RHIC DETECTOR ADVISORY COMMITTEE

Report of Review on Dec. 19 -20, 2002, at BNL

1. Introduction

BNL is currently considering possible upgrades to the RHIC accelerator and experiments. The detector advisory committee was convened by the BNL Physics Department to assist in initiating the detector upgrade process and to follow its progression through an R&D phase to construction projects.

The committee, consisting of Peter Braun-Munzinger (chair), Russell Betts, Carl Haber, Donald Geesaman, Berndt Mueller, Rick Van Berg, and Jerry Va'vra, met on Dec. 19 - 20, 2002 at BNL, to evaluate proposals by the STAR and PHENIX collaboration.

The committee's report, consisting of a brief evaluation of the physics case for the upgrades, as well as detailed comments on the various sub-projects presented in the open session, is given below. The sub-projects were evaluated on technical merit and feasibility as well as on their possible physics reach. The committee has not attempted to make a detailed evaluation of the man-power needed by the collaborations for these projects nor studied the possible impact of such a program on the currently running experiments.

2. Physics Motivation

After the first two Au-Au runs of RHIC, it has become clear that the existing detector systems have insufficient capabilities in several important physics areas:

In general, one notes that after the beautiful measurements of bulk properties in Au-Au collisions the program will move into a phase where emphasis will shift towards studies with improved sensitivity for rare phenomena as well as studies requiring very large data samples. This will necessitate upgrades in the data taking capability of some detectors as well as data acquisition systems.

In particular, the following physics areas require specific new instrumentation:

1. Measurement of identified particle yields in the p_T range 3-10 GeV/c and hadron yields beyond 10 GeV/c. The data taken in the first two runs have identified the range up to 10 GeV/c as not yet being asymptotic in the sense of pQCD, with strong dependence of nuclear suppression factors on the particle type. It indicates a complex interplay between "hard" and "soft" QCD dynamics, which cannot be factorized. This is likely to signal interesting physics of particle emission from dense and hot matter, but requires high statistics measurements with particle identification. In parallel, it is important to push into the asymptotic range, where matter effects on parton spectra (energy loss) are universal and independent of hadron type. This requires extended particle identification and the capability of large sample data taking with consequent high luminosity and optimal triggering.

2. Charm has emerged as a valuable probe of QCD dynamics of hot matter. The charm quark is heavy enough to be a participant, but not a driving agent of the dynamics. On the other hand, it is light enough to be copiously produced at the top RHIC energy.

Questions to be answered are whether charm quarks thermalize and participate in the collective flow, and how they hadronize. The development of heavy quark effective theory permits reliable theoretical predictions of certain phenomena involving hadrons with open charm beyond pQCD. The measurement of hadrons with open charm requires excellent vertex identification, which can only be achieved with state-of-the-art silicon vertex detectors. The need to take large event samples requires triggering capabilities, which do not currently exist for the muon system in PHENIX.

3. Low mass e+e- pairs (below 1 GeV) are a uniquely sensitive probe of the structure of dense and hot QCD matter. Data from the SPS have established the power of this probe, revealing evidence for in-medium modification of the spectral function of the rho- meson. Model independent predictions for the spectral function in baryon-symmetric hot matter are emerging from lattice gauge theory. The capability of making such a measurement at RHIC is presently missing. It will require powerful tools for background suppression of conversion and Dalitz pairs. The PHENIX detector has the clearest potential to be upgraded for this purpose.

Good vertex identification and a muon trigger in PHENIX will also be a significant improvement for the measurement of the gluon structure of the nucleon and of nuclei by means of heavy quark pair production. However, in the accessible x- and Q^2 window the expected effects of shadowing are not large.

3. STAR Proposals

3.1. STAR Inner Microvertexing Layer

The improvement of the STAR micro-vertexing capability will enable the experiment to measure charm quark yields in p-p and Au-Au collisions with significantly improved efficiency. This is an important and well motivated physics goal.

The STAR group has presented a convincing top down approach to the development and design of an inner microvertexing layer. Based upon this, they derive a set of system requirements which drives the design to very high resolution and very low material thickness.

