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HIGH ENERGY NUCLEAR BEAMS IN THE AGS AND RHIC**

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RELATIVISTIC HEAVY IONS AT BROOKHAVEN:
HIGH ENERGY NUCLEAR BEAMS IN THE AGS AND RHIC*

T. Ludlam

1. INTRODUCTION

The past few years have seen rapid development of a new field of physics in which the elementary properties of nuclear forces may be studied through the direct observation of strongly interacting matter in collisions of heavy ions at ultrarelativistic energies. These experiments are expected to reveal macroscopic volumes of hadronic matter with energy densities greater than 10 times that of the nuclear ground state¹⁻⁴. The possibility of creating such conditions in laboratory experiments has attracted increasing numbers of nuclear and particle physicists, and has led to proposals for nuclear beams at energies stretching to the limits of present-day accelerator technology.

The first round of these experiments will take place in 1986, with fixed target experiments at the Brookhaven AGS and CERN SPS. These programs will begin with relatively light ions ($A \approx 32$ 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 as illustrated in Fig. 1b.

The widespread interest and excitement attending these experiments is due in large measure to the likelihood that they will be followed in the near future by measurements with much higher beam masses and much higher collision energies. Within 2-3 years of this initial effort it will be possible to extend the mass range of the AGS beams, with a Booster Synchrotron, to cover essentially the entire periodic table up to $A \approx 200$. The next goal is then to reach much higher energies with colliding beams of heavy ions (Fig. 1c), creating thermodynamic conditions with near-zero baryon number which can be directly compared with calculations from quantum chromodynamics, and which approximate the conditions that existed when the universe condensed from a plasma of quarks and gluons to a gas of hadrons.

The concept of such a collider facility, which would reach center-of-mass collision energies at least 10 times higher than the fixed target experiments,

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INITIAL STATE BEFORE COLLISION

$\sqrt{s}/A \leq 5 \text{ GeV}$: BARYONS STOPPED IN OVER-ALL CM

AT HIGHER ENERGY, NUCLEI ARE TRANSPARENT TO EACH OTHER

Fig. 1 Schematic illustration of nuclear transparency in high energy collisions at zero impact parameter. The picture inferred from present data on high energy hadron-hadron and hadron-nucleus collisions. Within the energy range of the planned fixed target experiments the colliding nuclei bring each other to rest, producing a single fireball of highly compressed nuclear matter. At much higher energies the final state consists of two hot, dense, baryon-rich fireballs flying away from each other at large rapidity (the fragmentation regions), and thermally produced particles with near-zero net baryon number populating the central rapidity range.

has been identified as a high priority need in the long range plan for basic nuclear research in the United States, as outlined by the U.S. Department of Energy and National Science Foundation⁵. At Brookhaven the Relativistic Heavy Ion Collider (RHIC) project is a proposal to provide this facility, utilizing the AGS accelerator complex as injector to a dedicated heavy ion collider in the CBA tunnel with its existing experimental halls, support buildings and liquid helium refrigerator.

The system of accelerators which comprise the Brookhaven heavy ion program is illustrated in Fig. 2. At present, the heavy ion transfer tunnel through which ions are injected from the Tandem Van de Graaff to the AGS is nearing completion, with commissioning of ion beams accelerated in the AGS scheduled for the spring and summer of 1986. This marks the first step in a long term plan for heavy ion physics proposed at BNL, a summary of which is given in Table I. In the remainder of this paper I will describe the experimental program which is being prepared for the initial ion beams at the AGS (Sec. II), and then describe the RHIC proposal for a collider facility (Sec. III).

TABLE I

Heavy Ion Facilities at BNL

(*indicates proposed dates)

1986 Begin AGS Fixed Target Experiments

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

1988* AGS Experiments with Booster Synchrotron

Extend ion mass to $A \approx 200$ (Au)

1991* Begin RHIC Collider Experiments

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

Fig. 2 Site map of present and proposed accelerators. The Tandem Van de Graaff and the AGS with its linac injector are existing machines. The heavy ion transfer tunnel is presently under construction. The Booster Synchrotron for pre-injection to the AGS, and the RHIC colliding beams accelerator to the north of the AGS complex are proposed construction projects.

