Department of Energy
Washington, DC 20585

OCT 24 1994

Professor Ernest Moniz
DOE/NSF Nuclear Science Advisory Committee
Department of Physics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139-4307

Dear Professor Moniz:

The Relativistic Heavy Ion Collider (RHIC) Project at Brookhaven National Laboratory began construction in January 1991, and is scheduled to be completed in March 1999. Within the RHIC Project, $112 Million is allocated for detectors, which includes two large detectors (STAR and PHENIX), a complement of small detectors, the costs of conventional facilities and technical support during construction. Both STAR and PHENIX have been designed to have physics capabilities beyond those which can be achieved within the baseline construction funds; i.e., each has begun construction with a minimal configuration to begin a research effort when RHIC turns on, and each has a clearly defined improvement path requiring additional detector equipment. RHIC Project Management has developed a proposal for additional experimental equipment which extends the capabilities of the major detectors STAR and PHENIX and provides needed computing resources for the analysis of RHIC data. This proposal, presently undergoing final scientific review at Brookhaven and further technical and cost review within the RHIC Project, includes significant contributions and commitments from foreign institutions. In the near future both the Department of Energy (DOE) and the National Science Foundation (NSF) will make final decisions regarding this initiative.

NSAC is therefore asked to provide advice to DOE and NSF, by April 15, 1995, on the merit of proceeding on the funding of additional experimental equipment for RHIC. The committee should include in its considerations the results of existing technical and scientific reviews, as available. The recommendation should be consistent with the scientific priorities which will be contained in the new Long Range Plan.

Sincerely,

Robert A. Eisenstein

Robert Eisenstein
Director
Division of Physics
National Science Foundation

Wilmot N. Hess
Associate Director for
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Report of NSAC Subcommittee on RHIC Experimental Equipment

Background

In order to evaluate the recent request by RHIC management for $42 M (FY96 $) of funding for additional RHIC experimental equipment, the Nuclear Science Advisory Committee (NSAC) appointed the Subcommittee on RHIC Experimental Equipment to review the projects in this request. The Subcommittee was charged by NSAC to evaluate the increased scientific capability which would be realized with the requested funding and to assign relative scientific priority to different components of the proposal. Contributions and commitments from foreign institutions and additional equipment funding requests to the National Science Foundation were to be folded into the considerations, as well as technical feasibility and cost by making use of existing technical reviews, as appropriate. The full text of the charge is included in the Appendix. The Subcommittee membership is:

Konrad Gelbke (Michigan State University), chairman,
George Bertsch (University of Washington),
Douglas Bryman (TRIUMF),
Don Geesaman (Argonne National Laboratory),
Michael Marx (State University of New York at Stony Brook),
Berndt Mueller (Duke University),
Jürgen Schukraft (CERN).

In response to this charge, the Subcommittee requested and obtained written documentation about the physics goals and status of the base detectors; details on the individual upgrades including the physics goals and impact on the program, technical feasibility, cost and risk; relevant reports of the RHIC Technical Advisory Committee (TAC); and background materials on the Off-Line Computing Facility. A copy of the letter requesting this documentation is included in the Appendix. In addition, the Subcommittee met at Brookhaven National Laboratory (BNL) on January 4 and 5 for oral presentations and discussions of the physics goals of the RHIC detector base program and the gains anticipated from the additional experimental equipment requested for the PHENIX and STAR programs. In making its judgment, the Subcommittee relied on material presented and on existing technical reviews for those projects (STAR baseline detector and SVT, PHENIX baseline detector and muon arm) which were sufficiently far advanced to have undergone detailed technical evaluation by the RHIC Technical Advisory Committee. The Subcommittee did not attempt to make an independent verification of cost, risk, or schedule. The agenda of the meeting at BNL is included in the Appendix.

The Subcommittee understands that the hadron communities of nuclear physics and of high energy physics have considerable interest in the potential for exciting p+p and p+A physics at RHIC. With the exception of the spin program, this subject has not been reviewed in detail, and no clear priorities have been set by the RHIC Program Advisory Committee. This Subcommittee therefore focused on the contributions of the detector upgrades to the heavy ion program, but it is noted that the upgrades would be expected to have significant impact on p+p and p+A experiments which could considerably enhance the RHIC program.

Executive Summary

The RHIC baseline detector program is designed to address the most urgent physics questions related to the possible creation of a quark-gluon plasma. In view of the high scientific priority given to the physics at RHIC by NSAC's 1989 Long Range Plan and in view of the large investment in RHIC, the Subcommittee strongly recommends that funds be made available for additional experimental equipment to broaden the scope of the RHIC research program and thus ensure appropriate scientific return on investment. The order of priority of the recommendations is based upon judgments of scientific impact; considerations of urgency were taken into account when noted. The main recommendations are summarized below:

- Highest priority for additional equipment funds should be given to
  - ⇒ first and foremost, an Off-Line Computing Facility for all RHIC users, to provide capability for reconstruction and analysis of the expected large volume of RHIC data,
  - ⇒ the Silicon Vertex Tracker (SVT) for STAR which provides unique capabilities for event-by-event correlations with strange particle production and low-momentum particles,
  - ⇒ the Muon-Arm detectors for PHENIX which will provide measurements of single and di-muon production over a wide kinematic range, and
  - ⇒ the implementation of the Second Level Trigger for PHENIX required to access rare processes, such as J/ψ and ψ' production.
- Other important additions are
  - ⇒ the STAR Electromagnetic Calorimeter (EMC) and some Time-of-Flight (TOF) capability which will significantly enhance the scope of the STAR physics program by allowing measurement of and triggering on neutral energy and by extending the momentum range accessible to particle identification, and
  - ⇒ the mechanical installation of two additional layers of Time-Expansion Chambers (TEC) for PHENIX to allow the subsequent conversion of the TEC's to Transition Radiation Detectors (TRD).
- Serious consideration, with less urgency, should be given to
  - ⇒ the PHENIX high-resolution photon detector (BaF_2) which aims at the detection of photons from a long-lived mixed phase and which is considered to be an improvement of the baseline calorimeter capability at low energy, and

⇒ the Transition Radiation Detector (TRD) for PHENIX which improves the identification of electrons at momenta above 2 to 3 GeV/c.