In order to obtain the required performance a significant technical development is required which includes an active pixel sensor and new packaging approaches such has highly thinned silicon wafers. While ambitious in many regards the program appears quite feasible in the time interval proposed and with the requested level of support. The proposed work is also well leveraged by efforts supported outside the project.

The committee views this development plan very favorably and recommends that it be supported with high priority. This is exactly the type of effort that RHIC detector R&D funds should support. Furthermore, the new developments proposed here may influence the future direction of development in the microvertex detector field at large.

3.2. TPC FEE

The STAR TPC has functioned well at the RHIC design luminosity and above the design trigger rate. The system is currently capable of recording 10 central Au-Au events per second. In the FY03 run, DAQ improvements should allow 100 central Au-Au collisions per second to be presented to the level 3 trigger with data recording at approximately 30 Hz. As discussed above, two of the key elements of the planned physics program are increased sensitivity searches for rare phenomena, many of which cannot be isolated in early trigger stages, and studies requiring very large data samples, both for correlation analyses and searches for new phenomena in bulk QCD matter. It is, therefore, essential that STAR proceed on a path to upgrade their data acquisition capabilities. The collaboration proposed a goal of an order of magnitude increase, with 1 kHz presented to the level 3 trigger. The TPC gated grid is capable of cycling at this rate. The highest priority path in this project is developing a replacement for the present TPC front-end electronics (FEE) with a higher bandwidth system incorporating data compression. This development can capitalize on the substantial progress achieved in ALICE with the ALTRO FEE chip which is a 16 channel analog/hybrid chip with analogue to digital converter and digital signal processor subcores on the chip. It is capable of pedestal subtraction, gain correction, baseline restoration and filtering, zero suppression and chip buffering for 8 events. R&D funds are requested in FY03 to evaluate the suitability of the ALTRO chip and other possible technical alternatives relative to the science driven requirements. The requested R&D manpower support would be matched by LBNL funded manpower contributions to this project. The committee considered this R&D to be of extremely high priority for the STAR experiment and the RHIC program. Basing the upgrade on the ALICE developments appears to be a very sound and cost-effective path.

3.3. MRPC Time of Flight Development

Large acceptance time-of-flight particle identification (PID) has been a design goal of the STAR detector from its original concept. The recent exciting results for identified hadrons and the key promise of future research paths emphasize the need to complement the large acceptance of the TPC with a large acceptance particle identification system. A time of flight system is expected to extend the PID momentum range of the TPC dE/dx measurements alone by a factor of approximately 2.5. Multi-gap resistive plate chambers (MRPC) being developed for the ALICE experiment at CERN appear to offer an excellent cost-effective solution to implement time of flight measurements in STAR with the required resolution. Members of the STAR collaboration have participated in the CERN development work and tested a prototype STAR TOF module. The collaboration has identified the need to focus effort on the the readout electronics to deal with the amplification, noise and throughput issues and the stringent space budget within the STAR detector. The committee agrees with this priority.

The scope of the work in FY03 is to specify the amplifier and comparator, prototype the front end electronics and develop the time digitizer card which would integrate the CERN HPTDC chip into an electronics card that will work in the STAR TOF system. The latter work is supported by a Phase-I SBIR proposal. Collaboration institutions plan to commit 2.2 FTE to the project. 1 FTE is requested from R&D funds along with $26k for travel and prototypes.

The committee considers this development very important for the STAR detector and the RHIC program, in particular concerning event-by-event physics with identified particles and precision measurements of identified particles in the transition region between the hydrodynamic and hard scattering regime. Significant progress has already been made on this concept and we see this upgrade as likely to be ready for a full capital equipment proposal in the near future. We would like to emphasize the importance of a realistic system test in the true RHIC environment. We also strongly encourage the submission of a Phase II SBIR proposal for part of this work.