2. ION BEAMS IN THE AGS

The near-term program for high energy nucleus-nucleus collisions at Brookhaven involves the acceleration of ions in the AGS to energies up to $28Z/A$ GeV/amu, where Z/A is the charge-to-mass ratio of the accelerated nucleus. The existing Tandem Van de Graaff accelerators will serve as source and initial ion accelerator. The ions will then traverse the long (~ 2000 ft.) transfer line to the AGS accelerator (Fig. 2). The construction of this transfer line is now nearly complete, and first experiments are scheduled to begin in the fall of 1986.

The first round of experiments will involve direct injection, through the transfer line, from the Tandem accelerators to the AGS. In this mode, ions up to Sulfur ($A \approx 32$) can be accelerated, fully stripped, in the AGS. The AGS cannot accelerate partially stripped ions. Acceleration of heavier ions requires higher energies at injection for higher stripping efficiency. In 1988 or 1989 Brookhaven expects to complete construction of the Booster synchrotron as part of a general program to improve the AGS performance⁶. The Booster will provide fully stripped ions up to Gold ($A \approx 200$) for injection to the AGS, with beam intensities up to $\approx 10^9$ ions/sec. Experiments with even heavier beams (up to Uranium) can be done, if necessary, at reduced intensity or with the addition of a linear "pre-Booster" following the Tandem accelerators.

The AGS experimental halls contain four external beam lines capable of transporting particles at the full machine energy. Thus, in principle, four heavy ion experiments could be mounted simultaneously. There is, however, a strong program of experiments with high energy proton beams competing for beam lines and running time.

Three large experiments have been proposed for the nuclear beams, of which two have been approved for the initial running in 1986/87. In addition, several small, focussed searches will be run using passive detectors such as emulsions and plastic stacks. A list of experiments is given in Table II. Proposals for heavy ion beams at the AGS are reviewed by the same program advisory committee as is the high energy program with proton beams. This committee has been enlarged to include specialists in the new field. A Heavy Ion Users Group has been organized, with some 400 members.

Among the major experiments now in preparation, one (E802) involves the construction of a new spectrometer specifically designed for the measurement of particle production in nuclear collisions, with the capability for triggering on various event characteristics indicative of impact parameter, amount of energy deposited in the collision, or selected particle configurations in the final state. A plan view of this experiment is shown in Fig. 3. A moveable magnetic spectrometer subtending a solid angle of 25 msr pivots about the

Table II

Heavy Ion Experiments at the AGSElectronic Experiments:

E802	Studies of particle production at extreme baryon densities in nuclear collisions at the AGS. -1000 hours.	BNL/Hiroshima/LBL/MIT/ Tokyo
E810	A search for quark matter (QGP) and other new phenomena utilizing heavy ion collisions at the AGS. - 1650 hours.	BNL/CCNY/Johns Hopkins/ LBL
P814	Study of extreme peripheral collisions and of the transition from peripheral to central collisions in reactions induced by relativistic heavy ions. - 1200 hours.	BNL/CERN/LANL/SUNY Stony Brook/TelAviv/ New Mexico

Passive Detector Experiments:

E793	Search for fractionally charged nuclei in 15 GeV sulfur-oxygen collisions. - 8 hours.	UC Berkeley
E801	A search for quarks produced in heavy ion-mercury interactions. - 72 hours.	San Francisco State
E804	Search for fractional charge with heavy ion beams at the AGS. - 8 hours.	Indiana/Michigan
E806	Nuclear fragmentation in heavy ion collisions at 15 GeV/amu. - 10 hours.	U. Siegen
E808	Interactions of 14.1 GeV/amu nuclei from 160 to ^{197}Au in light and heavy targets. - 40 hours.	Krakow/LSU/Minnesota

EXPERIMENT #802

Fig. 3 Layout of AGS experiment E802. See text for details.

target to allow angular settings in the range $5^\circ < \theta_{\text{lab}} < 90^\circ$. This spectrometer includes particle identification via segmented Cerenkov counters and an array of scintillation counters for time-of-flight measurements. Each of the tracking, Cerenkov and time-of-flight detectors in this spectrometer arm will have an effective segmentation of several hundred detection elements. The experiment is designed to reconstruct and identify up to 20 charged particles in this spectrometer arm per event, at event rates up to a few 10^5 sec^{-1} . A small aperture system of gas Cerenkov counters, "Cerenkov complex", which moves to track the motion of the magnetic spectrometer, is tuned to identify higher momentum particles, with $P > 4 \text{ GeV}/c$. The system of particle identification is designed to distinguish π , K, P over a kinematic range sufficient to observe a Boltzmann source of temperature 200 MeV at rest in the nucleon-nucleon c.m. as the differential cross section falls through ~ 3 decades.

