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Status of the Relativistic Heavy Ion Collider

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1. Abstract

At the present time, commissioning of the 3.8 kilometer Relativistic Heavy Ion Collider (RHIC) is in full swing. On July 16, 1999, the commissioners were successful in circulating a Gold Ion Beam for the first time, in the Blue Ring, as power supplies were being checked out for beam into the Yellow Ring. The commissioning schedule is to accelerate beam in the Blue Ring, then spiral and accelerate beam in the Yellow Ring, then if all goes well, obtain some collisions, all before a fast approaching shutdown in mid-August. The four experimental regions, Star, Phenix, Brahms and Phobos are gearing up for their maiden beam runs and much effort is being spent to make the first glimpse of the beam an exciting one. Our Alignment Group has been working closely with the experimenters in these areas, mostly with MANCAT type component pre-surveys and in the near future installing and locating these various components relative to the RHIC Beam Line.

2 Machine History

High energy and nuclear physicists from around the world explore the basic structure of matter using the Alternating Gradient Synchrotron (AGS). At 40 years of age, the AGS stands the test of time and endurance as a world class machine. With the addition of the Booster Accelerator (1991), and tie in to the Tandem Van de Graaff, the AGS can accelerate protons to 33 billion electron volts (GeV), polarized protons to 22 GeV and heavy ions up to 14.6 GeV/nucleon. The AGS, in its new role as RHIC injector, will secure for itself an exclusive place in the setup of Nuclear and High Energy Physics at BNL.

The completed RHIC facility is a complex set of accelerators and beam transfer equipment connecting them. A significant portion of the total facility either exists or is under construction. Figure 1 is a site plan showing all the major components. The two existing Tandem Van de Graaff accelerators will serve for the initial ion acceleration. Exiting from the Van de Graaff, the ions will traverse 0.8 kilometers along the Heavy Ion Transfer Line (HITL) to the Booster synchrotron.

The Booster is located between the existing 200 MeV proton LINAC and the northwest quadrant of the AGS (see Fig. 1), its circumference being one quarter that of the AGS. Beam from the Van de Graaff will be injected into the booster and stacked in betatron phase space by filling the machine with about 8 consecutive turns. Each particle bunch train transferred from the Booster to the AGS is accelerated to the top AGS energy (28.1 GeV for protons; 10.4 GeV/u for gold) and is stripped of their K-shell electrons and transferred to the collider by a magnet system installed in the existing transfer line tunnels. A total of 57 bunches are injected into each

ring in boxcar fashion. Filling time per ring will be about 1 minute. The circumference of the collider is 3833.8 meters.

