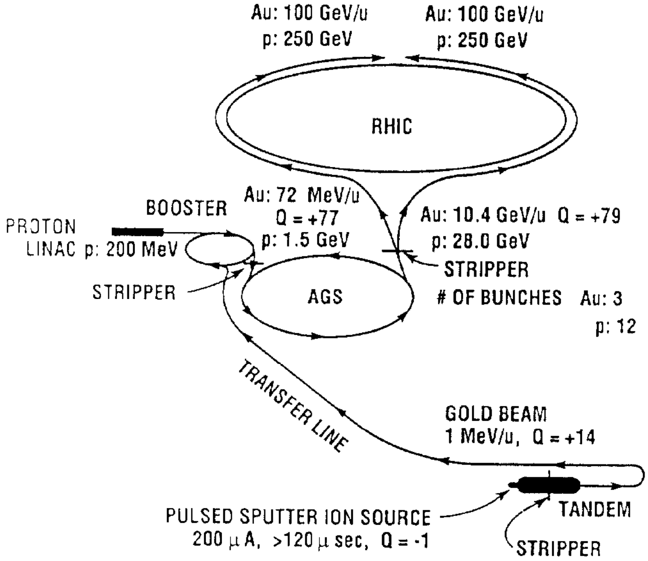

Figure 1. Overall configuration of accelerator complex for RHIC. An existing accelerator chain, which consists of the Tandem Van de Graaff, the Booster Synchrotron, and the AGS, serves as the injector to the RHIC collider.

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*Work performed under the auspices of the U.S. Department of Energy under Contract No. DE-AC02-76CH00016.

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II. COLLIDER CONFIGURATION

Figure 1 illustrates the RHIC accelerator strategy, which includes the use of an existing chain of accelerators—Tandem Van de Graaff, Booster Synchrotron (to be commissioned in 1991), and AGS—as the injector to the RHIC collider. Using gold ions as an example, negative ions from a pulsed sputter ion source (200 μA, >120 μsec, Q = −1) are accelerated by the first stage of the Tandem Van de Graaff, stripped of atomic electrons by a foil at the high voltage terminal to reach the charge Q = +14 state, and then accelerated to about 1 MeV/u by the Tandem's second stage. The ions are then transported through a 540 m long transfer line for injection into the Booster without further stripping. After multi-turn injections, the beam of ions is grouped into 3 bunches and accelerated to 72 MeV/u. A foil at the Booster exit strips all but two K-shell electrons, forming Q = +77 gold ions. The AGS, with planned improvement of its vacuum, will accelerate these bunches 10.4 GeV/u with insignificant loss by further electron stripping. Ions are fully stripped at the exit of the AGS and injected into RHIC collider rings. Beam stacking is done in the box-car fashion by repeating this cycle 19 times to establish 57 bunches for each ring. Overall filling time for two rings should be about 1 minute.

The bunches are captured in stationary buckets of the "acceleration rf" system operating at ~26.7 MHz, corresponding to a harmonics h = 57 × 6. With the exception of protons, all ion species must be accelerated through the gamma transition. The time required for the acceleration to the top energy is also ~1 minute. When the operating beam energy is reached, the bunches are transferred to the "storage rf" at ~160 MHz (h = 57 × 6 × 6). This six times higher frequency was chosen to compress the stored bunch so that a short (22 cm rms) collision diamond can be obtained for head-on collisions, an advantage for experiments.

The layout of the collider is shown schematically in Figure 2. It consists of two quasi-circular concentric rings in a common horizontal plane, oriented to intersect with one another at 6 locations along the ring. Each ring consists of three inner and three outer arcs (each ~355.5 m long) and six insertions (each ~283.5 m long) connecting the inner and outer arcs. Each arc is composed of 12 FODO cells, i.e., 24 half cells each consisting of a dipole unit (9.46 m long), and a unit made up of a sextupole (0.75 m long), a quadrupole (1.13 m long), and a corrector assembly (0.58 m long), all superconducting. The corrector assembly contains co-axial layers of cylinders on which decapole, octupole, quadrupole, and dipole correction coils are fixed. In the arc sections, the counter rotating beams are separated by 90 cm horizontally. Beams are to cross each other at the middle of each insertion section (see Figure 3). Each half of the insertion contains 9 quadrupoles and 2 dipoles for dispersion matching and β-function manipulation. Although the geometry of the insertion sections allows beam crossings at an angle up to 7 mrad, head-on collisions will be used as the standard mode of operation to minimize the beam instability which might arise from coherent bunch-to-bunch interaction. Two dipoles closest to the interaction point are to steer beams to a collinear path for collisions. Most of the magnets have a large coil inner diameter of 80 mm to allow enough aperture for the emittance growth due to intra-beam scattering. Quadrupoles close to the interaction point have a 130 mm coil inner diameter, and the closest dipole 200 mm.

