

THE RELATIVISTIC HEAVY ION COLLIDER AT BROOKHAVEN*

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Abstract

An overview of the RHIC project, recent project status, and R&D progress on its superconducting magnets are presented. Also discussed are the current construction and experimental programming plans at RHIC, including a call for letters of intent for experiments.

RHIC Overview

The principal mission of the RHIC project at Brookhaven National Laboratory is to construct a high energy hadron collider dedicated to the physics of relativistic heavy ion collisions. It consists of two intersecting superconducting magnet rings in the existing 3.8 km ring tunnel situated just north of the Alternating Gradient Synchrotron (AGS). Also included in the project is construction of major detector facilities for experiments on heavy ion collisions.

Counter rotating beams stored in these rings intersect at six locations evenly spaced along the ring. Of these, four locations will be assigned to heavy ion collision experiments. Ion species accelerated cover the atomic mass range of 200 (typically represented by gold) to hydrogen. The maximum energies attainable in each ring depend on the e/m ratio of the ion and typically are 100 GeV/u for gold and 250 GeV for hydrogen. The lower end of the energy is envisaged to be about 30 GeV/u limited by the intrabeam scattering which becomes severe with the increasing electric charge of ions. The number of bunches in each ring is 57 initially. The present design calls for a head-on collision of bunches at each experimental insertion. With $\sim 10^9$ gold ion in each bunch, an average luminosity of $\sim 2 \times 10^{26} \text{ cm}^{-2} \text{ sec}^{-1}$ is expected over the luminosity lifetime of 10 hours. In the case of protons greater than 10^{11} particles can be loaded into each bunch, leading to a luminosity $> 1.4 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$. In either case, this is not a hard upper limit of the luminosity.

An operational flexibility derived from having independent rings for two counter rotating beams allows collision of unequal species of ions. Namely, the bending fields of two rings can be adjusted independently according to the momentum of ions of a same velocity but with different e/m ratios. Such

flexibility, as well as an ability to cover a wide energy range, seems to be vital for the understanding of complex heavy ion collision phenomena, particularly that related to the on-set of quark-gluon plasma formation.

The construction of RHIC at BNL is cost effective since there exists an accelerator tunnel enclosure which had been built for CBA and is about 95% complete. There are four experimental areas for detectors, and there is a chain of heavy ion accelerators for injection which consists of the Tandem Van de Graaff, Booster Synchrotron (which will come into operation in 1991), and the AGS. In addition, the existing heavy ion physics program at the AGS can provide a well-developed scientific infrastructure for physics at RHIC.

Present Status

The RHIC project has made significant progress this past year. An initiation of the RHIC construction was included in the Presidential budget proposal to Congress for FY 1991. Needless to say, this budget proposal is based on the continued support of the nuclear physics community as exemplified by the conclusion of the NSAC Long Range Plan Working Group, urging an immediate start of RHIC construction. With Congressional approval, which we believe is of high certainty, construction of the collider can be started in the fall of 1990, with a goal of starting a colliding beam experiment in the spring of 1997.

This budget proposal includes a total estimated construction cost of \$397 M in 6 years. This amount includes \$90 to 100 M for the initial complement of major detectors. In addition, the project will continue to receive funding for accelerator and detector R&D at the level of about \$7 M through FY 1994, and envisages pre-operation funding starting in FY 1995.

The "RHIC Project" organization was estab-

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lished as a new entity within the Laboratory at the beginning of FY 1990 to manage the collider and detector R&D and construction. Under this project organization, a number of task forces are finalizing the details of the accelerator design and preparing for the industrial production of the standard superconducting magnets.

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
β^* (m)	2	2
Luminosity ($\text{cm}^{-2} \text{sec}^{-1}$)	$\sim 2 \times 10^{26}$	1.4×10^{31}
Lifetime (hr)	~ 10	> 10
Beam-beam tune spread/crossing	3×10^{-4}	4×10^{-3}

After intensive studies during the past several years, and with a number of reviews and workshops which evaluated and suggested some improvement, we believe that we have a definitive machine design on hand. Major expected performances of the RHIC collider are given in Table 1. Also developed is a suitable design of superconducting magnets which matches the requirements from the machine.

Anticipating that the construction of RHIC will begin in late 1990 and that collision experiments can start in mid-1997, BNL issued a call for Letters of Intent for experiments at RHIC this past May. The letters are due on September 28, 1990. The purposes of this call are for the Laboratory to receive an early indication of community interest in specific areas of physics research at RHIC and of the manner in which groups in the US and abroad are coming together to form collaborations. The early understanding of the requirements for the four interaction regions and experimental areas is an important function of the letters. They will also help the Laboratory to assess the need for experiment-specific R&D funds and to make decisions regarding the allocation of these funds. The formal call for proposals will be issued soon after the approval of the construction, hopefully in late 1990.