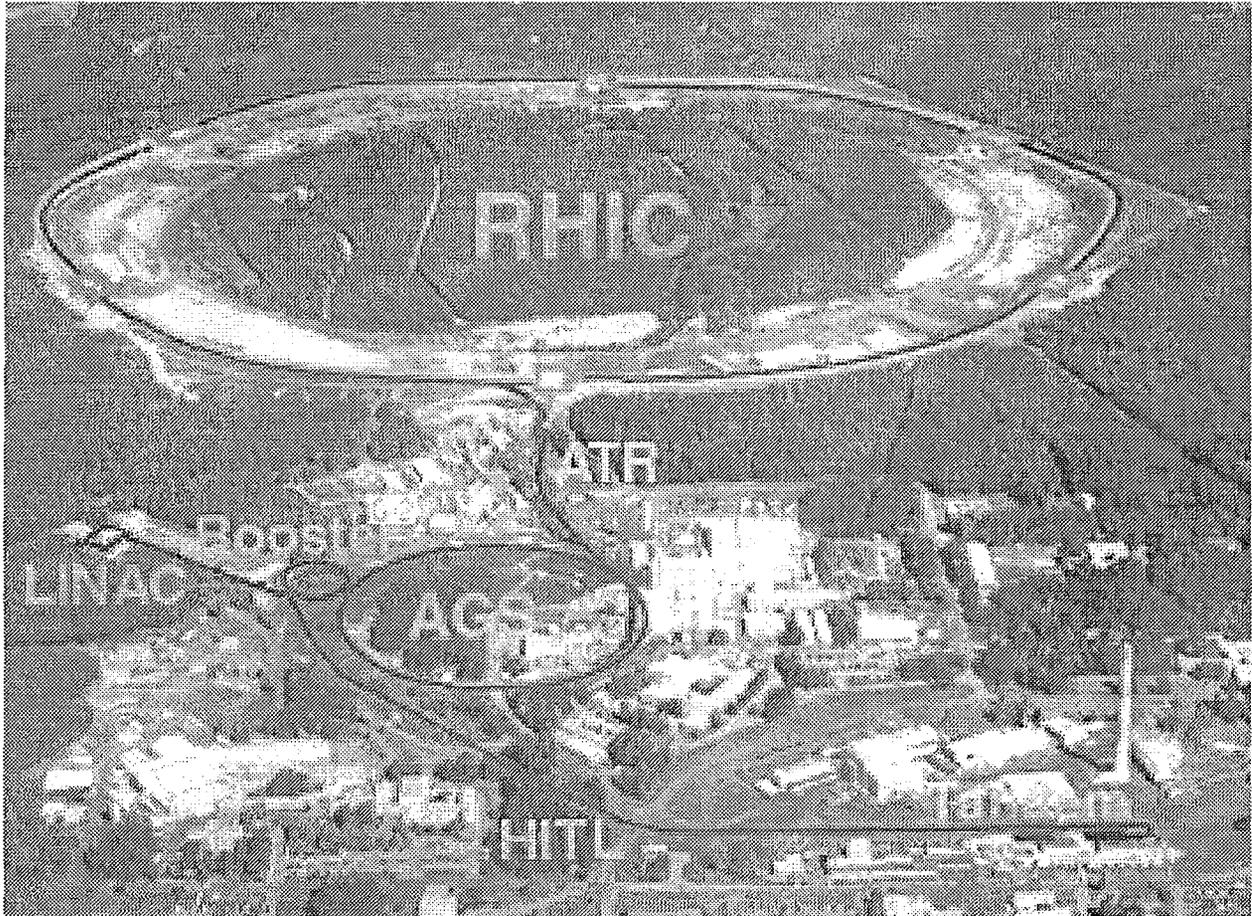


FIGURE 1

Bending and focusing of the ion beams is achieved with super conducting magnets, the maximum energy is about 100 GeV/u for gold and 250 GeV for protons. Maximum operational flexibility is obtained with single-layer cosign θ magnets, which are in separate vacuum vessels. The beams in the arcs will be 90 cm apart. The cold bore beam aperture was chosen to be 73 mm in diameter.

It will be possible to produce head-on collisions as well as crossings at angles up to 7 mrad. The free space available for experimental equipment around the intersecting points is about 9 meters. The RHIC lattice configuration allows for six beam interaction points, four of which are slated for detectors Star, Phoenix, Phobos and Brahms, all of which are awaiting beam collisions from our newest accelerator.

The AGS Survey and Alignment Group was given the task of aligning the components for Relativistic Heavy Ion Collider (RHIC) in 1991. The site of the RHIC Machine was



established in 1979 when ground was broken for what was to be the ISAbelle Accelerator. Facility construction was completed in 1984, but due to budget cuts and magnet construction problems, the project was canceled. Designers kept improving magnet concepts and interest was mounting in the Nuclear Physics community for a machine that could explore what was happening in our universe immediately after the big bang. With the conventional facility completed RHIC became a reality and from 1991 to the present time we have been building this machine. (1)

The survey effort was undertaken in a conventional fashion. There were twelve penetrations installed through the corrugated tunnel and dirt shielding, above which were placed towers that had visibility to a near machine center monument (via a 75 foot high tower) and its two nearest neighbor monuments. A trilateration survey was performed using the Leica ME5000 for our measuring tool. With a good set of primary monuments in hand we densified the remainder of the tunnel with floor monuments set approximately 1 meter off of the center line of each magnet cryostat. This left us enough room to set up our equipment and allowed for construction traffic to get by for installation of various equipment and components. We densified these monuments with trilateration and a braced quadrilateral scheme that yielded values that met our error budgets. Our error budgets were established by reviewing the tolerance set forth by the RHIC Design Manual listed below.

