Report of the
Technical Advisory Committee for RHIC Detector Upgrades
March 14-16, 2006

Committee members: *M. Cooper (LANL), C. Haber (LBNL), B. Mecking (JLab), J. Proudfoot (ANL), V. Radeka (BNL), R. VanBerg (U. Penn, not present at the review), J. Va'vra (SLAC)*

Introduction

This committee was convened by BNL to provide advice to the Laboratory on four proposed upgrades to the PHENIX and STAR detectors:

- PHENIX Forward Vertex Tracker (FVTX)
- PHENIX Nose Cone Calorimeter (NCC)
- STAR Heavy Flavor Tracker (HFT)
- STAR Integrated Tracking System (INT)

These upgrades play a prominent role in the future physics program for RHIC, as described in the "Mid-Term Strategic Plan for the Relativistic Heavy Ion Collider", submitted by BNL to DOE on Feb. 14, 2006. The committee was asked to assess each in the light of the proposed physics goals, and advise the Laboratory as to their feasibility and status of development, the soundness of the proposed costs and schedules, and their readiness to proceed as DOE construction projects on the proposed time scales.

The proposed upgrades are not all at the same stage of development. The two PHENIX upgrades (FVTX and NCC) are well advanced in their scientific and technical development, and are being proposed as Major Item of Equipment (MIE) projects to be funded in FY2008, with a Total Project Cost of less than $5M each. The two STAR projects are in a more developmental stage. The HFT relies on a newly-emerging technology for silicon pixel detectors, requiring substantial R&D effort in the years 2006-2008. The INT involves an optimization of the overall tracking configuration in STAR that is presently still under study. The STAR collaboration is aiming for both of these upgrades to begin construction as MIE projects in FY 2009.

The committee notes that both PHENIX and STAR have specified thin-walled beryllium beam pipes with a diameter of 3 cm in conjunction with the proposed vertex detectors. We recommend that this challenging aspect of the upgrade program be undertaken as a joint effort with the experts in the Collider-Accelerator Department, and with oversight by the Laboratory,.

The committee's findings and recommendations for the four proposals are given in the following sections.

PHENIX Forward Vertex Tracker

From a physics perspective the project is well motivated and the group has made a good scientific case. This was particularly well articulated in the responses to the committee's questions about the physics. The group should be encouraged to include these responses in the proposal and in future presentations, prominently. In particular, quantitative metrics that address the unique contributions of the FVTX are valuable tools to further support the case for this upgrade. Some particular points noted by the committee include the following.

- Identification of J/psi from B’s is not possible in the forward muon arms without this detector. Separation of charm from beauty also requires this detector. The same type of measurement from the inclusive spectrum appears to be hard, and likely to be systematics limited since the analysis requires the subtraction of one decay spectrum from the other. These systematics should be more thoroughly evaluated.
- W-boson physics will require a good understanding of the rate of fakes from mis-measured tracks at high P_t. It was stated that this fake rate is reduced by the FVTX, but no details were presented.

The overall layout and configuration seem appropriate for the measurement goals of this device. The committee finds that the FVTX is in a position to proceed to a construction phase in FY2008. We describe below some issues to be addressed, and steps to be taken, during the coming months in order to ensure a successful construction project that can be carried out with the proposed cost and schedule.

The technical design is based substantially on existing developments made by other groups. The front end readout is based up the FPIX chip developed at Fermilab for BTeV. A modification is foreseen (the PHX chip) which may appear to be largely a matter of configuration. However, a new layout may introduce new noise or coupling issues which are layout dependant. This needs to be considered and foreseen as part of the chip fabrication cycle. The mechanical design of the module derives from the design of the ATLAS pixel disks and uses the same engineering team.

This use of existing designs is an advantage, in that the prior R&D is leveraged, and elements may already be known to work. However, the use of existing designs has the potential disadvantage that it effectively takes responsibility for technical performance away from the team members who have a direct stake in the physics. A very tight liaison and interaction between the team members and these external “contractors” is very important. Clear demarcations of responsibility and deliverables need to be derived. This will need to be spelled out in a formal management plan for the project.

