THE RHIC PROJECT – STATUS AND PLANS[*]

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Abstract

The Relativistic Heavy Ion Collider (RHIC) Project is in the 4th year of an estimated 8 year construction cycle at Brookhaven National Laboratory. The accelerator complex is designed to collide a variety of ion species at center-of-mass energies up to 100 GeV/nucleon in a two ring superconducting structure. Industrial magnet production is in progress as well as the other accelerator systems. This presentation will outline the status of the construction effort, near and long term goals.

I. INTRODUCTION

The overriding motivation for colliding heavy ions at ultra-relativistic energies is the belief that it is possible to create macroscopic volumes of nuclear matter as such extreme conditions of temperature and energy density that a phase transition will occur from hadronic matter to a confined plasma of quarks and gluons.

The performance objectives of a heavy ion collider were originally formulated in 1983 by a Task Force for Relativistic Heavy Ion Physics [1]. The main goal is collisions at energies up to 100 GeV/u per beam for very heavy ions, which for the RHIC project is defined to be gold $(^{197}\mathrm{Au}^{79})$, but the program outlined also called for lighter ions all the way down to protons. Luminosity requirements for the heaviest ions were specified to be in the 10^{26-27} cm^{-2}s^{-1} range. The higher Au-Au total cross-section results in interaction rates comparable to p-p colliders although this luminosity is several orders of magnitude lower than those machines. A short interaction point length (<20 cm rms) is desirable for optimum detector design. The final, though most influential, experiment requirement was the need for collisions of different ion species (most notably p-Au) at the same center of mass energies per nucleon. This necessitates accommodating charge to mass ratios (A/Z) in the range of 1 (p) to 2.6 (Au). Stabilizing the collision point involves equalizing the rotation frequencies of the two beams which in turn requires the two rings to operate at different magnetic fields. The complications in the interaction region where the beams must pass through common magnets dictate a lattice design different from conventional hadron colliders.

Based on these general requirements the detailed RHIC machine parameters were derived and are outlined in Table 1. Operation of the RHIC collider at relatively low energies together with the enhanced intrabeam scattering, which scales as Z^4/A^2, result in beam of large transverse and longitudinal dimensions. This in turn has ramifications for the lattice (short cells, strong focusing), and magnet aperture. The rf system requirements are also determined by this consideration and the short interaction point. Colliders unlike fixed target machines, are designed to operate for extended periods at high energies. The economics of power consumption argue strongly for superconducting magnets and RHIC is a superconducting machine.

Table 1: Major Parameters for the Collider

Kinetic Ener.,Inj.-Top(each beam),Au	10.8-100	GeV/u
protons	28.3-250	GeV
No. of bunches/ring	57	
Circumference, 4-3/4 C$_{\mathrm{AGS}}$	3833.845	m
Beam separation in arcs	90	cm
Number of crossing points	6	
Free space at crossing points	±9	m
Beta @ crossing,horiz./vert.	10	m
low-beta insertion	1	m
Betatron tune, horiz./vert.	28.18,29.18	
Transition Energy, γ_T	23.60	
Magnetic rigidity,Bρ:@inj.	97.5	T·m
@top energy	839.5	T·m
Bending radius, arc dipole	242.781	m
No. dipoles (192/ring+12common)	396	
No. quadrupoles(276arc+216inser)	492	
Dipole field@100 GeV/u,Au	3.45	T
Arc dipole length, effective	9.45	m
Dipole current	5	kA
Arc quadrupole gradient	71.2	T·m
Arc quadrupole length, effective	1.11	m
Coil i.d. arc magnets	8	cm
Beam tube i.d.	6.9	cm
Operat. temp., He refrigerant	<4.6	K
Refrigeration capacity @ 4 K	24.8	kW
Vacuum, warm beam tube sections	5×10^{-10}	Torr
Beam stored energy	200	kJ
rf voltage, h=342	600	kV
rf voltage, h=2508	6	MV
Acceleration time	80	sec

