RHIC Detector Workshop
R&D for Future Detectors and Upgrades
Brookhaven National Laboratory
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Executive Summary

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Introduction

The Workshop was organized to discuss detector technology and upgrades of interest for the future physics program of the Relativistic Heavy Ion Collider. A list of the 105 registered participants is appended to this report. The agenda for the workshop, with links to the transparencies presented by invited speakers, can be found at the workshop website: www.star.bnl.gov/STAR/rhicworkshop.

The workshop provided a forum for continuing the dialogue begun as part of the NSAC Long Range Plan process regarding detector development. Detector upgrades will be required over the next several years to extend the physics reach of the present RHIC detectors, and possible new detectors, in anticipation of significant upgrades in machine capability. This workshop was planned as a means of setting the stage for specific R&D planning in areas of detector technology that are on the critical path for the next phase of experimentation at RHIC.

The four RHIC "baseline" detectors are now taking data and providing the first look at the high energy regime of heavy ion collisions in which new phenomena related to the quark-gluon phase of nuclear matter are expected to be revealed. These same detectors will also study the quark and gluon structure of the nucleon via high energy collisions of spin-polarized protons in the RHIC Spin program. This first exploratory phase of the RHIC research program is planned to extend through 2005. In the meantime a large and growing community of scientists is investigating the opportunities to exploit the unique capabilities of RHIC in the era beyond the discovery of the quark-gluon plasma. RHIC is the first truly "nuclear QCD" machine, with capabilities for high energy collisions of AA, pA, pp (spin), and, perhaps eventually, eA (polarized).

The scientific program for RHIC beyond the exploratory phase with the baseline detectors was a major topic of discussion during the recent Long Range Plan study, from which there emerged a broad consensus that upgrades to the machine and its detectors, to be implemented during the latter half of this decade, will afford unique new opportunities to study hot and dense nuclear matter with observables for which there exist reliable connections to QCD theory. Precision measurements of rare processes, such as particle production at very high p_t and q^2, call for increased machine luminosity. Specific plans exist to increase the RHIC luminosity by a factor of ~4 beyond the design value over the next few years by increasing the beam currents and improving the brightness of the beams at the crossing points. Over a longer period, a major upgrade is foreseen to utilize electron beam cooling to enhance the luminosity for heavy ion collisions by a further factor of ten.

Correspondingly, the present detectors require upgrades to exploit the enhanced machine performance and to provide specific measurement capability that does not now exist. Some examples that have been extensively studied include:

- Precision inner tracking devices capable of directly observing charm and beauty decays.
- Particle identification over large solid angles in the high track density environment of heavy ion collisions, utilizing time-of-flight and Cherenkov imaging techniques.
- Efficient rejection of Dalitz and conversion electron pairs to enable measurement of low-mass lepton pairs and low-p_t direct photons (e.g. the implementation of a "hadron blind" tracking detector).
- Improved data acquisition and trigger techniques to handle very large data volumes at high rates.
- Tracking and particle identification at large rapidities (comparable to the existing capabilities for STAR and PHENIX near central rapidity) for spin and pA physics.

A number of specific technologies are being investigated by the PHENIX, STAR and PHOBOS collaborations. Some R&D efforts have begun, and it is recognized that in several areas advances in technology beyond the present state are necessary in order to meet the requirements for upgraded RHIC detectors. The aims of this workshop were to identify the essential R&D, to assess the necessary resources and timescales, and to begin a process to fund and carry out the necessary development efforts to support detailed construction designs for detector upgrades.

It is recognized that this is a global effort, with many non-U.S. interests. For example, PHENIX collaborators with Japanese funding have begun significant efforts to develop improved techniques in precision tracking and high-momentum particle identification for upgrading that detector. There are many common interests between the RHIC experiments and the developments being pursued by European groups for the LHC experiments, particularly ALICE.

Nonetheless, it is clear that U.S. funding dedicated to detector R&D for RHIC is required on a timescale of 3-5 year prior to the start of construction of major upgrades (or new detectors) for this program. It is also recognized that budgets for nuclear science are tight, and funding opportunities very constrained. Therefore, priorities for new developments must be considered from both the scientific and the technical points of view. Coordination of R&D efforts among different experimental groups will be necessary within areas of technology where there are shared interests.

<u>The Essential R&D Needs--</u> Results from the working groups

Four working groups were convened in advance of this meeting to summarize and critique the current state of development in areas where refined or emerging technologies are of interest for the next phase of experiments at RHIC. These groups formed the core for discussions and conclusions at this workshop. The working groups and their convenors were:

Semiconductor Vertex Tracking	Rene Bellwied, Wayne State U.
Gas Tracking Detectors	Itzhak Tserruya, Weitzmann Inst.
Particle Identification	Hideki Hamagaki, Univ. Tokyo
Trigger/Data Acquisition	James Nagle, Columbia U.