3 Tolerance

Magnet Position Tolerances at 4 K

Beam Position Monitor - Reference Orbit¹

$$\Delta x = \Delta y = 0.25 \text{ mm rms}$$

Sextupole - Beam Position Monitor

$$\Delta x = \Delta y = 0.13 \text{ mm rms}$$

This tolerance refers to the magnetic center of the sextupole relative to the center of the BPM, all along the axis of the sextupole.

Quadrupole - Beam Position Monitor

$$\Delta x = \Delta y = 0.25 \text{ mm rms}$$

This tolerance refers to the magnetic center of the quadrupole relative to the center of the BPM, all along the axis of the quadrupole.

Dipole - Reference Orbit

$$|\Delta x = \Delta y = 0.50 \text{ mm rms}$$

Tolerance refers to the magnetic center as given by fiducial marks of the dipole relative to the reference orbit all along the axis of the dipole. The dipole magnetic center is defined as the magnetic center of its magnetization sextupole.

Dipole Rotation

$$\Delta\theta = 1 \text{ mrad rms}$$

The average horizontal component of the dipole magnetic field is to be less than 0.001 rms of the vertical component of the field.

Quadrupole Rotation

$$\Delta\theta = 1 \text{ mrad rms}$$

Longitudinal Error

$$\Delta s = 1.0 \text{ mm rms}$$

Refers to longitudinal position of all magnets with respect to their ideal position along the reference orbit.