II. MACHINE LAYOUT AND LATTICE

The complete RHIC facility will be a complex set of accelerators interconnected by beam transfer lines. The RHIC rings are shown schematically in figure 1. It is comprised of two identical, quasi-circular rings separated horizontally by 90 cm, and oriented to intersect with one another at six locations. Having 3-fold symmetry each ring consists of three inner and three outer arcs and six insertion regions joining the inner and outer arcs. Each arc consists of 11 FODO cells with each half cell consisting of a single dipole together with a spool piece assembly containing a quadrupole, sextupole and concentric correction elements. The nominal design magnetic rigidity of the dipoles if 840 T·m which corresponds to a design field of ~ 3.5 T at 100 GeV/u. Injection takes place at 100 T·m. The dipole coil i.d. of 8 cm is determined by the beam size at injection. The quadrupoles run at

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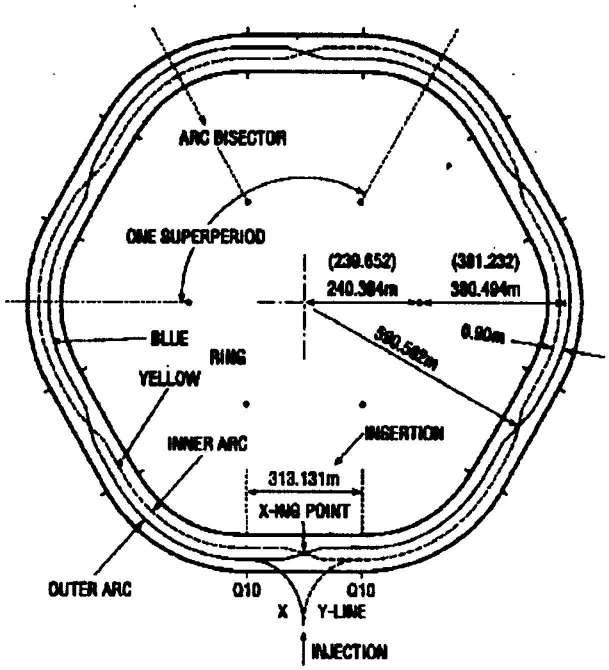

Figure. 1. Layout of the collider and in parenthesis of the tunnel.

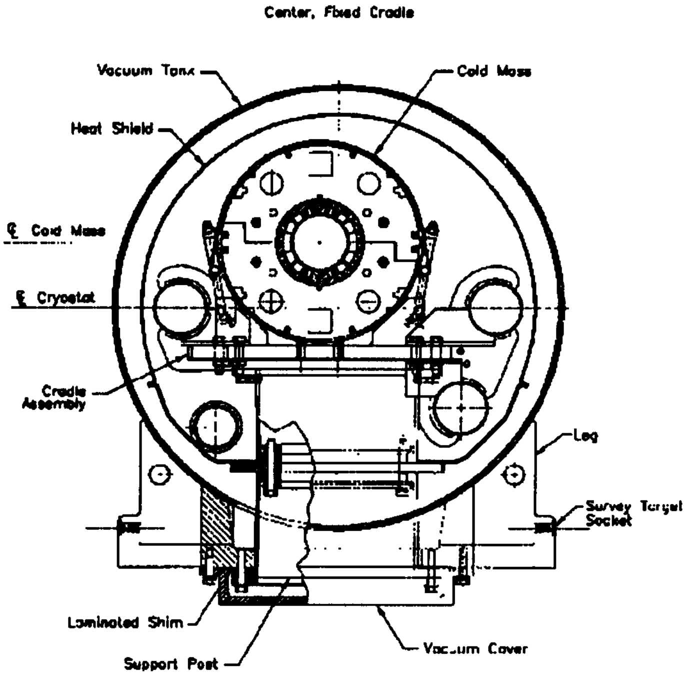

Figure. 2. Arc dipole with cryostat cross section.

a maximum gradient of 72 T·m and also have a coil i.d. of 8 cm. A cross-section of a dipole is shown in figure 2. The magnets are conceptually similar to the HERA dipoles with a 'cold-iron' design and cryogenic transfer lines located in the cryostat. Each dipole is 10.45m long.