Event selection at various on-line trigger levels is provided by several detectors, either singly or in combination:

- A total multiplicity array (TMA) surrounding the (active) target. The array consists of ~ 500 proportional tubes of $1 \times 1 \text{ cm}^2$ cross section, with cathode pad readout for subdivision along each tube. A total of 5000 pads allows for accurate, on-line multiplicity determination even for final states with several hundred charged particles.
- A wall of ~ 340 lead glass blocks to measure total neutral energy over a relatively large solid angle near $y \text{ c.m.} = 0$.
- A small-solid-angle total absorption sampling calorimeter at $\theta = 0^\circ$ to measure the total kinetic energy in all of the projectile fragments after non-central collisions.

With this equipment the basic aims of the experiment are to map out the characteristics of particle production, including resonance production and second-order interference effects due to source size, for event samples in which the global properties of the collision relating to impact parameter and energy deposition are well controlled, and with rate capability to allow selection of extreme thermodynamic conditions in rare events.

Another experiment (E810) plans to look at a large fraction of the final-state particles in each event, using the latest electronic techniques to achieve the goals of a classical streamer chamber experiment in the extremely difficult environment of high multiplicity nucleus-nucleus events. This experiment uses the Multiparticle Spectrometer (MPS) user facility at the AGS. This has been a part of the BNL high energy physics program for many years. It

Fig. 4 The Multi-Particle Spectrometer facility (MPS) at the AGS showing the present configuration with planar drift chambers (D1-D7) and MWPC's (P1-P3) inside the magnetic volume. Following the large dipole magnet are a pressurized gas Cerenkov counter (C1), two hodoscopes H1, H2 and timing scintillations T2.

Fig. 5 The MPS configured with a TPC detector for experiment E810.

is a large solid-angle detector based on a C-magnet with a pole area 6 ft. $\times$ 15 ft. with a 4 ft. high gap (see Fig. 4). The magnetic field volume is filled with tracking detectors, which currently consist of narrow-cell drift chambers designed for high rates and small multiplicities in experiments with proton beams and targets.

For the heavy ion experiments the MPS tracking detectors will be replaced by a new detector system based on the 3-dimensional point measurement capability of a large-volume time projection drift chamber (TPC). This would allow momentum measurement of essentially all charged particles emitted forward in the lab frame. The TPC detector, shown positioned in the MPS magnet in Fig. 5, is to be constructed as a joint effort with CERN experiment NA36. The TPC module is one meter long, 50 cm. high and wedge shaped along its length with a width of 30 cm. upstream and 70 cm. downstream. It will have an effective segmentation of $\sim 10,000$ resolution elements.

The MPS detector system includes several large multi-cell Cerenkov counter hodoscopes and a time-of-flight array which can be configured, as in Fig. 4, to allow particle identification for charged particles exiting the downstream end of the spectrometer magnet; the number of such particles is relatively small, and limited to the high momentum projectile-like component which is not swept away by the magnetic field.

In order to record the total multiplicity and angular distribution of charged particles the MPS experiment will surround the target with arrays of Charge Coupled Devices (CCD) serving as active detectors with an effective segmentation of $\sim 10^6$ pixels covering the full solid angle.

A third major experiment is being planned (P814) which would exploit calorimeter measurements over a large solid angle. The goal of this experiment is to investigate the properties of exotic nuclear states in a detector system whose capabilities range from a completely exclusive measurement of projectile fragmentation in a high precision forward spectrometer to the study of more central collisions with energy flow measurements in calorimeters. The fragmentation processes to be investigated may be initiated either by the nuclear or the Coulomb field of the target nucleus.

3. INTO THE FUTURE: RHIC

Following along the chronology of Table I, we see that if the proposed funding schedules hold true the experiments at the AGS should be exposed to beams of very heavy nuclei within a few years of the initial runs with sulfur beams. Beams up to mass 200 will be made possible by the addition of the Booster Synchrotron to the sequence of injectors to the AGS. It is assumed that the experiments described in the previous section will be upgraded to meet

the more severe demands of the heavy nuclear beams and to respond to the discoveries of the first exploratory measurements. With heavy beams available to the fixed target experiments the study of highly compressed baryon-rich nuclear matter should widen considerably in its scope and potential. The next step, to realize a high density state in which high temperatures are reached in matter consisting almost purely of particle-antiparticle pairs created in the collision, is the goal of a colliding beams facility where the center-of-mass collision energy can be extended at least an order of magnitude beyond the range of the fixed target experiments.