- The proposed addition of an external TPC for STAR should be deferred at this time.

Of the proposed additional equipment items, only the SVT and the Muon-Arm have undergone extensive and thorough technical reviews by the RHIC Technical Advisory Committee (TAC). The Subcommittee recommends that all remaining additional equipment items undergo similar scrutiny by the TAC before being approved for construction and that any possible negative impact on existing detector components be carefully evaluated. The computing facility will need a detailed plan and extensive review.

RHIC Baseline Detectors

Detectors funded by the RHIC project are the baseline versions of STAR and PHENIX plus two smaller detectors, not yet approved for construction, PHOBOS and BRAHMS. Together, these detectors have the minimum desired capability needed to address the most urgent physics questions during the "discovery" phase of RHIC research. The total cost of the baseline detector program (in actual-year dollars) is $112 M; Table 1 gives a budget summary.

	Cumulative through FY94	FY95	FY96	FY97	FY98	Total
Total Budget Authority	**30.4**	**11.8**	**22.5**	**28.4**	**18.9**	**112.0**
STAR	13.2	5.3	8.5	9.1	4.7	40.8
PHENIX	7.6	4.7	12.0	11.5	5.8	41.6
Small Detectors	0.3	0.3	0.8	4.1	7.1	12.6
Conv. Facil./Admin./Tech. Supp.	9.3	1.5	1.2	3.7	1.3	17.0

Table 1: Baseline detector funding (in actual-year $M).

The baseline version of STAR (Solenoidal Tracker At RHIC) consists of a large time projection chamber (TPC) positioned in a solenoidal magnet. A schematic of the detector (together with the proposed additional equipment for STAR) is shown in Fig. 1. The detector provides nearly full solid angle coverage for charged particles in the central region of rapidity and permits the measurement of rapidity and transverse momentum distributions of charged particles emitted in the central rapidity region in p+p, p+A, and A+A collisions by high resolution tracking. With nearly complete reconstruction of charged hadrons over its large acceptance, STAR fulfills the role of a global survey instrument capable of providing detailed characterization of hadronic production on an event-by-event basis, e.g. charged-particle multiplicity distribution, transverse momentum distributions from charged pions and kaons, strangeness content, and pion source size. STAR is the only detector at RHIC with the capability to determine thermodynamic quantities and charged-particle correlations on an event-by-event basis. This is important because signatures of a phase transition to the quark-gluon plasma may appear in the fluctuations of observables from event to event. Budgetary constraints did not permit the detector to have the originally planned capabilities in triggering, neutral energy measurement, strange particle measurement, low momentum particle detection, and particle identification.

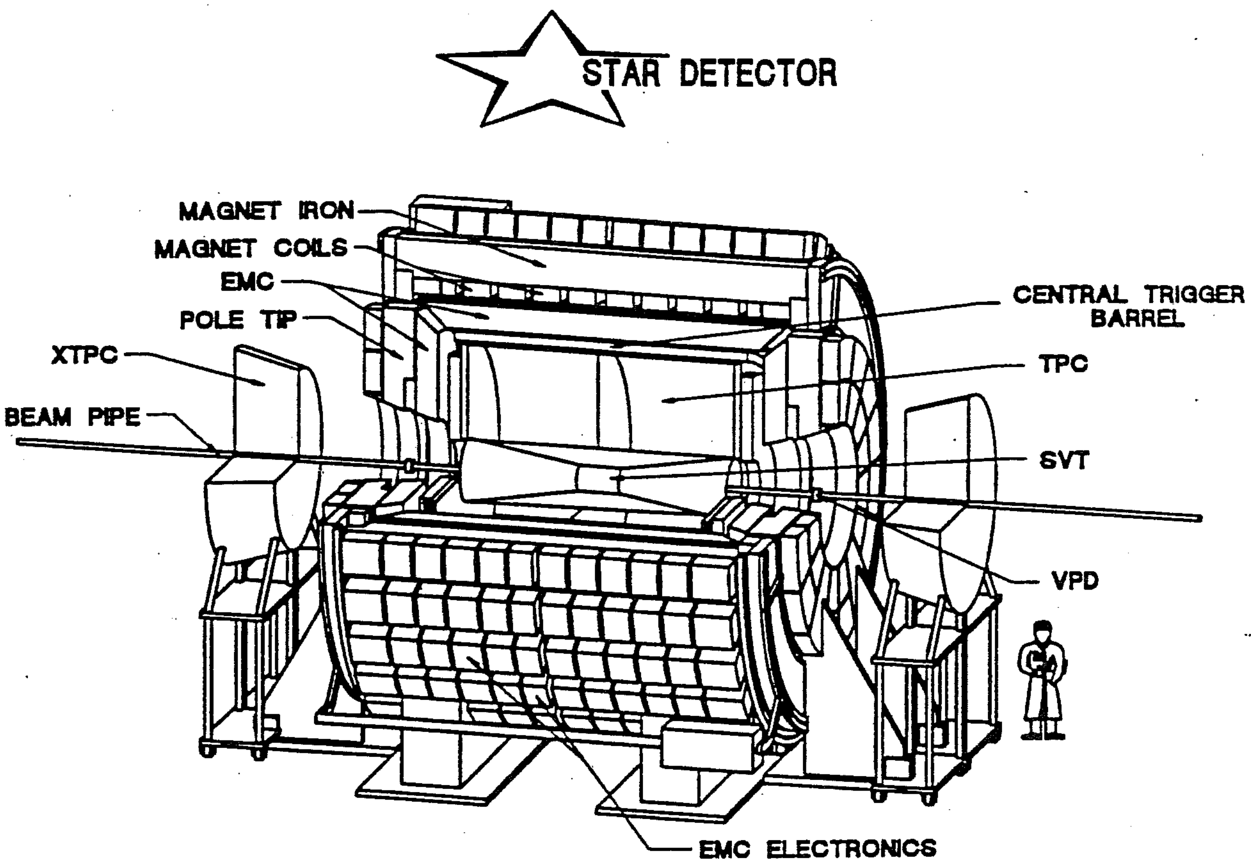

Figure 1: Schematic of STAR detector, including the requested additional equipment.