Collisions of the beams take place at the crossing point of the insertions. These regions contain the optics necessary for producing a small betatron amplitude function β^*, zero dispersion at the crossing point, and the bending magnets to bring the beams into head-on collisions. The 'non-arc' regions also contain the only warm regions of the machine where the machine utilities reside such as injection, beam abort, rf, collimators and specialized instrumentation. Locations available for these other devices are the 35m between Q3 and Q4, the missing dipole between Q7 and Q8, and the region adjacent to the short D9 dipole. The layout of an insertion, connecting the standard cells to the interaction point, is shown in figure 3. The magnetic elements in the Q10→Q4 region are identical in cross-section to the standard cell but with various lengths. The final focus triplet (Q1, Q2 & Q3), and bending magnets (D0 & DX) are non standard magnets with apertures of 13cm, 10cm and 18cm respectively. The focusing is relaxed at injection with a β^* value of 10m. During collisions at top energy a β^* of 1m can be attained resulting a betamax of 1400m in the triplet quadrupoles. The lattice functions in the IR's are shown in figure 4, for both injection and collisions.

III. COLLIDER PERFORMANCE AND LUMINOSITY LIFETIME

The nominal RHIC bunch parameters range from Au (10^9 ppb, 10πmm-mrad) to proton (10^{11} ppb, 20πmm-mrad) which together with 57 bunches in each ring and a β^* of 2m result in initial luminosities for various ion species as shown in figure 5. The initial luminosity increases with the lighter ion species since the ion source maintains the electric charge ($N_b Z$) per bunch roughly constant. In contrast to hadron colliders the beam-beam tune shift is relatively small ($\sim$ 0.012 maximum) and does not limit the performance.

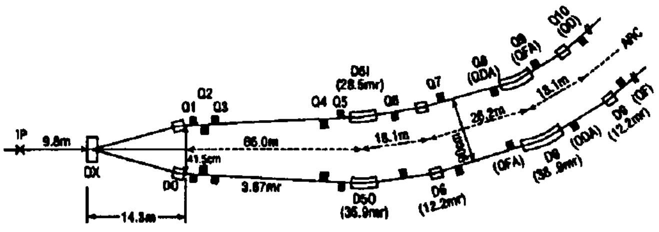

Figure. 3. Expanded layout of RHIC half insertion.

Limitations on the average luminosity arise from several effects. As previously mentioned intrabeam scattering growth rates scale as Z^4/A^2 which results in growth times for Au ions an order of magnitude larger than those for protons even though the bunch intensity is two orders of magnitude lower. This effect has been extensively studied in the RHIC scenario [2,3] and the calculations show some quite dramatic effects. Figure 6 shows the estimated longitudinal growth as a function of time during a store. The beam expands to fill the available bucket area during the first two hours and then starts to fall out of the bucket. During the nominal 10 hour store, 40% of the circulating beam is estimated to be lost due to this effect. In addition, transverse emittance growth will also occur with an increase from $10 \rightarrow 40\pi$mm-mrad expected. The initial luminosity lifetime is thus relatively short, 0.9 hr, rising to 11.1 hr by the end of 10