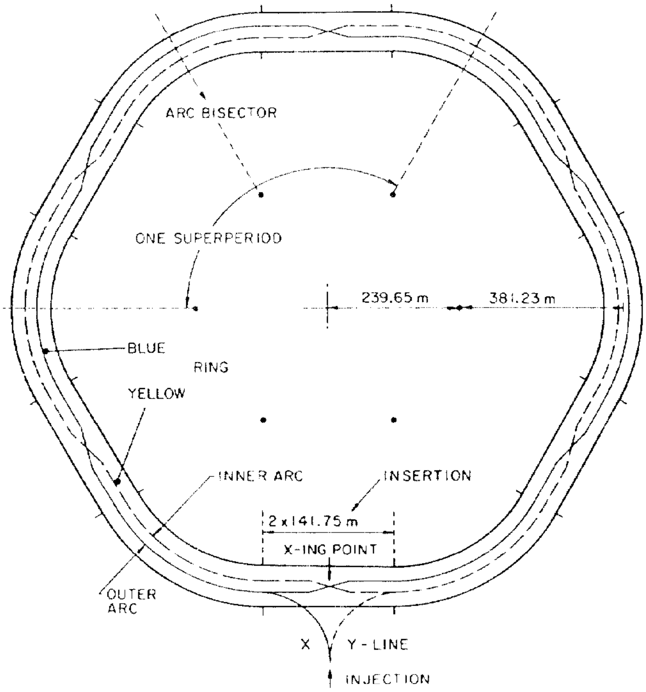

Figure 2. Layout of the RHIC collider.

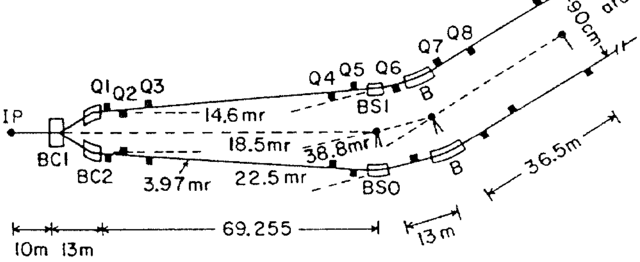

Figure 3. Layout of one half of the insertion section connecting inner and outer arcs of a ring.

III. EXPECTED PERFORMANCE

Major RHIC performance estimates are summarized in Table 1.

Table 1. RHIC Performance Estimates

No. bunches	57	
Bunch spacing (nsec)	224	
Collision angle	0	
Free space at crossing point (m)	±9	
	Au	p
No. particles/bunch	1×10^9	1×10^{11}
Top energy (GeV/u)	100	250
Emittance (π mm · mrad)	60	20
Diamond length (cm rms)	22	20
Beta* (m)	2	2
Luminosity ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$)	$\sim 2 \times 10^{26}$	1.4×10^{31}
Lifetime (hr)	~10	>10
Beam-beam tune spread/ crossing	3×10^{-4}	4×10^{-3}

Energy: The top kinetic energy of each beam is designed to be 100 GeV/u for heavy ions, about 125 GeV/u for light ions, and 250 GeV for protons. The collider will be able to operate over a wide range of energy, typically from 30 GeV/u to the top energy.

Luminosity: The collider is designed for an Au-Au luminosity of about $2 \times 10^{26}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, and for a proton-proton luminosity of $1.4 \times 10^{31}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ at the top energy, while maintaining the option for future upgrades by an order of magnitude. The luminosity will be higher for light ions and is energy dependent, decreasing in first approximation proportional to the beam energy.

Ion Species: The collider will accommodate a range of ion species with mass number of about 200 (Au) to 1 (proton). Asymmetric operation with protons colliding with heavy ions is unique to RHIC. Uranium is a viable species and can be considered as a future upgrade but requires the development of a suitable ion source.

Luminosity Lifetime: The luminosity lifetime is expected to be about 10 hours for Au-Au operation at the top energy, and is believed to be limited by the emittance growth due to intra-beam scattering which is significant for heavy ions. Thus, the lifetime becomes shorter for lower energies and longer for light ions.

IV. PROJECT STATUS AND RECENT DEVELOPMENTS

During the past year, the layout of the rings was re-studied from the viewpoint of actual mechanical layout of ring components in the tunnel. The cost savings by a standardization of ring components, simplification of the ring installation, and the beam optics including tunability and correctability were the principal concerns in this study. The optimization in this study resulted in a number of small but significant modifications to the layout given in the Conceptual Design Report.[1]

The development of 8 cm bore superconducting arc dipole magnets has been a major emphasis in the RHIC R&D program. A relatively modest magnetic field of 3.45 T required for the arc dipoles makes the magnet design simple (see Figure 4). It has a single layer cosθ coil design with low carbon yoke iron lamination acting as a collar. A high-precision injection-molded mineral-loaded phenolic (RX 630) is used as the insulator/spacer between the coil and the yoke lamination. The superconducting cables used are similar to the Rutherford cables developed for the outer coil of the SSC 40 mm dipoles. Namely, they have a keystone angle of ~1.2°, made up of 30 strands of 6 μm NbTi composite wires (0.648 mm diameter), but with a Cu to superconductor ratio of 2.25:1. Eight full-length model dipoles were built. These satisfied the RHIC requirement in the magnetic field strength with a comfortable margin (~30% for the last two R&D units). The field quality of these magnets almost satisfied the requirement, but with an error in the b_2 and b_4 harmonic components. This error is small enough to be easily adjusted by minor iteration of wedge dimension in the manufacturing process. After the eight, two additional dipoles were fabricated. The new