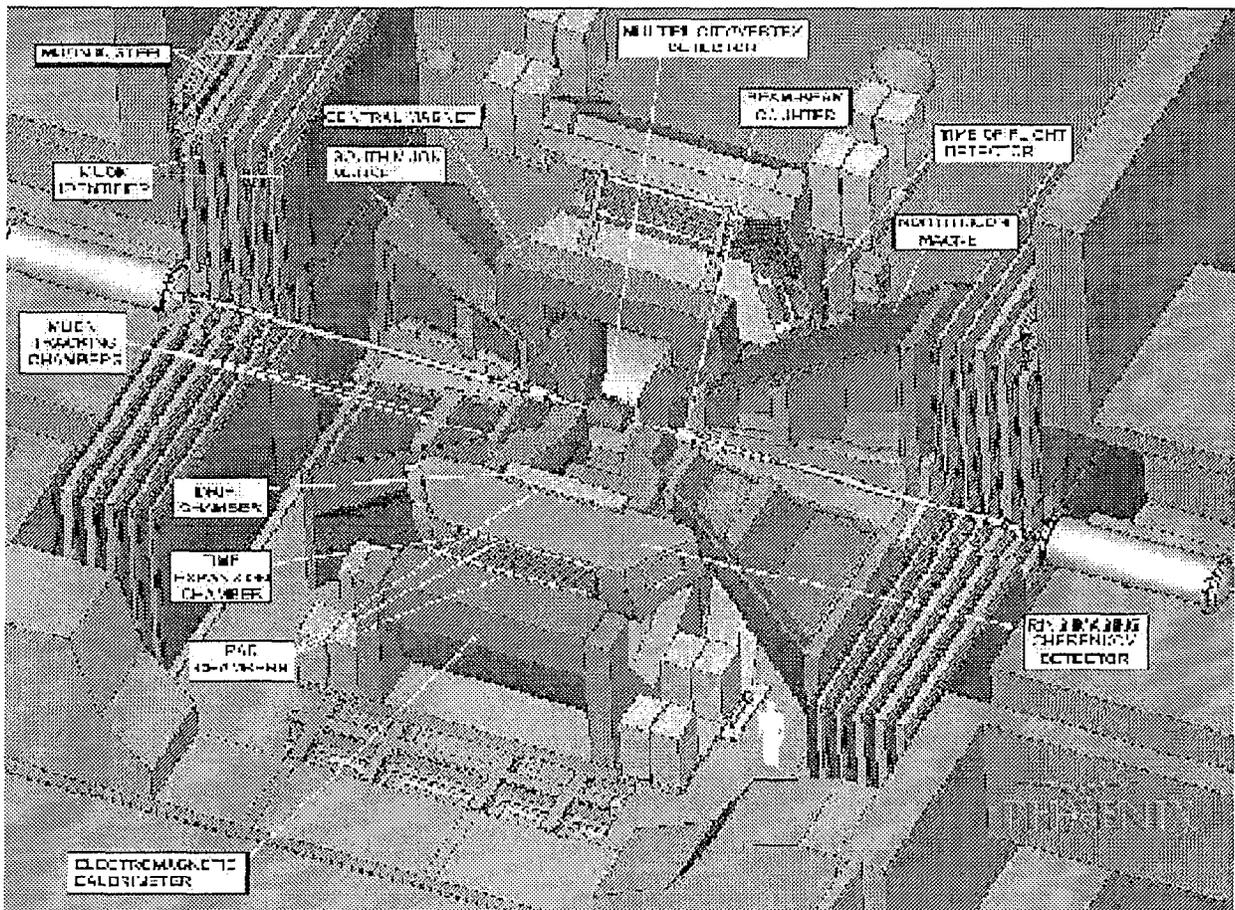
Long Term Position Stability

¹Reference orbit positions are based upon tunnel net and primary monument measurements.

Magnet pre-surveys were done on each magnet. Dipoles were installed in their cryostat off site, so that when they arrived at BNL their coldmass and cryostat relative position could be established. Our combined function CQS magnets, corrector, quadrupole and sextuple, were cryostated on site and each was measured for various characteristics. This was accomplished using our MANCAT System purchased from Leica. Either an antenna measurement or colloidal solution was passed through a CQS so that the magnetic characteristics could be tied to the reference file and used by the accelerator physicist to establish the acceptability as well as the position to set the magnet in the tunnel. These values were then given back to the alignment group to set the magnet in the tunnel.

4 Experiments Pre-survey

By far the most interesting aspect of the alignment efforts of RHIC have been the four experiments, PHENIX, STAR, PHOBOS and BRAHMS. They have presented the alignment group with many challenges in the past and I am sure many future requests will be just as demanding and rewarding as they are met.