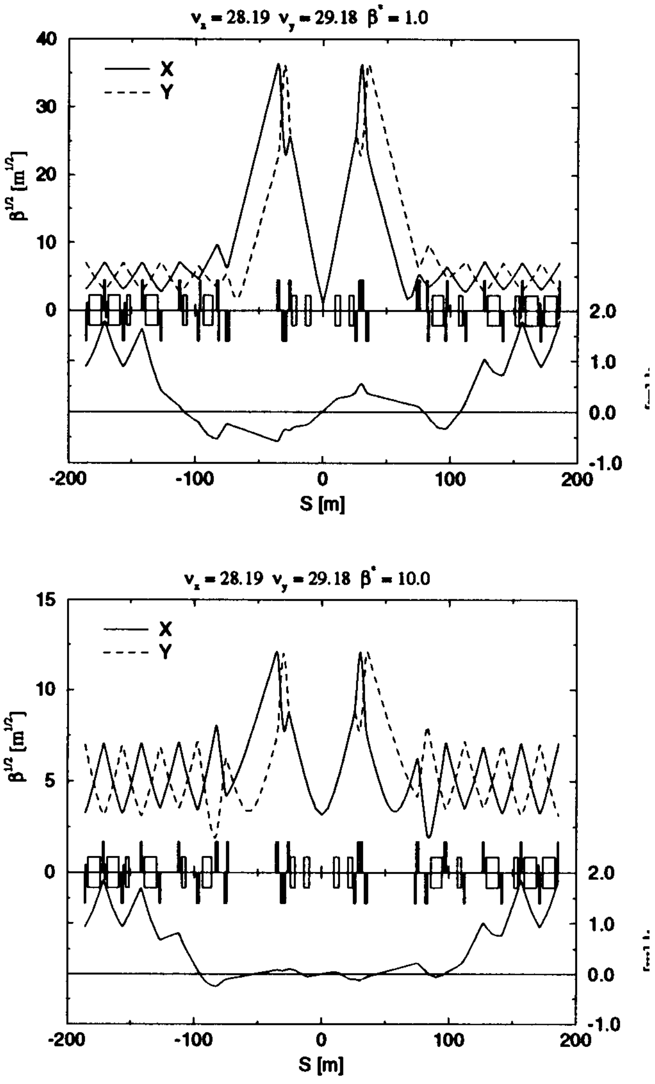

Figure. 4. Betatron and dispersion functions in the insertion region.

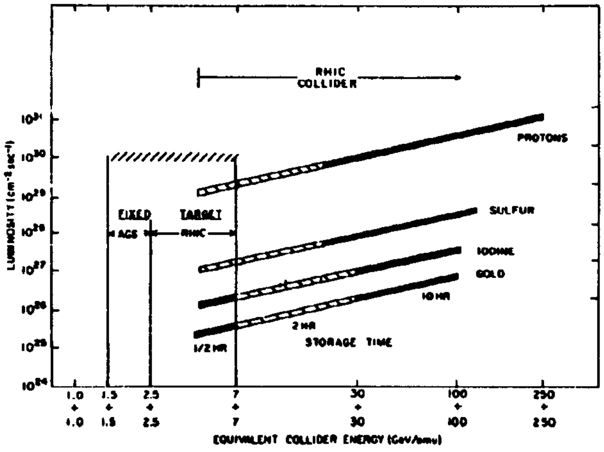

Figure. 5. The initial luminosity, for various ion species, as a function of collision energy over the full range accessible with RHIC.

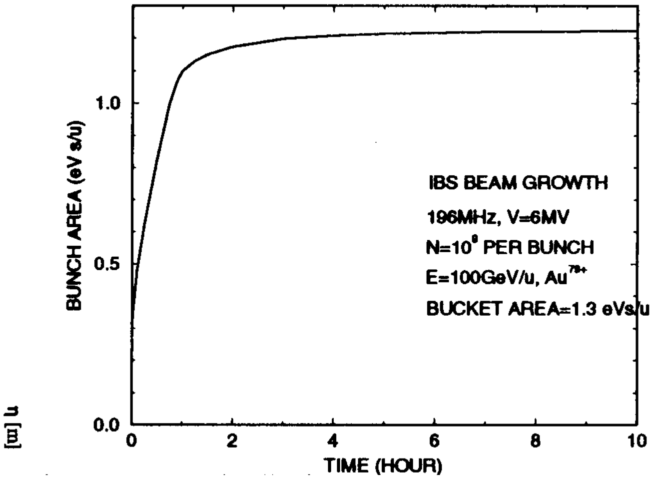

Figure. 6. Longitudinal and transverse emittance growth from IBS v's time in the store.

hours. Significant beam losses are also expected to provide enhanced background rates for the detectors which will require the protection of remote collimation devices. The large transverse emittances also have dynamic aperture implications in the triplet quadrupoles and have been used to define the desired field quality specifications in these elements.