In August 1984, after a long series of workshops, discussions at several international conferences, and with the cooperation of accelerator design experts from laboratories throughout the U.S. and Europe, Brookhaven submitted to the U.S. Department of Energy a conceptual design for a Relativistic Heavy Ion Collider⁷. During the course of this design study a number of heretofore unappreciated features of accelerator physics came to light regarding the special case of storing beams of highly charged ions. Most important of these is the phenomenon of intrabeam scattering⁸ which imposes strong limitations on the performance of a heavy ion collider. Nonetheless a design was arrived at to meet all of the important physics requirements for such a facility at a cost well within the expectations of the NSAC long range plan (i.e., significantly less than 200 million US \$).

The RHIC proposal calls for a top beam energy of 100 GeV/amu for $A \approx 200$, and the acceleration of ion masses spanning the full periodic table. The proposed accelerator complex utilizes the existing Tandem Van de Graaff and AGS as source and injector, and will provide center-of-mass collision energies ranging from $1.5 + 1.5$ GeV/amu to $100 + 100$ GeV/amu. This energy range is covered with no inaccessible gaps, and adequate beam intensities throughout, as illustrated in Fig. 6. Because of the effects of intrabeam scattering, operation in the collider mode at very low energy would require very large aperture (and therefore very expensive) magnets — much more so than is required at the top energies. For this reason the energy range is covered in three segments, as shown in the figure, using the AGS beams for fixed target experiments ($\sqrt{s}/A < 5$ GeV/amu); one collider beam striking an internal gas jet target ($5 \text{ GeV/amu} < \sqrt{s}/A < 14 \text{ GeV/amu}$), and the colliding beams covering the high energy range ($14 \text{ GeV/amu} < \sqrt{s}/A < 200 \text{ GeV/amu}$). The complete facility will thus provide heavy ion collisions over a spectrum of energies which begins just above the present Bevalac, extends through the range of the high energy fixed target experiments which are currently in preparation, and on up to the extremely high energies now being glimpsed in rare cosmic ray events.

Fig. 6 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.

During the year which has elapsed since the first submission of the proposal a detailed review of all aspects of the machine design has been undertaken in order to develop an R&D plan and a complete specification of the machine parameters which would allow a construction project to begin at the earliest possible date. As a result of that review an updated proposal has been prepared for submission in the fall of 1985. The new proposal contains no major changes in the scope or cost of the project. The essential new aspects are:

- The RHIC magnet design has been fully specified. The arc dipole magnets are single-layer, $\cos\theta$ coils with coil i.d. of 8.0 cm and yoke length of 9.7 m. In a departure from the previous proposal, those will be separate rather than dual magnets. This choice was made in part because the new antisymmetric lattice allows the beams to be more widely spaced in the arcs without unreasonable requirements on the insertion magnets. The choice of separate magnets further adds to the flexibility of the machine and reduces the cost of operation and maintenance.
- The present plan calls for a four year construction plan, which is proposed to begin in FY 88 with completion in FY 91.

A complete R&D plan for the RHIC project has been prepared which addresses all the major R&D tasks which have to be performed prior to or during the construction phase. A large portion of this development work involves the magnets. An important component of the magnet R&D is being carried out under a cooperative agreement with DESY whereby HERA magnet tooling becomes available for RHIC magnets in return for BNL's participation in evaluation and testing of superconductor for HERA construction. The first magnets to evaluate the single layer, $\cos\theta$ dipole design concept in a curved magnet have been built to half the full design length, and initial tests have been very successful. Prototype magnets having the full RHIC specifications will be tested within a year.

The completed construction work from the ISABELLE/CBA project which will be re-used for RHIC includes considerably more than just the ring tunnel. Among these assets are: the injection tunnels from the AGS, four completed experimental areas (two more undeveloped experimental areas also exist), a central control building, and the completed liquid helium refrigerator for cooling the entire system of superconducting magnets. The four intersection regions which have already in place the structures necessary for an operating experimental area are indicated in Fig. 2. These areas are at the 2, 4, 6 and 8 o'clock locations.

In April 1985, a workshop involving about 100 experimenters and theorists was convened at Brookhaven to develop conceptual designs for a first round of experiments for RHIC⁴. This resulted in a set of detector designs which can

serve as a concrete basis for discussion of the physics potential of the machine and for developing detector cost estimates.