A recent TAC review (October 1994) found STAR generally on schedule with a slight growth in budget which had been adequately addressed by use of contingency and some small descoping. The remaining contingency, 18.7% of the cost to complete, was found to be low for a project at this stage (approximately 25% complete), but the TAC did not regard this as a serious concern at that time.

The PHENIX experiment is designed to measure leptons and photons produced in nucleus-nucleus collisions at RHIC energies. These particles are well suited as probes of the quark-gluon plasma because they do not suffer absorption or rescattering in the hadronic final state. A schematic of the detector (together with the proposed additional equipment for PHENIX) is shown in Fig. 2. The heart of the PHENIX detector is a pair of spectrometers backed by calorimeters, subtending 2 sr solid angle and capable of identifying and measuring electrons and photons. Charged hadrons can be identified over part of the spectrometer acceptance. One important measurement possible with PHENIX is the effect of the hot, dense environment on the masses and widths of the vector mesons via their decay into electron pairs. Another key observable is the yield of direct photons bearing information about the hottest phase of the plasma development. The hadron spectrometers allow measurements of identified particle spectra as indicators of a phase transition, consequences of jet production and quenching, interferometric correlations of pions and kaons, and strangeness production. The original detector plan included a muon spectrometer, but its instrumentation was omitted from the baseline detector due to budgetary constraints.

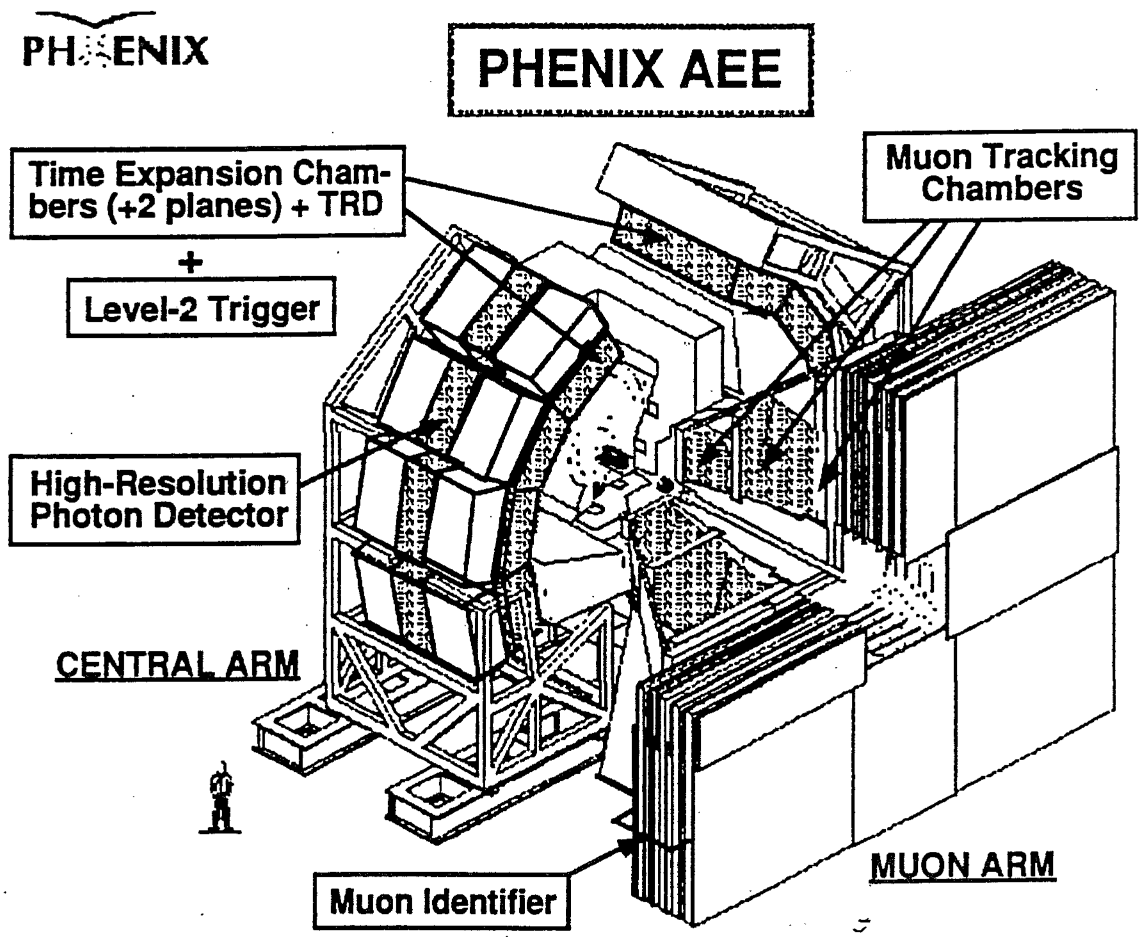

Figure 2: Schematic of PHENIX detector, including the requested additional equipment.

The baseline PHENIX cost in FY93 dollars was \$30.1 M plus \$6.6 M contingency (≈ 22 %) for the DOE funded parts. Other, in kind contributions total \$27.4 M. PHENIX will have its first annual progress review in March 1995.