The fabrication plan is based substantially on existing resources at the Fermilab SiDet facility. However, Fermilab is not a collaborator and is effectively acting as a “job-shop” here. Based upon its experience on CDF, D0, and other silicon projects there is most certainly the proper infrastructure and technical skills and manpower at SiDet to do a project like the FVTX. However, Fermilab has not played this “contractor” role before. The PHENIX group should be strongly integrated into the management and day-to-day operations of the fabrication project to ensure that all specifications are met, that assembly rates are maintained, and that unforeseen problems are identified and dealt with rapidly. PHENIX needs to take responsibility for the assembly project even though they are using Fermilab substantially as a technical resource. Again, this must be specified in the formal management plan.

The proposal document as presented is strong on physics and simulation but needs additional work to better specify the technical details of the design and fabrication plan. Given the intention to start construction in October 2007 a complete technical design report needs to be written urgently. Among the elements to be included are:

- Final design of the PHX chip
- Final design of the module consisting of the PHX chip, bonds, HDI, sensor, and interconnect to the external DAQ. A choice between a bump or wire-bonded solution is fundamental to the module design and needs to be made in the very near future. Criteria to consider are electrical performance, fabrication rates, material, and cost (in roughly this order).
- Final design of the mechanical support structure and cooling system.
- A complete fabrication plan including a detailed model of the process with time and manpower estimates included. Consider component availability and delivery rates explicitly.
- A complete testing plan at all levels including all components.
- Commissioning will be a major enterprise, and insufficient time is allowed for this in the schedule. A careful plan should also be developed.
- A new schedule with key milestones called out at all appropriate levels.

The schedule as presented delays key aspects of the mechanical design until the start of construction. These seem much too late. Resources need to be found to complete this aspect now.

The physicist manpower as presented, roughly 8 FTE per year, contains substantial fractional commitments and has a large contribution for simulation and analysis. It is not clear the latter even belongs in the manpower table for a construction project. It represents 40% of the effort during much of the construction phase. More substantial physicist manpower directed at technical/fabrication aspects of the project may be required. This plan should be revisited during the preparation of the final proposal and technical design report.

PHENIX Nose Cone Calorimeter

This proposal is well thought-out, clearly presented and well motivated by physics questions central to the RHIC program. The principal physics motivation is to extend the PHENIX coverage for high-energy π^0 and photons, and to enhance the capabilitity of the forward muon arms with a measurement of electromagnetic energy, thereby adding the measurement of χ_c in heavy ion collisions (Cu+Cu and possibly also Au+Au). Since this measurement is of unique importance in understanding the properties of new states of matter at RHIC, a more careful evaluation of the performance of this detector in Au+Au should be considered, and any changes which may allow better performance in Au+Au incorporated in the design if at all possible.

We note that the proposed DOE-funded project will provide one Nosecone Calorimeter. The collaboration expects to construct the second NCC with resources provided by non-U.S. collaborators. The second NCC would follow about one year behind the first. These plans are in an early stage. In this review, the committee has focused only on the project to construct the first NCC. From a technical standpoint, the committee concludes that this project can proceed to the construction phase in FY2008. We describe below some issues to be resolved in order to ensure that the project can be carried out with the proposed cost and schedule.

This is a novel calorimeter design, and a new experience for the group. Assuming that the design may probably still need 2-3 iterations before the final solution is solid, the time schedule is very tight. It is recommended to decide on the final electronics solution, including the cooling, as soon as possible.

The final electronics chain tests should also include tests in the RHIC environment, with special consideration given to the possible effects of neutron backgrounds.

Optimization of the calorimeter absorber and sampling structure should continue. In particular, attention should be given to the measurements for photons from the χ_c, for which the resolution and linearity are important.

The dynamic range must be decided upon soon. The desire to extend the dynamic range to cover minimum ionizing particles needs to be better justified, and a choice of ADC selected. If a non-linear or piecewise-linear ADC is selected then the implications of this must be included in terms of operation and calibration.

Cooling of the SVX4 chip is likely to be necessary. There is presently no plan to do this. If no cooling is foreseen, then the impact must be clearly described

A plan for prototype studies in 2006/2007 is essential to establish the cost and performance (resolution, linearity and noise) of this calorimeter

Mechanical design and integration is at an early stage – the committee was unconvinced that the amount of engineering effort assigned to this task would be sufficient. Given the plan to band the detector bricks together, thought must be given to both seismic loads and loads which may be experienced by the structure during movement of the detector (such as an emergency stop)

Construction of a sector mockup should be considered as a way to confirm the layout of readout boards and services, since space is extremely tight.