One of these designs, a calorimeter-based experiment with multiple small-aperture spectrometers^{10, 11} is illustrated in Figs. 7 and 8. The full-solid-angle calorimeter gives energy and angular resolution for energy flow measurements in high multiplicity events, and for observing jets and jet-like rapidity fluctuations from plasma excitations. The depth of this calorimeter does not have to be very large, because the energy is carried by numerous particles of moderate energy, and a few percent of leakage has little effect. This device is well-suited for accurate and sensitive measurements of the transverse energy (E_T) spectrum in different rapidity regions, and a search for localized structures in energy flow produced with very low cross sections. The emphasis is on large energy deposits, and the design takes advantage of this fact to produce an economical and compact device.

This instrument would also provide a facility for a number of independent experiments on the detailed properties of the high energy density events by observing particles through small apertures, or "ports" provided in the calorimeter. The calorimeter then selects events with large or specially configured energy flow and gives a complete map of the flow over all angles, while the several instrumented ports provide detailed measurements on individual particles. The particle multiplicities at RHIC are so very high that a small aperture, i.e., one which is small enough not to distort the measurement of energy flow, still transmits a large number of particles. Individual events may be statistically characterized by features of particle spectra or quantum numbers, while the number of particles in the spectrometers is kept small enough (e.g., $\lesssim 50$) as to be manageable with conventional tracking and data analysis techniques.

Figure 8 shows a design for one of these port spectrometers. It has a dipole magnet external to the calorimeter, and utilizes a time projection chamber (TPC) and drift chambers (DC) for particle tracking, with ring imaging Cerenkov counter (RICH) and time-of-flight (TOF) measurements for particle identification. The calorimeter facility could include several port spectrometers which might range in scale from quite a small effort to that of a medium-sized experiment. A well thought out plan for data acquisition is required to accommodate such a program efficiently.

Figure 9 shows a detector system for measurement of muon pairs in high E_T events,^{10, 12} an experiment which could play the crucial role of studying directly the radiation of virtual photons from quark-antiquark annihilation in the plasma. The problem of $\mu^+\mu^-$ measurement at RHIC is rather different from that at other collider experiments. The main region of interest is for $m_T = (m_{\mu\mu}^2 + p_\perp^2)^{1/2} \approx 1-20$ GeV. The production of J/ψ , T , and (at the level of

Fig. 7 (a) The concept for a 4π calorimeter system with small aperture ports which may be instrumented with special-purpose spectrometers. Some of the ports are long, narrow slits. (In this illustration all of the ports are shown in the plan of the cross section, which overemphasizes their total solid angle. In fact, $\approx 95\%$ of the solid angle is covered by calorimeter) (Ref. 21).

(b) A realization of this calorimeter system using modular devices based on existing detectors. The central part has 4 walls for complete azimuthal coverage; two of the walls are omitted from the drawing for clarity (Ref. 22).

Fig. 8 A "Port" spectrometer for the calorimeter system, covering 10° in θ and ϕ at $y = 0$ (Ref. 22).

Fig. 9 Plan view of a muon pair spectrometer for RHIC. The drawing shows one half of the detector which is symmetric about the intersection point (Ref. 23).

a few events per year Z^0 states should also be studied as high mass points for the spectrum of elementary interactions. The main criterion for the design of this experiment is rapid absorption of the large number of pions, whose decay would otherwise yield a disastrous background of muons. This calls for a special beam pipe allowing high density absorber as close as possible to the collision point. This absorber provides calorimetric energy flow information. The muon momentum is measured with the aid of toroidal magnetic fields beyond the compact first absorber-calorimeter. In Fig. 9, the central region of ± 2 rapidity units is covered by uranium absorber instrumented as a calorimeter with liquid argon as the active readout element. The inner surface of this absorber is 1 cm from the beam axis. Following the absorber is a set of iron toroids interleaved with planes of proportional drift tubes for measuring the muon's direction and momentum. At forward angles ($2 < y < 3$) the attempt is made to reduce multiple scattering and thereby to measure to lower values of m_T . This is accomplished by using an aluminum absorber (larger ratio of radiation length to absorption length) and an air-core magnet system. The aluminum is also an active calorimeter with liquid argon readout. This design provides sufficient background rejection to observe dimuons in the high multiplicity environment of RHIC while at the same time reaching to transverse masses low enough to be interesting for the study of a quark-gluon plasma.