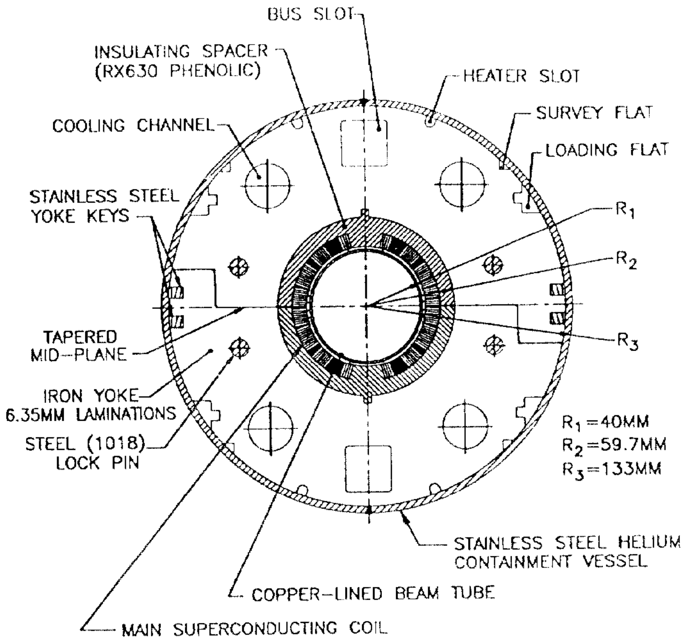

Figure 4. Cross section of RHIC arc dipole magnet.

dipole design incorporates features suggested by industrial manufacturing studies which simplify manufacturing, thus reducing the cost. The dipoles are now close to the final design.

We intend to have industry build all 80 mm bore dipole, quadrupole, sextupole, and corrector magnets. An Industrial Technology Orientation session was held in October 1990 at BNL in preparation for the issuance of a Request for Proposal (RFP). The session was attended by ~80 participants representing 34 industrial firms, confirming industry's enthusiasm for this Project. Presently, the RFP for the development of the production tooling and manufacturing of 80 mm bore dipole magnets is in preparation. The anticipated release is May or June 1991, with contract award this fall. The RFP for the procurement of other magnets will follow. We plan to procure the total quantity of superconducting cable from one supplier to assure uniformity. The cable produced will be characterized at BNL and supplied to industry for the dipole and quadrupole manufacturing. A pilot program for cable production is in progress at three qualified suppliers (63,000 feet each). An order for the full quantity production (1.7 million feet) will be placed in the fall of 1991, after an evaluation of the cables manufactured in the pilot program.

One FODO-cell consisting of two dipole magnets and two sextupole/quadrupole/corrector magnet assemblies was assembled to test (1) the mechanical assembly scheme of a train of arc magnets, (2) the mechanical and electrical properties of the magnets under a number of thermal and electrical cycles, and (3) the behavior of the system, such as the pressure build-up under quench conditions. The tests were successful, confirming the soundness of the magnet design and also providing guides to improve the interconnect design.

In expectation of colliding beam operation beginning in the spring of 1997, the Laboratory has issued a call for letters of intent for initial experiments using RHIC. Nine letters of intent supported by ~300 enthusiastic physicists from the U.S. and abroad were received by the September 1990 deadline. Although RHIC storage rings intersect each other at 6 locations, the current scope of the RHIC Project calls for the use of 3 existing experimental halls and one open area for studies of nuclear phenomena. This, together with the limited funding (~$100 million) allocated to the construction of the initial complement of detectors, indicates that two, at most three, proposals of significant scale can be approved. An effort is underway to see if the experimental groups can be consolidated before going into the costly proposal formulation by each group. The Laboratory plans to select the first-round detectors before mid 1992 to allow sufficient time for their construction. Meanwhile, R&D for detector technology, which is essential to fully exploit the physics potential of RHIC, has been actively supported by the RHIC Project organization at the level of $1 million in FY 1990, $2 million in FY 1991 and hopefully ~$3 million in FY 1992.

The RHIC Project has taken significant steps forward in recent months. In the technical areas, key personnel responsible for most of the accelerator subsystems have been identified, and are working toward finalizing the detailed design. Further increases in the Project scientific and engineering staff level are expected for the next few years. In addition, the Project management organization has been strengthened by including the areas of environment, safety and health aspects and quality assurance.

On Friday, April 12, the Laboratory held a cerebration to mark the official beginning of the RHIC construction.

V. REFERENCES

[1] Conceptual Design of the Relativisitic Heavy Ion Collider, May 1989, Brookhaven National Laboratory, BNL 52195.