STAR Heavy Flavor Tracker and Integrated Tracking

STAR has proposed a precision vertex tracking device, the Heavy Flavor Tracker, using a new technology for fine-grained pixel detectors. This uses CMOS Active Pixel Sensors (APS) technology, with the potential for 30 μm pixel size on silicon sensors only 50 μm thick. The technology is being developed at the IReS Laboratory in Strasbourg, France, as well as at LBNL. The proposed HFT would utilize two layers of such sensors, at 2 cm and 5 cm radii from the collision axis. The readout rate is relatively slow (4 msec per frame, with possible upgrade to 0.2 msec), resulting in multiple-event pile-up, but the occupancy is very small, as the detector will have 10^8 pixels. The detector would rely on additional tracking information to make the connection from TPC tracks to the correct hit segments in the pixel layers. The existing Silicon Strip Detector (SSD) may be used for an intermediate space point. However, as part of its Integrated Tracking upgrade (INT), STAR is proposing a new 3-layer set of silicon strip detectors to surround the HFT.

In addition to the intermediate layers of silicon strip detectors to surround the HFT, the Integrated Tracking upgrade aims to provide new tracking capability in the forward direction, at angles subtended by the End Cap Electromagnetic Calorimeter, in the pseudorapidity range $\eta \sim 1\text{-}2$, where the TPC tracking is not adequate to resolve the charge sign of high-energy electrons from $W^{\pm}$ decays. In the present proposal, the forward tracking elements would consist of four discs of silicon strips close to the collision region, and larger-area detectors downstream using gas detectors with segmented readout based on GEM technology. The collaboration is still in the process of simulating the physics measurements and optimizing the configuration for the Integrated Tracking upgrades.

Heavy Flavor Tracker

Physics Motivation

The proposal to add a heavy-flavor tracker (HFT) to the STAR detector will significantly enhance the capabilities of STAR in the mid-rapidity range. The detection of a displaced secondary vertex will cleanly identify the production of heavy flavors from the topology of the event alone. For example, D-meson decays can be identified without the need for kaon identification and without combinatorial background.

Heavy flavor measurements are important for the RHIC program to clarify the properties of the dense medium created in heavy-ion collisions. Important issues to be addressed are the questions regarding the extent to which thermalization, flow, and energy loss for heavy quarks differ from what has been observed for the light flavors.

In addition to its role in heavy–flavor identification, the low-mass HFT will also play an important role in reducing the background in vector meson mass spectra (measured in e^+e^- decays) due to contributions from photon conversions.

Detector Concept and Technology

The proposed APS technology is the most promising choice for high granularity, low radiation length, and low power dissipation vertex tracking in an environment such as RHIC.

The proposed design configuration maximizes the solid angle coverage while keeping the number of detector layers and the area of silicon at a minimum. It is assumed that the small beam pipe diameter will be consistent with reliable machine operation. The overall concept and implementation plan is well thought out.

This is a cutting edge technology, and it will be used for the first time on a fairly large scale in a large physics experiment. If successful, it will have a significant impact on future experiments.

Technical Issues

The basic sensor cell (pixel), while based on "standard" CMOS process, depends critically on some properties of the process usually not specified by the foundry. For example, the dark current at the femto-amp level is not important for most CMOS applications. While the broad-based and outstanding R&D program at IRES is commendable, one will have to capture a good point in the continuing development progress and an available CMOS process to focus on the design of the device to be used for HFT.

The decision on how thin the sensors need to be should be based on the yield, and ease of handling of the sensors, as well as on minimizing multiple scattering, taking into account other materials necessary in the detector assembly.

The mechanical design concept makes use of advanced composite materials. The present design is mostly motivated by the desire to make possible installation and removal of the detector in a short time. Design variations which would improve the position stability of the detector components with respect to each other might be considered. A well thought out design for the readout was presented.

Cost, Schedule, Manpower

- This is a well planned project which recognizes that it has limitations in the available manpower and funding, particularly with respect to mechanical engineering.

- The overall listed manpower (~25 FTE integrated over a five year period) will not be sufficient.

- Given the cutting edge technology, the proposed schedule does not contain sufficient float.

- The cost estimate has been made with realistic contingency figures.