The Fourth RHIC Workshop at BNL on July 2-7, 1990 was attended by 180 enthusiastic physicists from the US and abroad. Seven detector ideas gen-

erated in this Workshop are listed in Table 2. Two TPC ideas and the di-muon detector try to cover a large solid angle as is usually the case for collider detectors. Others, however, focus on limited mid-rapidity region where signals from processes of interest such as a formation of quark-gluon plasma are expected.

RHIC Accelerator Configuration

The overall accelerator configuration of the RHIC facility is shown in Fig. 1. Taking the gold ion as an example, negative ion beams from a pulsed sputter ion source (200 μA , $> 120 \mu\text{sec}$, $Q = -1$) are accelerated by the first stage of the Tandem Van de Graaff, stripped of atomic electrons to $Q \sim +14$ by a foil at the high voltage terminal, and accelerated by the second stage to $\sim 1 \text{ MeV/u}$. The beams are then transported through a 540 m-long transfer line to the Booster without further stripping of atomic electrons. A test performed for the gold beam indicated that $\sim 2 \times 10^{10}$ gold ions can be delivered to the Booster in 120 μsec . After multi-turn injection, beams are grouped into 3 bunches and accelerated to 72 MeV/u. A foil at the Booster exit strips all atomic electrons except for two tightly bound K-shell electrons. The AGS, with its improved vacuum, can accelerate 3 bunches of $Q = +77$ gold ions to 10.4 GeV/u with only a few percent loss. Ions are fully stripped at the exit of the AGS and injected into the RHIC storage rings. Beam stacking is done in box-car fashion by repeating this acceleration cycle 19 times to establish 57 bunches for each ring. The overall filling time of both rings should be about 1 min.

The bunches are captured in stationary buckets of the so-called acceleration rf system operating at $\sim 26.7 \text{ MHz}$, corresponding to a harmonic $h = 57 \times 6$. With the exception of protons, all ion species must be accelerated through the transition energy. After reaching the operating beam energy

Table 2. Detector Ideas for RHIC

Focussing Axial Spectrometer
<i>Willis, Lissauer, Nagamiya et al.</i>
Two-Arm Spectrometer
<i>Hayano, Tannenbaum et al.</i>
Solenoidal TPC Spectrometer
<i>LBL/Purdue/Frankfurt/Max Plank et al.</i>
Full Solid Angle Dipole TPC Spectrometer
<i>Lindenbaum et al.</i>
4-Coil Superconducting Toroid Spectrometer
<i>Braun-Munzinger et al.</i>
Full Azimuth Modular Spectrometer
<i>Busza et al.</i>
Di-Muon Detector
<i>Young, Aronson et al.</i>

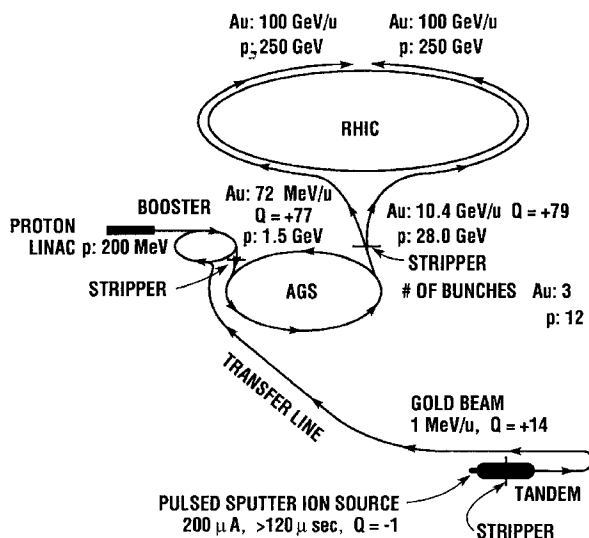


Fig. 1. Overall configuration of accelerator complex for RHIC. An accelerator chain which consists of Tandem Van de Graaff, the Booster Synchrotron, and the AGS serves as the injector to the RHIC collider.

in the range 30 to 100 GeV/u (which takes about 1 min), the bunches are transferred to the so-called storage rf at 160 MHz ($h = 57 \times 6 \times 6$). This 6 times higher frequency was chosen to limit the growth of the bunch length due to intrabeam scatterings to ~ 31 cm (or collision diamond rms length ~ 22 cm).