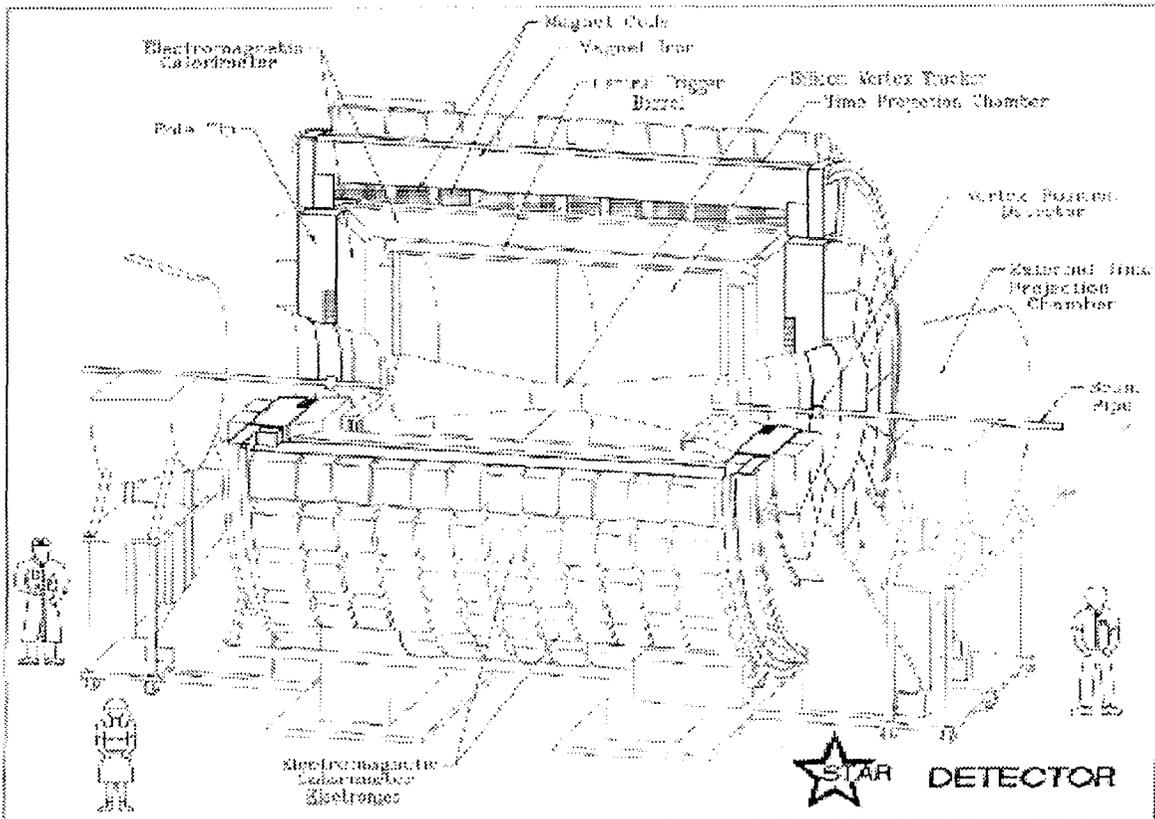
PHENIX DETECTOR

4a) The PHENIX detector will look for many different particles emerging from RHIC collisions, including photons, electrons, muons and quark-containing particles called hadrons. To do so, it will use large steel magnets that surround the area where RHIC collisions will take place.

Photons (particles of light) and leptons (electrons and muons) are not affected by the strong force, which binds quarks and gluons together into hadrons. Because they can emerge from the interior of a RHIC collision unchanged, photons and leptons can carry information about processes or action within the collision. By concentrating on them, PHENIX will be able to "gaze" inside the collision and gain insight into its internal structure. For example, escaping photons can reveal information about temperature.

Physically, at 3,000 tons, PHENIX has over 450 members from 45 institutions in 10 countries. PHENIX is located at the 8 o'clock position on the RHIC ring.

4b) RHIC STAR will specialize in tracking the thousands of particles that will be produced by each RHIC collision. As big as a house, STAR will search for signatures of the form of matter that RHIC aims to create: the quark-gluon plasma. It will also investigate the behavior of matter at high energy density by making measurements over a large area.