- Silicon fabrication costs are not a major part of the project cost, and allowing for four detector copies is justified.

Recommendations

1. This R&D effort should proceed. The proposed schedule for realizing a working detector is very tight, and, as the STAR project manager noted at this review, the funding profile shown in BNL's Mid-Term Plan for RHIC is not well matched to the

current plan for R&D activities. BNL and STAR should work with DOE to make realistic plans for this valuable project.

2. The STAR/HFT team should consider a third detector layer in coordination with the Intermediate Tracker, and analyze various aspects of an integrated design concept.

Integrated Tracking Upgrade: Intermediate and Forward tracking detectors
The committee concurs with the assessment that the heavy flavor tracker (HFT) and integrated tracking upgrades (INT) are critical for the future of STAR. The entire STAR collaboration should engage in the success of the integrated tracking and supply assistance where needed.

The scientific goals of the tracking systems are well motivated. For heavy ion physics, the role of the Inner Silicon Tracker (IST) in making the connection between the HFT and tracks in the TPC is crucial for fully exploiting the HFT in the study of heavy flavor production. For the spin program, the forward tracker is the key element for the charge determination in studies of parity-violating W decay.

The committee commends the effort made for this review but feels the review occurred too early in the definition of the project for the collaboration to have optimized their choices. Although impressive progress has been made in defining the overall scope of the project, the design should be based on a more complete simulation. Two important metrics to be determined in the simulation and connected to the goals are 1) the required tracking accuracy for determining the position of the particle at the surface of the HFT, and 2) the probability of charge mis-identification in the forward tracker as a function of momentum and rapidity. The affect of mis-measurement of the charge on the relevant asymmetry determination should be illustrated.

The committee recommends that the overall structure (including the HFT) of the various tracking devices should be optimized against the physics goals. The team should consider limiting the number of technologies employed. Perhaps everything can be done with Si and one readout system. The disks of the Forward Silicon Tracker might be rearranged into an optimized layout that would eliminate the need for the GEM detectors.

The committee recommends that a complete simulation be undertaken to define the optimal detector. Some of the issues that a good simulation would clarify include:

1. Would the overall design benefit from having three HFT layers? Would more HFT layers reduce the requirements on the IST?
2. The reason for a separate IST along with the existing Si Strip Detector (SSD) needs further study. Perhaps fewer layers would be required, with possibly only two layers if there is an additional HFT layer.
3. The choice of strip geometry versus pad readout could be justified. Naively, 1-mm x1-mm pads point into a volume characterized by 1mm^2. 0.060-mm x 40-mm strips point into a volume characterized by 2.6mm^2. A different optimization of the strip geometry may make the pad readout unnecessary.

4. The orientation of the strips normal to the beam in the IST is radically different from what one might expect, given the geometry of the TPC. What performance characteristics justify this choice?
5. The forward GEM tracker does not look too promising because of the backgrounds from backscatter and the TPC mechanical structure and electronics. Can it provide the required information in this background environment?
6. The total materials budget for the trackers needs to be determined. The services and readout of the IST/SSD should be included in the simulation. Does the full complement of readouts, cooling lines, mechanical supports, etc. modify the detector choices? Do the detectors still meet their performance requirements?

Some other points that need resolving or that deserve consideration include:

1. A decision between GEM and silicon technologies should be carefully made based on overall cost, i.e including the electronics.
2. The GEM foil company, Tech-Etch, is new to this area of manufacturing. The collaboration should be careful about relying on their success alone.
3. The COMPASS experience with GEMs might not translate into a cylindrical, collider geometry.
4. If the SSD is to be reused, could it help in the charge discrimination by sliding it to larger rapidity?
5. The mechanical support system needs to be fleshed out in detail. Does the total materials budget for the trackers influence the design?
6. The cross coupling of the detectors with high speed electronics should be taken into account when designing the ladders. Test early, and beware of assumptions based on experience at lower bandwidths. Take the best chips for the job, not just what is on the shelf.

Whereas the costs presented did not represent all project manpower, nor any contingency, RHIC management and DOE should expect the estimated costs to grow by a factor of two or more, i.e. to exceed $16M. Some significant reduction in this cost should be realized once the tracker is truly integrated.

The committee strongly recommends that the collaboration keep working, and return for a future review in about 6 months, when the design is more mature.