An important element in the consideration of future detectors for RHIC is the need for high-resolution, compact detectors operating close to the interaction point, with collision rates (luminosities) up to forty times greater than the current RHIC design values. For example, a small TPC considered for upgrades in both STAR and PHENIX will be exposed to about the same number of particle tracks per event in heavy ion collisions as the present large TPC in STAR (assuming approximately the same phi and eta coverage). Smaller chamber dimensions will require a much better absolute position resolution in all coordinates. Higher luminosity will result in much higher readout speed and data rates. The readout electrodes will have a finer granularity (the number of pads per unit area) by a factor between 10 and 40 to satisfy the position resolution requirements. Power dissipation per signal channel in the readout electronics on the chamber will have to be reduced by more than an order of magnitude to make the cooling and temperature control of such a small, low mass detector practical.

From the working group discussions, the following areas were identified where R&D can and should proceed immediately…

<u>Fine-grain tracking with silicon detectors</u>

A number of technologies now under development elsewhere need to be studied for specific applications in the RHIC environment. These include hybrid (bump bonded) pixel detectors, such as those being developed for the ALICE detector, and Monolithic Active Pixel Sensors in CMOS technology. At this workshop, new ideas for CCD detectors with fast readout (column-wise readout) were presented which may prove feasible for RHIC applications. Issues to be addressed include pixel size, overall thickness in radiation lengths, (is it feasible to make a full detector, including support structures, cooling, on-board readout, etc. less than ~2%X_0 thick?), zero suppression, radiation hardness, luminosity limitations, feasibility and cost of fabrication. The desire for close-in detectors capable of resolving the decay vertices of charm particles in the higher luminosity environment requires studies of all of these issues, and improvements on the present technology limits in most.

Silicon strip detectors are now employed in a number of collider vertex detectors , and it will be useful to extend and optimize the technology for large area detectors at RHIC, such as the forward trackers envisioned by PHENIX and STAR.

Fine-grain tracking with gas detectors; Hadron Blind Detector

A particular area of interest is in the measurement of low mass electron pairs, which requires good electron identification and pion rejection in order to reject the high level of background arising from Dalitz decays and photon conversions. One possible approach to this problem is to build a detector that will provide good electron/pion separation, particularly at low momentum, such as small, fast TPC or a Hadron Blind Detector (HBD). These detectors would most likely require the use of micropattern detectors, such as GEMs or Micromegas, as readout devices in order to achieve the required gain, spatial resolution and efficiency in the RHIC environment. In addition, the HBD would require the use of photosensitve materials inside the gas detector, such as CsI as a photocathode, in order to detect the Cherenkov light emitted by electrons.

There are three critical areas that require R&D well in advance of a construction project:

1. Studies of ***gases with fast electron drift***, which will have sufficient UV transparency for combined TPC-HBD operation and good gain properties for stable operation with micropattern electrodes (GEM or Micromegas):

2. ***Micropattern gas electrode design*** with stable gain and very low positive ion transmission into the drift volume of the TPC or HBD. Conventional TPC gating techniques to minimize space charge effects may not be compatible at all with a fast TPC which has to record multiple events within a single drift time, and, with a fast low noise readout;

3. ***Readout electrode ("anode") design*** with a granularity optimized for double track resolution and for minimum number of signal channels. The electrode will have to have some interpolating properties (allow centroid finding) to achieve a good position resolution. While micropattern electrodes for gas gain make possible good resolution in both coordinates, position interpolation is more challenging than with wire chambers. The electrode design will have to incorporate in a three-dimensional structure the front end electronics, all interconnections, and cooling. We highlight the necessary monolithic circuit design in the section below on Microelectronics.

Microelectronics for fine-grain, low-mass detectors

All of the present RHIC detectors are read out by custom monolithic electronics, with ~17 custom chip designs serving gas, silicon, and scintillation detectors. RHIC was among the leaders of this approach, but an ensuing decade of progress in microelectronics technology has made higher integration densities possible.

Compared to the existing RHIC detectors, the proposed upgrades call for nearly 200 times as many electronic channels while maintaining the same power, cost, and volume. To achieve this remarkable granularity will require an intense microelectronics R&D effort. Designers will need to gain experience with ultra-scaled CMOS submicron technology and with the associated computer-aided tools for million-transistor designs. Equally important is to evaluate interconnect and cooling technologies that will be needed for the reliable assembly of detector-mounted electronics with up to 5000 channels/cm^2. The critical issues of power consumption, data sparsification, and the trigger/DAQ interface will also require study at an early phase in the development cycle.