Two smaller detectors, PHOBOS and BRAHMS, are in the advanced design phase, but have not yet received approval for construction. PHOBOS exploits a single detector technology (silicon pads and micro-strips) to provide a compact device capable of measuring the charged particle multiplicity distribution over a very large rapidity range. An additional pair of spectrometer arms is designed to measure identified particles down to very low momenta ($p_t \leq 30$ MeV/c). BRAHMS consists of two movable small-aperture spectrometer arms designed to allow measurement of inclusive production of identified charged hadrons over nearly the entire range of rapidity.

By necessity, there is some overlap in the capabilities of all four detectors. All detectors have sensitivity to charged particle multiplicity and particle density at mid-rapidity to allow event characterization by impact parameter, and all detectors can be used to measure hadronic resonances and to carry out intensity interferometry.

RHIC Additional Experimental Equipment Requests (in FY96-$M)							
Detector	**Total DOE**	**External**	**FY96**	**FY97**	**FY98**	**FY99**	**FY2000**
PHENIX AEE total	**16.91**		**2.40**	**3.41**	**4.72**	**4.20**	**2.18**
μ-Arm #1	10.51		2.00	2.25	3.20	2.30	0.76
μ-Arm #2		10-12 (Jap)					
BaF_2	3.68	2.9 (NSF)	0.40	0.60	0.90	1.15	0.63
TEC&TRD	1.56		0.00	0.28	0.34	0.45	0.49
Level-2 Trigger	1.16		0.00	0.28	0.28	0.30	0.30
STAR AEE total	**16.87**		**2.27**	**3.74**	**4.51**	**4.21**	**2.14**
EMC	7.80	6.6 (Russia)	0.22	0.90	2.22	3.13	1.33
SVT	5.71		1.71	2.28	1.72	0.00	0.00
TOF	2.22		0.11	0.28	0.28	0.74	0.81
XTPC	1.14	3.1 (Germany)	0.23	0.28	0.29	0.34	0.00
Comput. Equip.	**7.80**		**0.70**	**1.70**	**2.10**	**2.70**	**0.60**
Total AEE	**41.58**		**5.37**	**8.85**	**11.33**	**11.11**	**4.92**

Table 2: Funding profile for additional experimental equipment requested by RHIC management (in FY96-$M). These numbers include contingency: approximately 30% for the SVT; 25% for the μ-Arm #1, EMC, TOF, and XTPC; 22% for the Level-2 Trigger; 21% for the TEC&TRD, and 11% for the BaF_2-array.

Both the STAR and PHENIX collaborations wish to overcome the limitation of their respective baseline detectors, to expand the scope of the RHIC physics program, and to allow efficient analysis of the large amounts of data which will be taken once RHIC starts operation. The individual additional experimental equipment (AEE) requests for STAR and PHENIX are discussed in the following. The individual additional equipment items for STAR and PHENIX are identified in Figs. 1 and 2, respectively. The total cost (in FY96 dollars) of the AEE proposal is $41.6 M. Table 2 gives a breakdown of the individual upgrade costs and the funding profile proposed by RHIC management.

STAR Equipment Request

Silicon Vertex Tracker (SVT)

The STAR collaboration proposes to add to the baseline experiment a novel silicon drift detector which would provide a high-resolution, high-granularity tracking device close to the primary vertex. This detector would cover the full azimuth and 2 units of rapidity, essentially matching the coverage of the TPC. The detector would cost $5.7 M (all to be provided by DOE), in addition to the significant investment of R&D funds already expended.

The proposed SVT will allow the detection of short-lived strange hadrons, notably neutral K-mesons and strange baryons. This capability will provide information about the degree of flavor equilibration, a crucial signal for the presence of a deconfined, chirally-restored phase of hadronic matter. Measurements of strange baryon yields at the CERN-SPS have shown deviations from the predictions of hadronic cascade models, which could indicate precursor phenomena of color deconfinement. Studies of strangeness production at the higher energy densities accessible at RHIC should be in the initial RHIC research program, because strangeness has been widely viewed as an indicator of the quark-gluon-plasma phase-transition. In addition, the SVT will extend the dynamic range of STAR into the low-p_t region, 40 MeV/c $\leq p_t \leq$ 200 MeV/c.

The design of the SVT utilizes the novel silicon drift technique, which provides both longitudinal and azimuthal position measurements with high resolution. The long drift time is not a disadvantage in this application since it is well matched to the long drift time already inherent in the use of the TPC. The detector consists of 216 silicon drift detector wafers, each 6x6 cm^2 in size and containing 480 channels, corresponding to a total of 103,680 channels. The SVT will have a resolution of 20 μm in both directions, using information from drift time and charge sharing.

The proof of principle of the silicon drift technique has been established, and wafer designs adequate for STAR can be produced at BNL. Beam test results of production quality drift detectors have also demonstrated their viability, although the signal-to-noise ratios and hence the resolutions have fallen short of the specifications and bench test results. The most significant concern is the lack of progress in the electronics design and subsequent system tests, the results of which might point to the need for additional iterations to achieve ultimate resolution. Thus, there is some risk of slippage in the schedule which calls for readiness of the SVT during the initial experiments at RHIC. The most severe demands on SVT resolution must be satisfied for the separation of secondary vertices associated with charm from those associated with strangeness. It is reasonable to wait past the initial running for these measurements. This high-resolution capability could be implemented at a later date, as STAR has provided the means for installing and maintaining the SVT after the TPC is operational.

The Subcommittee views the implementation of the STAR SVT as one of the highest priorities for the AEE proposal; it will add unique and important physics capabilities to the RHIC program.

Time-of-Flight system (TOF)

The proposed Time-of-Flight system (TOF) is designed to improve the charged-particle (π, K, p) identification capability of STAR at high momenta (0.6 GeV/c $\leq p_t(\pi^\pm) \leq$ 1.2 GeV/c, 0.6 GeV/c $\leq p_t(K^\pm) \leq$ 2 GeV/c, 1 GeV/c $\leq p_t(p) \leq$ 3 GeV/c) where particle identification via energy loss measurements becomes impossible, and it will permit ϕ-meson detection with good acceptance. This enhanced particle identification capability in the central rapidity region is important for the reliable determination of hydrodynamic observables, such as flow, in correlation with thermodynamic variables, allowing a more accurate temperature determination which is needed for identifying a first order phase transition. It will also extend the p_t-range for intensity interferometry with identified particles.