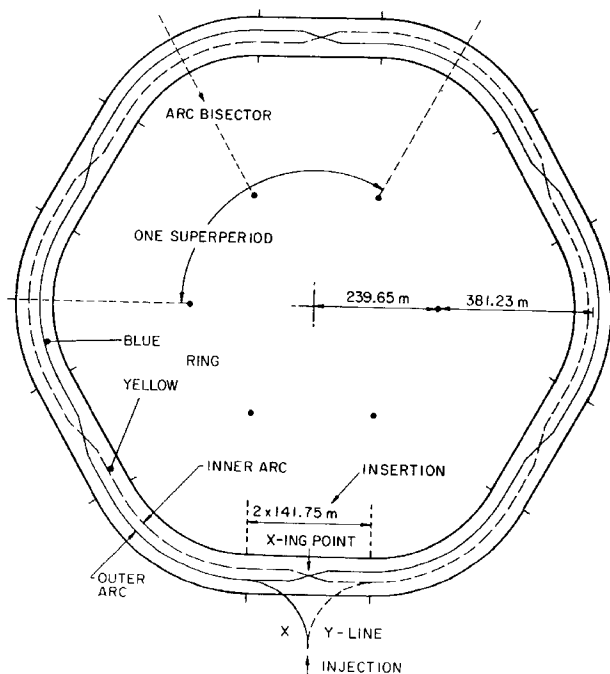


Fig. 2. Layout of the RHIC collider.

A general layout of the collider is shown in Fig. 2. It is composed of two identical, quasi-circular concentric rings (3.8 km in circumference) in a common horizontal plane, oriented to intersect with one another at 6 locations along the ring. Having 3-fold symmetry, each ring consists of three inner and three outer arcs (each ~ 355.5 m long) and six insertions (each 283.5 m long) joining the inner and outer arcs. Each arc is composed of 24 half cells each with a 9.46 m long dipole, a 1.13-m long quadrupole, a 0.75 m-long sextupole, and a 0.58-m long corrector assembly, all being superconducting magnets. The arc magnets have an 80-mm coil inner diameter to provide enough aperture for enlarged beam emittance caused by intrabeam scattering. The spacing of the two beams in the arc section is 90 cm. The experimental insertion (Fig. 3) has two dipoles (beam manipulation) for head-on collisions on each side of the collision point.

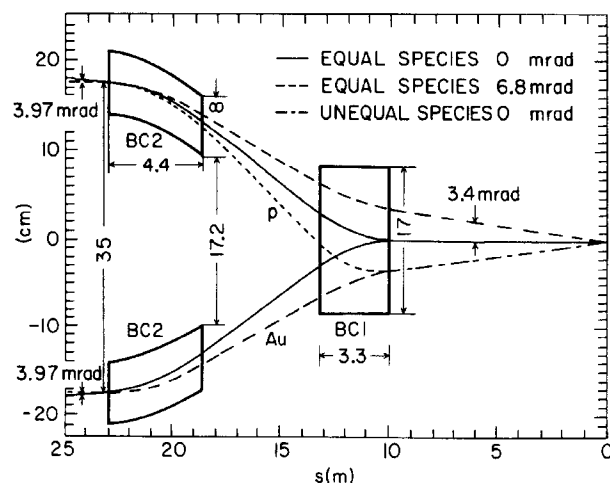


Fig. 3. Layout of one half of the experimental insertions. Two dipole magnets closest to the intersection point (BC1 and BC2) manipulate the beam to achieve head on collisions.

RHIC Superconducting Magnet R&D

An intensive research and development program on superconducting magnets has been carried out over the last several years. Having a requirement of relatively modest dipole field strength of 3.45 T, the dipole magnet as shown in Fig. 4 has a simple one-layer $\cos\theta$ coil design with low carbon yoke iron lamination, acting also as the collar. A high-precision injection-molded mineral-loaded phenolic (RX 630) is used as the insulator and spacer between the coil assembly and the iron yoke lamination. The eight R&D magnets which have been tested to date (Fig. 5) show that all magnets exceeded the field strength required for RHIC, the most recent units having as much as $\sim 30\%$ margin. The field quality measurement of the most recent 4 dipoles gave (1) random

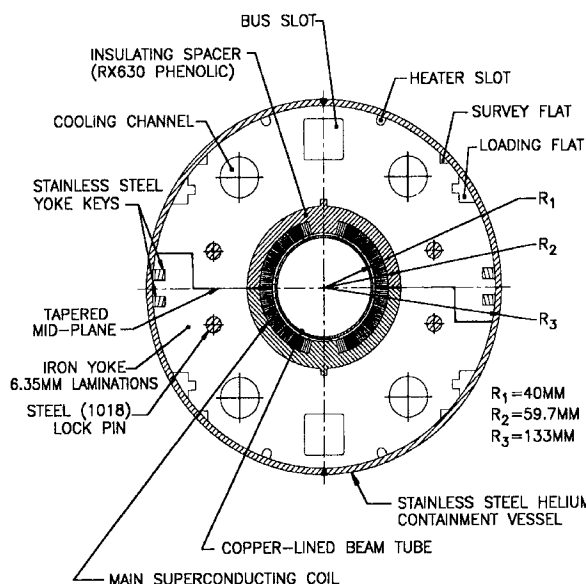


Fig. 4. Cross section of RHIC arc dipole magnet.

variations in all multi-pole terms much smaller than the tolerances required; (2) average values of all un-allowed multipole terms and of the b_6 term, which are within systematic tolerances; and (3) average values of b_2 and b_4 , which are small enough to be easily adjusted in an iteration of coil cross section in the industrial process.