3.4. DAQ

An increase in RHIC luminosity will require changes in and upgrades to the STAR DAQ. The major upgrade to the STAR detectors would be new, fast, TPC readout electronics based upon the ALICE ALTRO chip. Thus it is foreseen that the major DAQ challenge will be to couple the ALTRO back end into the STAR environment. The other sub-detectors in STAR are much smaller in terms of data volume and are expected to be much simpler to deal with and, thus, were not addressed in the proposal.

The present STAR DAQ system is based upon a hierarchy of commercial VME crates and the planned RHIC luminosity increases implies data volumes beyond what this architecture can easily handle. The proposal calls for detailed evaluation of commercial computing and interconnect technologies in FY03 with a view to building a demonstration system in FY05. While the committee agrees with the basic plan as presented, it is likely that the technological change in the commercial sector will be sufficiently great over the next few years that it is premature to settle now on a technology for use in about 2010. Therefore, we recommend a watchful survey of emerging and available technologies, but no investment in actual devices until the 04 or 05 time frame.

However, the TPC upgrade path is well determined at the front end level by the selection of the ALTRO chip and it does make sense to build a simple RB (Receiver Board) to allow use of prototype ALTRO front ends with the present STAR DAQ architecture. This should allow the collaboration to become familiar with the details of using the ALTRO and prepare the way for a second generation architectural choice in one or two years.

4. PHENIX Proposals

4.1. PHENIX Microvertex Tracking Detector

The extension of the capabilities of the PHENIX detector to provide a direct measurement of open charm and open beauty will have major impact on a number of physics questions in both Au-Au and pp collisions. This upgrade is therefore a very high priority in the future development of PHENIX.

It is likely that a detector system with adequate performance can be constructed using existing technology and it is therefore possible and desirable that a detailed proposal for this upgrade be in place in time for inclusion in the planning process for FY05 construction funds.

In order to meet this aggressive schedule, it is imperative that the collaboration move forward efficiently and effectively to identify the relevant technologies and incorporate them in a design. We therefore recommend a concentration of efforts on the most promising options at the earliest possible time. This effort should focus on the detectors and readout with the design of the mechanical support being deferred until the detector itself is fully specified.

We note that the wish to simultaneously operate the vertex detector with the hadron-blind and tracking detectors for low-mass e+e- pairs may place considerable and undesirable stress on the vertex detector design, particularly on the thickness of material in the detectors and readout. It may therefore be prudent to consider an option where these measurements are made independently.

This effort is crucial for the future of PHENIX.

4.2. Hadron Blind Detector

A hadron-blind detector (HBD) is a new detector concept. The technique needs a single electron detection capability, a transparent radiator gas in far UV region and an efficient photocathode converting the Cherenkov photons into photoelectrons. The proposed photocathode is a CsI film evaporated on top of a GEM foil. The photoelectrons are amplified by a system of three GEMs with pad readout. The necessary total gas gain is above 10^4. The CF_4 radiator gas provides a large N_0 value, i.e. produces a large number of photoelectrons detected in the device, because it is very transparent in the VUV region. The proposal was to combine the TPC and HBD into one common gas volume. Overall, the technique is very elegant, promising to detect electrons in a RHIC hadronic environment, however, it combines several very novel features. To be convinced that this new technique will work in the RHIC environment of very heavily ionizing particles, we recommend the following long-term tests:

1. Install a working GEM detector operating with a CF_4 gas in the RHIC environment as soon as possible. The idea is to check if the highly ionizing ions could trigger either a spark or the Malter effect (a continuous discharge current). At present, it is not even clear what the rate of such highly ionizing events would be. For example, longevity of the CsI photocathode requires a very low water content in the system. This in turn tends to enhance the chance to trigger such discharges. It is important to acquire long-term experience in the RHIC environment as it is almost impossible to create similar conditions in the laboratory.