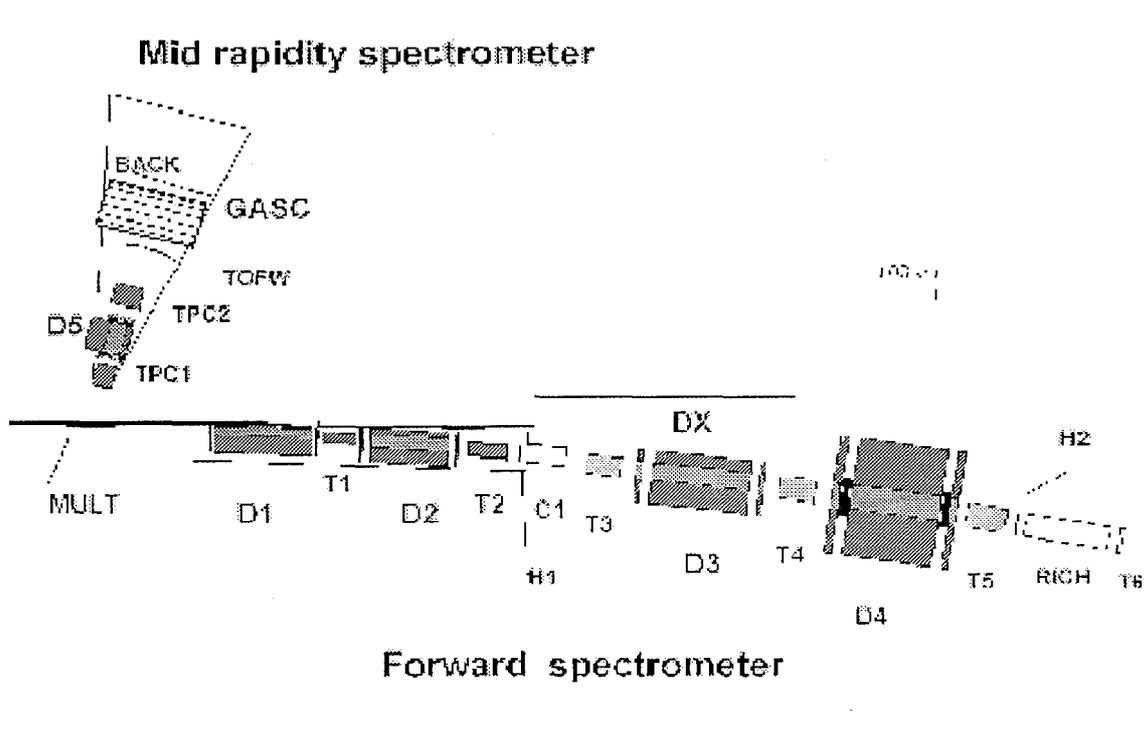
STAR DETECTOR

STAR's "heart" is the Time Projection Chamber (TPC), made of many electronic systems, which will track and identify particles. As each collision occurs, STAR will measure many parameters simultaneously to look for signs of the quark-gluon plasma. It will "run time backwards," reconstructing thousands of bits of information from thousands of events per second.

The goal of STAR is to obtain a fundamental understanding of the microscopic structure of interactions between particles called hadrons, which are made of quarks and gluons. The process might be compared to examining the many different products which come out of a factory and trying to figure out what kind of machinery produced them.

The STAR team is composed of over 400 scientists and engineers from 33 institutions in 7 countries. STAR is located at the 6 o'clock position on the RHIC ring.

4c) Brahms Experiment is one of RHIC's two smaller detectors is the BRAHMS experiment. This device will study particles called charged hadrons as they pass through detectors called spectrometers.