Two R&D units of quadrupole-sextupole-corrector assemblies were also built and tested. An assembly consists of a quadrupole with a construction

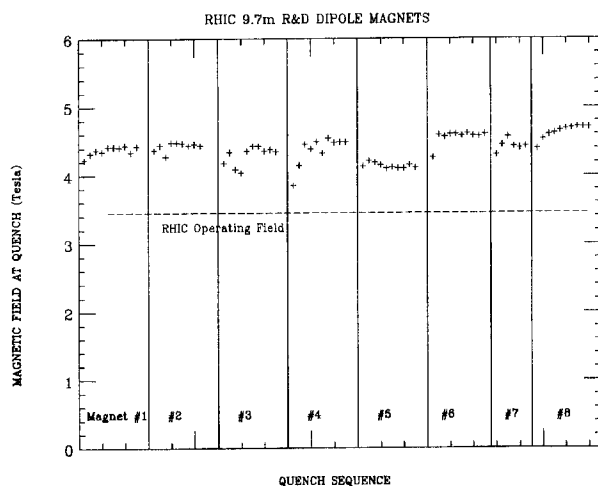


Fig. 5. The quench performance of 8 RHIC dipole R&D units. In all cases, the first quench exceeded the operating magnetic field of RHIC. The latest prototype unit demonstrated that there is about 30% of margin in the field strength.

similar to the dipole but with 4 poles, a sextupole with superconducting wire coils and a corrector assembly with multiple concentric cylinders of 4 different multipole correction windings. The results showed that magnetic elements all meet the RHIC requirements with a 50 to 100% margin.

Expected Performance of RHIC

The design luminosity for the collisions of various species of ions as a function of collision energy over the RHIC collider energy range is shown in Fig. 6. On the right-hand scale, the frequency of central collisions corresponding to an impact parameter <1 Fermi is indicated. Also shown is the energy range covered by the RHIC collider accessible with a

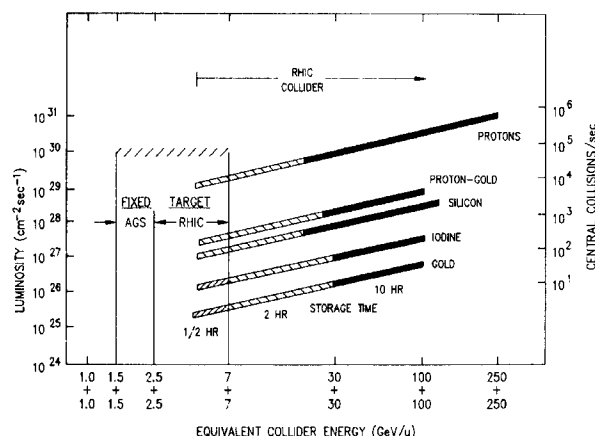


Fig. 6. The design luminosity for various ion masses as a function of collision energy. Also shown is the range of energy accessible with the AGS and RHIC in a fixed target mode of operation.

shorter luminosity lifetime and by fixed-target experiment by RHIC and AGS. Also shown is the expected performance for proton-on-gold which represents the most extreme case of non-equal species collision.

Conclusions

The plan to build the RHIC has made significant steps forward during the past year, and has come to a point of anticipating an authorization to start construction during FY 1991. The design of the accelerator is currently being finalized. The results of R&D have shown that quality superconducting magnets which meet the RHIC requirement can be manufactured with a comfortable margin. If authorized and the proposed 6-year funding schedule is sustained, colliding beam experiments can be started in mid 1997. The time is ripe for RHIC and for exciting physics at this unique collider dedicated to heavy ion collisions.

DISCUSSION

Q. C. Fabjan (CERN): Could you, please, comment on possibilities to increase the luminosity, particularly for ion-ion collisions?

A. S. Ozaki: There are three areas to work on to achieve higher luminosity. The first is to increase the number of bunches per beam from 57 to 114, possibly to 171. The second is to develop a method of stochastic cooling of bunched beam to cool the bunch size growth from intrabeam scattering, allowing more ions per bunch. The third is to employ a pair of mini-beta quadrupole to electron beta-function of the collision point. We can foresee an order of magnitude increase in future.