The combination of SVT, central TPC, and TOF will provide almost complete information about final state hadrons emitted with thermal energies in the central rapidity region and will thus provide an excellent diagnostic tool for determining the thermodynamic and kinematic characteristics of hot hadronic matter created in nucleus-nucleus collisions at RHIC energies. This capability of isolating events exhibiting features characteristic of a phase transition is viewed as important.

The TOF array as presented to the Subcommittee consists of 2000 individual scintillation counters, covering approximately 1/3 of the central barrel region of STAR ($|\eta| < 1$) at a distance of 2 m from the vertex. The counters are individually read out by mesh dynode photomultiplier tubes (PMT's), capable of operating in the 5 kG central field. The estimated cost is $2.2 M, to be provided by DOE funds.

The design is conceptually simple and straightforward and relies on a proven technique, i.e. scintillators read out by PMT's. The design resolution ($\Delta t <$ 100 ps rms) has been demonstrated in a test beam at the relevant magnetic field with commercially available PMT's. The front-end electronics (discriminator, TDC, ADC) will be identical to the one under development for the PHENIX TOF array. The granularity of the array leads to an expected occupancy of order 20% for Au+Au reactions which does not leave a big safety margin should the particle multiplicities (or the experimental background) turn out to be much larger than predicted by current simulations.

Integration of the array into STAR should pose no problems in principle, as the TOF array will replace the corresponding section of the (coarse granularity) scintillator trigger barrel.

A major problem and risk of the proposed technology is cost; it is dominated by the uncertainty in the price for the PMT. By working with a Russian supplier, the STAR collaboration hopes to reduce the price from the current offer of \$870/tube to \$330/tube (the latter number was used in the overall cost estimate). For a fixed total cost, the number of channels and therefore the phase-space coverage will depend critically on this assumption.

A small-area TOF array (of the order of a few hundred channels) will be sufficient to measure inclusive particle ratios and correlate them to other observables measured event-by-event in STAR. Such a smaller array would already significantly enhance the physics capabilities of this experiment. A much larger array (of the order of 50% coverage of the barrel region) is needed for meaningful measurements of K/π-ratios or kaon p_t-spectra on an event-by-event basis. While the minimum size needed for either inclusive or event-by-event physics must be further investigated and documented by the STAR collaboration, the current proposal (30% coverage) seems to fall somewhat in between these two alternatives.

The Subcommittee feels that STAR should aim at a coverage which is sufficient for event-by-event Kaon (and possibly proton) identification, which in other observables is the prominent feature and strength of STAR. If fiscal constraints are such that this cannot be realized, a small area TOF array would still be very valuable, and further R&D should be encouraged to search for a viable solution for large area coverage.

Electromagnetic Calorimeter (EMC)

The STAR group proposes to add an electromagnetic calorimeter (EMC) to the baseline detector. This detector would cost \$14.4 M, of which \$7.8 M is requested from the DOE, the balance coming from in-kind contributions from Russian collaborators.

The proposed EMC will provide measurements of the neutral energy emitted at central rapidity (mostly π^0 and η mesons) and will thus provide additional information about the hadronic final state. The EMC lends itself to interesting triggering capabilities allowing, for example, selection of events with unusual isospin distribution patterns which could be created in the chiral phase transition. RHIC will be the first heavy-ion accelerator to reach an energy domain for which perturbative QCD interactions will constitute an important mechanism for energy deposition at central rapidity. The EMC will allow unique diagnostics for hard and semi-hard QCD phenomena in p+p and p+A collisions and provide unique capabilities for measurements of gluon distributions and gluon shadowing – important input to QCD-based models of nuclear reactions at RHIC energies. For polarized p+p collisions, the EMC will allow the measurement of spin-dependent parton structure functions, an important goal in particle physics.

The detector is a lead-scintillator sampling calorimeter, consisting of lead absorber sheets interspersed with scintillator tiles. The light from the scintillators is sampled by wavelength shifting optical fibers fused to clear fibers which bring the light to photomultipliers located outside the magnetic volume. The detector comprises a barrel section covering the full azimuth and ± 1 units of rapidity with 1200 readout towers, and a single end calorimeter with 720 towers covering the rapidity interval from 1 to 2.

Provisions are made to include a shower maximum detector to improve spatial resolution and distinguish single photons. The general technology is well developed and similar detectors have been built and operated by many experiments. A test module has been constructed and operated in a test beam giving performance as expected.

Completion of this detector is proposed for approximately 18 months after initial RHIC turn-on and this schedule is reasonably matched to the expectations of RHIC running conditions needing this detector -- i.e. full luminosity and start of p-A collisions. There is some urgency to installation of a fraction of the barrel modules below the TPC because later installation of these modules would be difficult and costly in time. The Subcommittee views the completion of the EMC as an important enhancement of the STAR physics capability.

External TPC (XTPC)

A set of two external TPC's (XTPC's) is proposed to extend the charged-particle acceptance of STAR toward the fragmentation regions ($2 < |\eta| < 4.5$, full azimuthal coverage) to measure charged-particle multiplicity and baryon distributions. The XTPC's are of novel design (radial drift, inner radius 10 cm, outer radius 2m) and would cost $4.2 M, most of which would be covered by foreign funds ($3.1 M are pledged by the MPI-Munich). The possibility of combining the XTPC's with a photon-multiplicity array (provided in full by foreign contributions) is under investigation, but was not discussed further during the presentations.