In addition to IBS, significant beam depletion is also expected from the interactions at the crossing point from electro-magnetic interactions. The Lorentz contracted Coulomb field of the Au ions is sufficiently intense to produce large numbers of electron pairs (estimated cross-section 33,000 barns!) as the bunches pass through each other. These are relatively low energy electrons (a few 10's of KeV kinetic) so that pair production itself does not adversely affect the beam. Within this electron cloud however, an ion can capture an electron and change it's charge state by one. These particles will then be lost during the next several turns. Coulomb dissociation is also significant with the ions breaking up into several lighter fragments. Particle depletion cross sections from these effects (and the much smaller rate of nuclear interactions) have been estimated [4] to be 250 barns per high luminosity IR. The reduction in integrated luminosity during 10 hours arising from particle depletion is 15% but becomes more significant for higher luminosity upgrade scenarios.

Compared to proton colliders the beam-gas cross section for Au ions is large (7 barns) which results in a stringent specification on the ring wide average beam tube vacuum in the warm regions of the machine of 5×10^{-10} torr.

IV. COLLIDER STATUS & PLANS

The main focus of the construction project to this point in time has been the magnet program. RHIC will use both in-house and industrially made superconducting magnets. The dipole magnets are currently under fabrication at Northop-Grumman Industries and the program is well underway with over 100 magnets delivered, accepted and installed on stands in the tunnel. Cold testing has been performed on 40 of these magnets so far and the initial and plateau quench data is shown in figure 7. The magnets exhibit a healthy 30% operating margin and none of the magnets tests to date has quenched below the nominal operating current of 5kA. The field quality has been measured for all dipoles (either warm, cold or both) and is summarized in figure 8 which shows $\Delta B/B$ v's offset for a subset of magnets. The dashed curves show the range of nominal field quality used in the machine simulations. The magnet ensemble lies comfortably inside these values. In addition to the dipoles, 30% of the quadrupoles are at hand (Northrop-Grumman) and show a greater operating margin than the dipoles. Sextupole and trim quadrupole production (Everson Industries) is complete with the majority of elements achieving short sample under cold testing. Magnets produced in house include the nested correction elements (40% complete) and the triplet quadrupoles (66% complete). The remaining magnetic elements for the ring are the splitting dipoles in the IR regions. Of the 2 kinds of magnets, the 10 cm dipole is in mechanical design, the 18 cm one is still in magnetic design.

The AGS to RHIC transfer line(s) is 600m long and requires a total of 143 conventional magnets. This system is complete, installed and has been under vacuum. Cable termination and power supply testing is presently in progress. The transfer line will require the first operation of the RHIC control system.

In addition to installation effort in the transfer line, activities are underway in the main tunnel enclosure. The infrastructure is complete in the arc sections with magnet stands, cable tray, and survey grid in place. Interfacing the superconducting dipoles to the corrector-quadrupole-sextupole assemblies in the arc sections is just getting underway and will represent the major effort for the foreseeable future. The interaction region magnets will be the final elements to be installed. The cryogenic system is supplied from a single large refrigerator (24 kW at 4K) which is available now. Transfer line connections to the tunnel and above ground feeds (valve boxes) will be delivered over a 30 month period which started in March 1995.

The short term schedule is defined primarily by two integrated system tests. The first involves extracting beam from the AGS and transporting it down the transfer line to an internal beam dump and is scheduled for the fall of 1995. This test will validate the AGS single turn extraction system and allow a detailed measurement of the beam and lattice parameters of the incoming RHIC beam. New controls, personnel safety, vacuum and instrumentation systems will be commissioned for this activity. Twelve months later the sextant test will extend this beam transport to include the full injection line and 1/6 of the superconducting ring. This test will represent the first test of the sub-systems associated with the rings: cryogenics, vacuum, power supplies, instrumentation, and controls. The start of full machine commissioning is presently estimated for the beginning of 1999 with partial ring cooldown starting several months earlier.