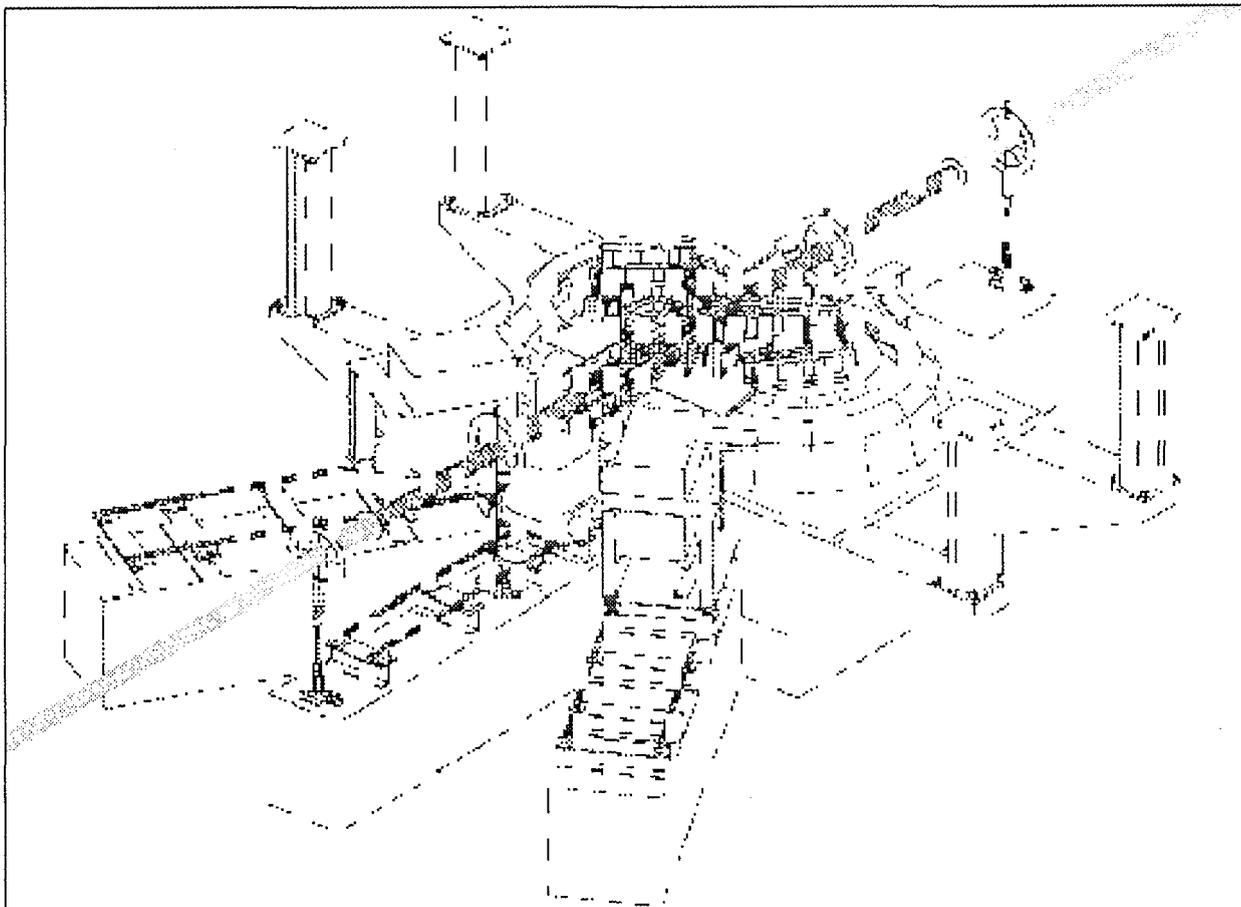


BRAHMS DETECTOR

BRAHMS will measure only a small number of particles emerging from a specific set of angles during each collision. The momentum, energy and other characteristics of the particles will be measured very precisely.

BRAHMS has 51 participants from 14 institutions in eight countries. BRAHMS is located at the 2 o'clock position on the RHIC ring.

4d) PHOBOS Experiment is the other of RHIC's two smaller experiments, is based on the premise that interesting collisions will be rare. Thus the PHOBOS detector is designed to examine a very large number of collisions and to develop a broad view of the overall consequences, along with detailed information about a small subset of the fragments ejected from the plasma.



PHOBOS DETECTOR

This technique will permit researchers to detect rare and unusual events quickly and to study in detail about 1 percent of the produced particles.

Seventy scientists from 12 institutions in three nations are working on PHOBOS, which is located at the 10 o'clock position on the RHIC ring. (2)



5. Status of the Relativistic Heavy Ion Collider

Complicated!

We have been building this machine now for almost ten years, twenty if you start counting when ground was first broken for start of construction, it has been a long complicated path to completion. As stated in the abstract the beam was circulated in the blue ring in July, 1999, and we now know that it was circulated in the yellow ring in August, 1999. Unfortunately, there were no collisions observed, which was a goal that eluded the beam commissioners. There are many reasons for the milestones reached during our first experience with circulating beam. We have had an extremely dedicated, hard working, focused team working diligently to bring this machine into reality.

Power supplies are still under construction; our electrical technicians are anxiously awaiting their arrival and connection to the system so that beam parameters can be better controlled.

When the machine was being pressure tested, the helium lines were tested to 330 pounds of pressure, which created problems with the pseudo assembly areas. In some instances, the helium lines would fail and physically bend the bellows region between interconnects several inches out of alignment. These areas were fixed before the commissioning run. This occurred in areas where the helium line extended 1.5 to 2 meters beyond the cryostat in the DU5 regions. In other DU magnets where the beam tube extends about 0.5 meters from the cryostat, the effects were smaller and not corrected before the commissioning run. This has caused all sorts of problems with the machine by limiting the aperture the commissioners had to steer the beam around these areas. The combination of problems exhausted most of the commissioning efforts. They were able to get the beam to circulate in both rings, but there is much to do. Plans are in process to slow down the timetable for the next RHIC beam run to address some of these problems. The alignment of the DU's means 192 openings of the interconnect regions, installing masks that would eliminate the ability of the unit to move under pressure and fiducializing and realigning the unit into its proper position. This effort is expected to take between 50 and 120 working days, depending on the resources used to accomplish this task. The good news is this time frame will let the power supplies catch up to a more reasonable configuration for running the beam.

3. References

[1] Francis X Karl, Current Alignment Operations Procedures For RHIC Third International Workshop on Accelerator Alignment October 1, 1993 Annecy, Fr

[2] <http://www.rhic.bnl.gov/html2/experiments.html>