For the very forward region, the choice of radial drift is attractive because it ensures good two-track resolution in the region of largest occupancy (i.e. close to the beam). Radial TPC's, as well as new read-out chambers based on micro-strip technology, are undergoing R&D at this moment, and a proof-of-principle is expected in the near future. Conventional rectangular TPC's are considered as a back-up solution. In either case, the electronics will be identical in design to that used for the central TPC.

The XTPC, if built with radial drift, is a challenging project which will have to undergo further R&D and in-depth technical review in order to establish the feasibility.

The XTPC's will provide tracking, charge-sign determination and limited momentum resolution close to the fragmentation region, but no detailed particle identification. The physics in the forward, baryon dense regime is potentially very different from the central region and of significant interest. However, the capability of the XTPC's to do sensitive measurements in this region (e.g. particle momentum spectra, flavor composition, intensity interferometry) remains to be demonstrated. The charge sign determination, according to current simulations, would be sufficient to measure the net charge excess and therefore the proton distribution ("stopping") on an inclusive basis, complementing the more direct measurement of protons in the BRAHMS spectrometer.

The XTPC's will provide multiplicity distributions ($d^2N/d\eta d\phi$) and fluctuations thereof on an event-by-event basis. This will be a significant addition for STAR and extend its capability of global event characterization and fluctuations over a much larger rapidity range. The Subcommittee recommends that the STAR collaboration investigate whether the use of a simple multiplicity array could provide similar performance at a greatly reduced cost. Otherwise, the physics case for the XTPC needs to be strengthened. Therefore, the XTPC is not recommended for additional funding at this time.

PHENIX Equipment Request

Muon Arm

The baseline PHENIX detector has a partially funded muon arm; it includes the magnets, but lacks the active elements. Completion of the muon arm would cost $10.5 M, to be borne solely by the DOE.

The muon arm is designed to detect muons emitted at polar angles $\theta = 10° - 35°$. It is designed to measure muon pairs from ϕ, J/ψ and Υ decays and with momenta above about 2 GeV/c with good efficiency and mass resolution (expected to be $6\% / \sqrt{M}$). Although vector mesons of low mass (ω, ϕ) and medium mass (J/ψ, ψ') are produced at relatively large rates, a good understanding of the combinatorial background is required in the low-mass region where the signal-to-background ratio is of the order of 1/100. In the high-mass region (Υ, Υ'), the decay background is negligible, and the unlike-sign di-muon continuum is dominated by prompt muons from Drell-Yan and other processes. The second muon arm (see below) will significantly increase the statistics in this high-mass region, which will be particularly helpful for the measurement of Υ'' and the continuum. In addition, e-μ coincidence measurements will allow determination of charmed meson production and of the decay background to be subtracted from di-muon spectra.

The muon arm would provide a significant enhancement for the RHIC physics program. It is essential for Υ-measurements and very important for J/ψ–measurements. Muon pair measurements would greatly expand J/ψ coverage in rapidity and complement e^+e^- studies done at central rapidity. Experiments at CERN with 200 GeV/nucleon collisions indicate that the production of J/ψ particles may be strongly quenched in the dense matter environment. The J/ψ's were studied at CERN with a muon spectrometer, which provides good efficiency. Limited J/ψ detection is possible via the e^+e^- decay branch, but the primary tool designed for studying J/ψ production at RHIC is the full muon-detection system which was deferred in the baseline PHENIX detector. Since the J/ψ yield is one of the very few observables that showed evidence of a dense medium in the CERN experiments, the Subcommittee judged it essential to have this part of the PHENIX apparatus added and operational from the beginning of RHIC operation. Delaying the muon arm implementation to later years would seriously impede the physics scope of RHIC and have the unfortunate consequence of requiring significant lost time for subsequent installation.

The proposed muon arm is well suited to these measurements. Extensive simulations of the muon arm detectors have been carried out, producing realistic design goals. A copper "nose-cone" and the central magnet pole tip absorb forward going hadrons. Penetrating muons are tracked with three stages of chambers and subsequently identified in an array consisting of three layers of absorbers interleaved with streamer tubes. The tracking detectors (either drift chambers or cathode strip chambers) have been prototyped, and beam tests indicate that the technical requirements such as position resolution and efficiency are readily achievable in the RHIC environment. Similarly, the limited streamer tube technology chosen for the muon identifier has been well established in other comparable applications. Initial engineering considerations involving detectors, electronics, mechanical layout, and support structures all appear reasonable.

The Subcommittee concluded that the feasibility of the proposed muon arm was well established and that an aggressive schedule of design decisions, procurement and installation should allow it to be available for physics at the RHIC start-up.

A second muon (south) arm is proposed (and funded) by the RIKEN-supported Japanese group. Although it is primarily intended for important spin physics, the second arm will also greatly enhance the μ-pair acceptance for relativistic heavy-ion studies and allow the potentially interesting large angle (i.e. large mass at low p_t) region of μ-μ pairs to be accessed.

Level 2 trigger

PHENIX is primarily designed to look at electromagnetic processes which occur at rates of order α_{em} or α_{em}^2 (e.g. electron pairs) lower than hadronic processes. Most of these occur in a high combinatorial background. The data rate of central Au+Au collisions at design luminosity is 224 Mbytes/s -- to be compared with an archiving speed of 20 Mbytes/s. The data rates in p+Au or Si+Au are two and four times larger, respectively. If the system is run near the throughput rate, unprecedented data volumes (200 TB/year) will be archived. The Level-2 trigger provides real-time event-by-event selectivity to ensure high efficiency for interesting rare events while rejecting the dominant fraction of other collisions. For example, the J/ψ also decays into e^+e^- pairs, but the absence of a simple signal in the high-multiplicity background requires a Level-2 trigger to select these decays. The cost of the Level-2 trigger is estimated at $1.16 M, to be provided by DOE funds.

The PHENIX Level-2 trigger has been integrated into the on-line system design from the beginning. It is recognized that initial running will occur at less than design luminosity, but it is essential to verify the performance of the Level-2 trigger architecture and algorithms before they can be relied upon to control data acquisition. This requires intensive studies with real data sets and realistic trigger hardware. To ensure a smooth evolution from initial experimentation to production-mode data taking at design luminosity, the Level-2 trigger must be available at Day 1.