V. CONCLUSIONS

With the overall machine design stable the RHIC Project is well into the superconducting magnet production program. The magnet quality to date is good and production is achieving the requisite rate. About one quarter of the magnets are in place in the ring enclosure and magnet interfacing is getting underway. In addition to the magnet activities the injection line between the AGS and RHIC is largely complete, and installation of the initial elements of the cryogenic distribution system has started. The medium term schedule is focused around two integrated system

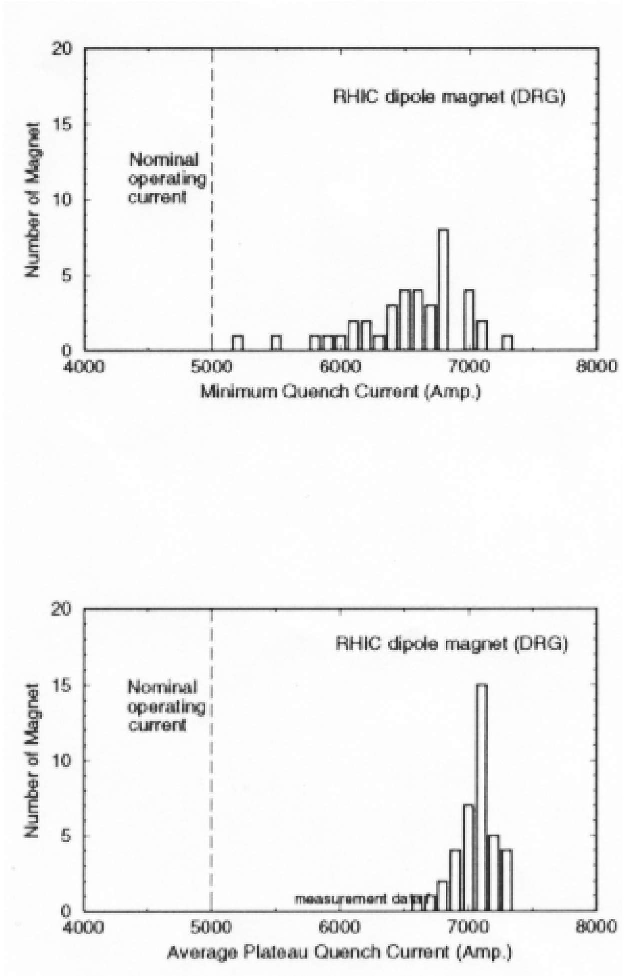

Figure. 7. Initial and plateau quench data.

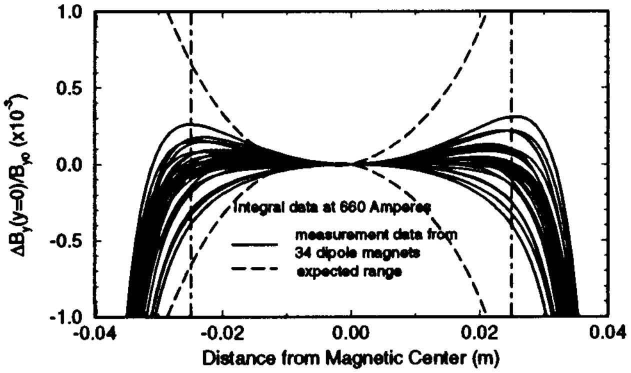

Figure. 8. Field quality.

tests. The first involves extracting beam from the AGS and transporting it down the injection line to the ring enclosure. This is scheduled to take place during the Fall of 1995. The following year a similar test involving beam transport through a full machine sextant will permit early operation of the major machine systems in a realistic operating environment. Start of beam commissioning for the Collider is set for the beginning of 1999.

References

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