<u>Particle Identification</u>

A critical element in the design of the present RHIC detectors has been the capability for identification of soft hadrons in events of very high particle density. For the next phase of experimentation this capability needs to be extended to higher momenta and larger solid angles wherever possible. Major items under consideration in this area include:

- The use of Aerogel Cherenkov radiator to extend PID in the PHENIX central arm to momenta ~9 GeV/c. Work is underway in Japan to understand the properties of Aerogel and develop readout techniques.
- The use of multigap resistive plate chambers to provide large-area, fine-grain time-of-flight detection for STAR.
- Photocathode and readout structures for large-area, fine-grain ring imaging Cherenkov detectors.

<u>Data acquisition and trigger development</u>

The next round of RHIC experiments will have larger data volumes per event and larger event rates… in each case, about an order of magnitude greater than the present values. This is similar to the environment faced by the LHC ALICE detector. As a base model, it is assumed that the upgraded RHIC detectors will record ~1MB/event; the Level-0 triggers will accept events at a rate of 25 KHz; and that data can be archived at a rate of 250 MB/sec. This calls for a coordinated effort in front-end electronics (zero suppression in FEE), fast gate arrays, high speed digital signal processors, advances in digital trigger technologies (ASICS), and increased data archiving capability. The triggering requirements to take advantage of the higher luminosity and new detectors will be extreme. The technology is changing very fast and without R&D it will not be possible to make use of these necessary advances. This is an area where there are both specific requirements for different experiments and also shared interests among the experiments. The R&D over the next 3-4 years will require the dedicated effort of ~5 engineering/technical FTE.

Time Scales and Costs

The envisioned upgrades to the RHIC detectors associated with the "RHIC II" initiative discussed in last year's Long Range Plan process have been refined with further study in recent months. This workshop has identified specific areas where detector R&D is required now in order to develop conceptual designs and begin construction over the next 3-5 years. Although the working groups at this workshop have not provided detailed estimates of costs and schedules, it appears that the level of R&D effort proposed at the Town Meeting on High Energy Nuclear Physics, January 2001, is appropriate. (See the White Paper on High Energy Nuclear Physics on the NSAC web site www.star.bnl.gov/STAR/nsac.) Taking account of the fact that no explicit funding for R&D has been allocated by DOE for FY 2002, this plan calls for an R&D funding level of $1M - $2M/yr beginning in FY 2004, with start-up funding of $.5M in FY 2003. Some work has begun in the current fiscal year, with internal funding at laboratories and universities in the U.S., and cooperative efforts are emerging with non-U.S. support, particularly in Japan.

Coordinating an R&D Plan

An important issue is the question of how to develop and coordinate a plan for funding and carrying out the necessary R&D. As in past examples of R&D funding for large detector projects (such as the R&D program that preceded the construction of the RHIC baseline detectors), it can be expected that funding allocations and priorities will be driven by proposals, with some method for peer review.

Since the detector collaborations are developing internal plans and priorities for upgrades, it is natural to expect that each collaboration will prepare an overall proposal for R&D based on its upgrade plans. These proposals would incorporate the interests of individual institutions. These collaboration-wide proposals could then be bundled into a single plan, including some shared R&D where appropriate, that could be forwarded to DOE with the blessing of Brookhaven management and the general RHIC community. Such a plan would be more effective, and useful for DOE, than a large number of independent proposals.

With this in mind, we (the organizers and convenors of this workshop) recommend that BNL issue a formal call for proposals from the RHIC detector collaborations for R&D funding necessary to develop, design, and initiate construction of new detector elements to extend the physics reach and exploit the improved machine capability of the "RHIC II" era. This call should include the possibility of R&D proposed by proponents of completely new detectors. It should also encourage cooperative efforts in areas where there is a shared interest in particular areas of technology development. These proposals should be submitted to BNL management by the end of May 2002. BNL should then facilitate a means to incorporate these proposals into a single request to DOE for initiation of an R&D funding program for RHIC detector upgrades. This request should reach DOE in September 2002. As a part of the process of preparing a final proposal for submission to DOE, it may be of value to convene a follow-up workshop early in the coming summer to discuss and refine the proposed R&D plan.

Once a funding program is initiated, the task of setting priorities, guiding decisions regarding specific funding allocations, and monitoring progress could be aided by a carefully chosen steering committee that might be convened either by DOE or BNL.

Appendix 1

Registered Participants

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