The hardware design of the Level-2 system appears solid. However major additional work is still required on the trigger algorithms. To date only the di-muon trigger has been investigated at an acceptable level. In addition, the levels of both signal and background are considerably uncertain in the RHIC environment. The collaboration understands these issues, and the Subcommittee believes they have proposed a hardware structure with the flexibility to deal with them. The Subcommittee considers this request for additional equipment to be of very high priority since a significant delay in funding would likely compromise the performance of PHENIX in the second and third years of operation.

Transition Radiation Detector (TRD)

It is proposed to enhance the particle identification capability of PHENIX, in particular for electrons at high momentum, by increasing the number of time expansion chambers (TEC) from four (as in the baseline detector) to six and converting them to transition radiation detectors (TRD). The TRD detectors become useful for electron identification at momenta above 2 to 3 GeV/c augmenting the ring imaging Cerenkov (RICH) detector which provides insufficient pion-electron separation at momenta above 3.5 GeV/c. The combined pion/electron discrimination of the TRD and the electromagnetic calorimeters at $p > 3$ GeV/c is estimated to be better than 10^{-4}. In addition, the extra planes of chambers will improve the dE/dx resolution significantly. The combination of additional particle identification capability and redundancy, especially for pion rejection, would substantially improve PHENIX's capability to selectively study rare high-p_t physics processes. The Subcommittee recommends this upgrade. The cost for the TEC mechanics alone is $300 k (without contingency), which is part of the total estimated cost of the TRD upgrade of $1.56 M (with contingency), to be provided by DOE funds.

The mechanical system has been designed to facilitate this upgrade to six chambers with TRD readout. Although the detailed design of the TRD is in progress, it appears that a reasonable concept for the chamber and radiator system exists. Some questions concerning the operation of the TRD in the high multiplicity RHIC environment may need to be answered by beam tests of prototypes and further simulations. The effects on low-p_t measurements due to multiple scattering in the added material of the TRD also merits further investigation.

It would be efficient and cost-effective to construct the additional two TEC planes in the initial production run and to install them together with the original four chambers; installation at a later date would require a lengthy shutdown. The conversion to a TRD (radiators, gas system, additional electronics, etc.) could then be done later without disassembling the PHENIX detector.

High-Resolution Photon Spectrometer (BaF_2)

The BaF_2 array is designed for direct photon measurements below 1 GeV. Direct photons above 1 GeV can be measured in the base configuration of PHENIX, but below that energy background problems become increasingly formidable, and improved resolution may be needed. Lower energy photons are produced in the mixed plasma phase, and their yield depends on the duration of that phase. This gives a strong motivation to augment the experiment to extend the range towards lower p_t. The physics is very important for RHIC, and it may be partially pursued using the baseline lead glass and lead scintillator calorimetry. The high resolution photon detector is designed to push the transverse momentum acceptance for electromagnetic and hence π^0 detection as low as possible. The high-resolution photon detector provides substantially better resolution than any of the other photon detectors at RHIC increasing the peak to total ratio of the π^0 signal by a factor of three to four. The high-resolution photon detector allows background π^0's to be reconstructed more efficiently, providing the means to study direct photons in the energy range 0.5-1.0 GeV, hopefully with a sensitivity of $\gamma/\pi^0 < 5\%$.

The choice of technology (BaF_2 crystals) is appropriate for this physics, and offers the distinct advantages of superior energy and time resolution. Crystals of the right dimensions and properties have been obtained from Chinese vendors. The collaboration has negotiated an attractive price and delivery schedule with these vendors. If there is no early commitment to this project, price and delivery time may increase significantly. The BaF_2 crystal array has been well integrated into the PHENIX design and could be installed after turn-on, but this would require a shut down of several months duration. The total cost of this project is $6.6 M, with an anticipated contribution of $2.9 M from the NSF.

The Subcommittee views this detector as an improvement of the baseline detector lead glass capability at low energy.

Off-Line Computing Facility

The data processing requirements for RHIC experiments are extreme and exceed the computing resources presently available at Brookhaven or any of the other collaborating institutions. Estimates of RHIC computing needs are still evolving and highly uncertain. A 1992 estimate of 40 GFlop now appears inadequate, and a system goal of 170 GFlop was presented to the Subcommittee. The Subcommittee understands the pressing need for major computing resources, but it was not in a position to make an independent assessment of the overall computing effort needed to process the data produced for steady state RHIC operation. Rapidly evolving technology and falling computer costs make it advantageous to make major hardware purchases as late as possible. However the structural and organizational issues need to be resolved well in advance and should be addressed with a high priority.

The overall plan to create a large off-line computing facility with network-connected CPU/memory and robotic mass-storage, capable of satisfying all major data-analysis needs of RHIC users is attractive since it takes advantage of economies of scale and is viable. Fast long-distance computer links to the users' home-institutions will provide access to off-site users, although the majority of the effort is expected to be at BNL. This concept of analyzing the bulk of the RHIC data at Brookhaven is endorsed by the Subcommittee. The cost of the needed facility is uncertain, and some of the performance-per-dollar projections for mass storage and archiving may be optimistic. Overall, the estimated need of $8 M appears to be of the correct order of magnitude.

The Subcommittee gives highest priority to the proposed creation of an off-line computing facility capable of meeting the data analysis needs of RHIC users. Because of the large and uncertain cost, the Subcommittee recommends the development of a detailed structural plan on how to meet the integrated user needs, including anticipated needs for home-based computing capability by individual RHIC user groups. This plan should be reviewed and carefully scrutinized by an external group of experts before implementation.