2. CF_4 gas has a complicated chemistry. Possible effects due to its chemical composition will not show up in short-term tests. However, a long-term experiment requires that they be addressed. To mention a few examples: a) One could etch the GEM's copper electrodes in a continuous current discharge. It is therefore important to design the GEM high voltage in such a way as to retain a sensitivity to small currents as low as a few hundred nA. This may require a high segmentation of the GEM electrodes in the RHIC background environment. It is important to gain an experience in catching such discharges in very early stages. For example, use of a simple resistor divider to run the GEM multi-electrodes may reduce sensitivity to a discharge current. We recommend feeding voltages from individual HV power supplies. b) CF_4-based radicals react easily with various system impurities, such as Si, which can then be efficiently distributed throughout the system, if a closed-loop gas system is used. Usual filtering methods do not seem to work. This seems to be the experience in the high radiation environment of the ATLAS experiment at CERN. Again, an early experience with such problems and consultation with the chemists is highly recommended. c) There is some small but nonzero chance to form a HF molecule in a presence of CF_4, water and the plasma. Its effect on the CsI photocathode should be understood.

3. A choice of CF_4 gas has a very clear advantage to obtain a high value of N_0. Nevertheless, it is important to perform the above long-term tests also with an alternative

gas choice, perhaps CH_4, in order to have a solution in case that CF_4 gas does not work out.

4. We highly recommend a separation of the TPC and HBD detectors, see also the separate section on the compact TPC. It would greatly simplify a basic operation including possible TPC repairs. It would also simplify the TPC field cage design. Furthermore, it would allow different choices of gas if found necessary.

4.3. DAQ

An upgraded and improved DAQ system will be vital for running an upgraded PHENIX detector which would take advantage of RHIC luminosity improvements. The PHENIX group has pointed out a number of areas that need to be revised, but, because of the elegant architecture of the basic system, most revisions can be kept to a single class of off detector devices - the DCMs. Upgrades to bandwidth should be achievable, as they note, simply by moving to more modern optical and differential signalling technologies.

The collaboration presented a reasonable plan to examine, over the remainder of FY 03, possible system architectures appropriate to the increased luminosity, to survey optical and other high speed technologies, and to begin conceptual design of a new DCM module. The committee strongly supports this plan, but notes that given the developing nature of the plans for the silicon tracking, HBD, and new TPC detectors, it is probably premature to actually begin detailed design of a DCM. This is underscored even more by the uncertainty surrounding zero suppression requirements and solutions (at least for the silicon systems) - the final front end designs may or may not require zero suppression services from the DCM.

The committee expects that the PHENIX DAQ group will be much closer to final specifications for the detector front ends by the end of FY03 and would be able to present a plan for actual development engineering for FY04 funding.

5. Joint PHENIX-STAR Proposals

5.1. Compact TPC Development

Both experiments propose an R&D effort into the development of a micro-TPC. This is a gas-filled detetctor with compact dimensions which should provide high-rate tracking capability and particle identification via dE/dx measurements. Keeping in mind the expected luminosity upgrade at RHIC the drift time of this detector should be less than 5 μs. Depending on the choice of gas this leads to a maximum drift distance of about 40 cm. In STAR such a detector will operate in the solenoidal field such that the drift direction can be aligned with the magnetic field, thereby minimizing Lorentz angle distortions. In PHENIX, the magnetic field is not uniform, and special care has to be taken to minimize the effect of distortions. Nevertheless, the electrons drift in the gas mainly along the beam direction. Both experiments would like to use GEM based detectors as read-out chambers, mainly to get the required position resolution of about 100 μm.

In general, the committee is impressed by the efforts of the STAR and PHENIX teams to develop this novel detector concept. If successful this would break new ground for tracking in a high luminosity, high multiplicity environment. We therefore support this R&D effort and have the following specific comments:

1. As discussed above, we strongly recommend to uncouple the effort on the TPC from that on the HBD. This should significantly facilitate construction of a field cage and allow the work to focus on important questions such as choice of drift gas, and distortions from space charge and ExB effects.

2. Experience with GEM based detectors in collider experiments is limited. Therefore, we recommend to perform long-term tests in the RHIC environment with realistic detector configurations.

3. The ion feed-back through the GEM's into the detector volume needs to be studied in detail.

4. A prototype detector with field cage, read-out chambers, etc., should be built as soon as possible to study the performance of such a detector with lasers, cosmic rays, and under beam conditions.