Both of the detector systems described above avoid the problem of individually resolving a large fraction of the thousands of particles which can be expected in a single event with large energy deposition in the colliding nuclei. Many interesting measurements could, nonetheless, be carried out with a large solid angle "visual" detector capable of recording a very large number of charged tracks. Tracking detectors capable of resolving high densities of tracks have been developed for high energy physics experiments, and feasible designs have been studied which employ three dimensional tracking detectors in large aperture magnetic spectrometers covering the central rapidity range at RHIC¹³.

Measurements in the fragmentation region ($y \lesssim 3$) are more difficult, but it will be important to have experimental access to the very small scattering angles where the net baryon density is large, and where exotic nuclear states may be found. The requirements for a spectrometer covering the momentum range $5 < p < 150$ GeV/c at small angles in a hadron collider are not much different from those of fixed target experiments at the CERN SPS or Fermilab accelerators. At the collider, however, there is the additional constraint that the spectrometer must fit within the machine lattice. One solution which has been given detailed examination¹⁴ is illustrated in Fig. 10. Here one of the machine insertion magnets is replaced by a special, long, large aperture

Fig. 10 Forward spectrometer magnet for experiments in the fragmentation region (Ref. 13). The magnets labelled BC2 are part of the machine lattice.

(a) Perspective view showing the long dipole magnet L4 in the place of BC1 in the machine insertion lattice.

(b) View of L4 in the narrow angle hall at RHIC. Trajectories are shown for particles of the indicated momenta (GeV/c), produced at 0° in the collision, exiting the side ports of the magnet.

superconducting spectrometer magnet (called "L4"). This magnet would be 10 m long, with a field strength of 1.8 Tesla. It would have a vertical gap of about 1 m, and a horizontal gap somewhat larger. Ports are provided in the sides of the magnet to allow low momentum particles to exit into external spectrometers. The total multiplicity at the entrance of the magnet is very high (about 1000 charged particles for Au + Au at 100 GeV/A), but the particle density is reduced to manageable levels by the natural divergence and the momentum dispersion within the magnet. A representative estimate of the costs for such a complement of detectors was arrived at during the workshop and is summarized in Table III.

Table III

Summary of RHIC Detector Cost Estimates*

1. Calorimeter-based Experiment with "Slit" Spectrometer	\$11.9 M
2. Muon Pair Spectrometer	7.3 M
3. Magnetic Spectrometer for Tracking at Mid-rapidity	16.0 M
4. Large Solid Angle Dipole Spectrometer	12.5 M
5. Forward Spectrometer for Fragmentation Regions	<u>5.2 M</u>
	\$52.9 M

* From the April, 1985 Workshop on "Experiments for a Relativistic Heavy Ion Collider". Estimates are in FY 85 \$, exclusive of contingency and escalation.

REFERENCES

- 1) T. Ludlam and H. Wegner (eds.), Proc. of the Third International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, "Quark Matter '83", Nucl. Phys. A418 (1984).
- 2) K. Kajantie (ed.), Proc. of the Fourth International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, "Quark Matter '84", Springer-Verlag, Berlin, 1985.
- 3) L. Schroeder (ed.) Proc. of the LBL Workshop on Detectors for Relativistic Nuclear Collisions, LBL-18225 (1984).
- 4) P. Haustein and C. Woody (eds), Proc. Workshop on "Experiments for a Relativistic Heavy Ion Collider", BNL 51921 (1985).
- 5) "A Long Range Plan for Nuclear Science", report of DOE/NSF Nuclear Science Advisory Committee (December, 1983).
- 6) R. B. Palmer, Proc. Conf. on Intersections Between Particle and Nuclear Physics (R. Mischke, ed.), AIP, N.Y. (1984), p. 197.

- 7) "RHIC and Quark Matter: Proposal for a Relativistic Heavy Ion Collider at Brookhaven National Laboratory", BNL 51801 (August 1984).
- 8) A. Ruggiero, Proc. Conf. on Intersections Between Particle and Nuclear Physics (R. Mischke, ed.), AIP, N.Y. (1984), p. 424.
- 9) "The R&D Plan for a Relativistic Heavy Ion Collider (RHIC)", BNL 36818, September 1985.
- 10) W. Willis, Ref. 4.
- 11) T. Åkesson et al., Ref. 4.
- 12) S. Aronson et al., Ref. 4.
- 13) S. J. Lindenbaum and L. S. Schroeder, Ref. 4.
- 14) M. Faessler et al., Ref. 4.