[redacted]

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December 29, 1994

Professor Konrad Gelbke
Cyclotron Laboratory
Michigan State University
East Lansing, Michigan 48824

Dear Konrad,

In a letter dated October 24, 1994, NSAC has been asked to provide advice to DOE and NSF on the scientific merits of a request to provide $42M (FY96 $) of funding for additional RHIC experimental equipment. The full charge to NSAC is enclosed. RHIC is a very high priority initiative for nuclear physics and, within the project, $112M has been allocated for base equipment. These capabilities provide the core needs for the RHIC experimental program at construction completion (March 1999). RHIC Project Management has now developed a proposal for extending the physics capabilities of the large detectors STAR and PHENIX and for providing enhanced analysis capabilities. To evaluate this proposal, NSAC is establishing a Subcommittee on RHIC Experimental Equipment, composed of:

K. Gelbke (Michigan State University), chairman
G. Bertsch (University of Washington)
D. Bryman (TRIUMF)
J. Schukraft (CERN)
D. Geesaman (Argonne National Laboratory)
M. Marx (State University of New York at Stony Brook)
B. Mueller (Duke University)

NSAC has also been asked to provide the agencies a new Long Range Plan (LRP), with an interim report due in April 1995. The NSAC recommendation on the RHIC equipment request must be folded in to the LRP scientific priorities. Thus, we are asking for a subcommittee interim report to NSAC at its February 24-25, 1995 meeting and a final report by March 1, 1995, so that your recommendations can be used effectively in the LRP process. The final NSAC recommendation will be issued concurrent with the LRP interim report.

Based on the charge to NSAC, the specific charge to the Subcommittee on RHIC Experimental Equipment is to provide NSAC with an evaluation of the increased scientific capability which would be realized with the requested funding. Contributions and commitments from foreign institutions and additional equipment funding requests to the National Science Foundation should be folded into your considerations of increased scientific capability of the RHIC detectors. Clearly, these scientific judgments are somewhat dependent on technical feasibility and cost. You should use existing technical reviews, as appropriate. Relative scientific priority should be assigned to different components of the proposal.

NSAC will rely heavily on your report in making its recommendations consistent with overall LRP scientific priorities. The nuclear science community appreciates very much your willingness to take part in this important evaluation.

Sincerely yours,

Ernest J. Moniz
Chairman
Nuclear Science
Advisory Committee

EJM/ll

xc: NSAC
D. Hendrie, DOE
J. Lightbody, NSF

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December 2, 1994

Dr. Thomas W. Ludlam
Bldg 510C
Brookhaven National Lab
Upton, NY 11973

Dear Tom:

The following persons have agreed to serve on the NSAC Subcommittee on RHIC Experimental Equipment: Konrad Gelbke (Michigan State University), George Bertsch (University of Washington), Doug Bryman (TRIUMF), Don Geesaman (Argonne National Laboratory), Michael Marx (SUNY, Stony Brook), Berndt Mueller (Duke University); one more person has to be nominated.

As discussed over the telephone, I would like to hold the fact-finding meeting at Brookhaven National Laboratory during January 4 and 5. Please provide advance written material to the committee members no later than December 15. The following issues should be addressed:

1. Overview of baseline detector program:

- Physics objectives of baseline program.
- Compromises made to optimize baseline program.
- Overlap and complementarity of the four baseline detectors.
- Funds already expended and/or committed.
- Technical feasibility and risk of approved detectors constructions.

2. Individual detector upgrades:

- Physics objectives for each upgrade.
- Subproject leaders and their past scientific accomplishments.
- Physics overlap with other detectors (incl. upgrades) and unique new physics obtainable.
- Technical feasibility, cost, and risk of proposed upgrade.
- Relative scientific priorities inside the respective collaboration.

- Urgency and impact of delayed or reduced funding.
- Impact of physics lost without the proposed upgrade.

3. Off-line computing facility:

- Conceptual plan, cost, and time schedule.
- Options for lower cost implementation.
- User input and participation (past and present).

In the written material, please include sufficient detail on technical risk and cost, plus information from previous technical reviews. In its deliberations the committee will consider cost, feasibility, and physics motivation.

I also enclose a draft agenda for the fact-finding meeting at BNL.

Best regards,

C. Konrad Gelbke

Agenda for Subcommittee on RHIC Experimental Equipment

Subcommittee Members: Konrad Gelbke (Michigan State University), George Bertsch (University of Washington), Doug Bryman (TRIUMF), Don Geesaman (Argonne National Laboratory), Michael Marx (SUNY, Stony Brook), Berndt Mueller (Duke University), Jürgen Schukraft (CERN)

Wednesday, January 4, 1995

8:30 - 9:00	Committee Executive Session
9:00 - 9:30	Overview, incl. small detectors. (Ozaki, Ludlam)
9:30 - 9:40	Discussion
9:40 - 10:20	STAR baseline detector and physics program (Harris)
10:20 - 10:40	STAR: Discussion
10:40 - 11:00	Break
11:00 - 11:40	PHENIX baseline detector and physics program (Nagamiya)
11:40 - 12:00	PHENIX: Discussion
12:00 - 12:30	Committee Executive Session: Briefing on NSF/DOE Issues (Hendrie)
12:30 - 1:30	Working lunch for committee
1:30 - 2:00	Overview from RHIC Technical Advisory Committee (Mecking)
2:00 - 3:30	STAR AEE presentations (SVT, EMCal, TOF, External TPC)
3:30 - 4:00	Break
4:00 - 5:30	STAR AEE: Discussion
5:30 - 6:30	Executive Meeting
7:30	Working Dinner, writing

Thursday, January 5, 1995

8:30 - 10:00	PHENIX AEE presentations (Muon Arm, Photon Detector, Hi-P_t)
10:00 - 10:30	Break
10:30 - 12:00	PHENIX AEE: Discussion
12:00 - 1:30	Executive Lunch
1:30 - 2:00	Computing presentation
2:00 - 2:30	Computing needs: Discussion
2:30 - 4:30	Executive meeting, outlining of report
4:30	Closeout meeting
5:00	Adjourn