Department of Energy
Office of Nuclear Physics Report

on the

Technical, Cost, Schedule, and Management Review

of the

STAR Time-of-Flight (TOF) Detector

August 22-23, 2005

Executive Summary

On August 22-23, 2004, the Director of the Office of Nuclear Physics (NP) Facilities and Projects Management Division performed a Technical, Cost, Schedule and Management Review of the proposed Solenoid Tracker At the Relativistic (STAR) Heavy Ion Collider Time-of-Flight (TOF) detector. The primary purpose of the review was to evaluate the proposed technical scope, cost and schedule baselines of the project, and the effectiveness of the project management structure. The review was held at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) on August 22-23, 2005.

The STAR TOF detector is a large acceptance device that is intended to significantly increase the particle identification (PID) capabilities of the STAR detector at RHIC. The STAR TOF consists of an array of 120 trays of multi-gap resistive plate chamber (MRPC) modules that cover the entire acceptance of the STAR Time-Projection-Chamber (TPC). The main features of the proposed arrangement is to achieve a timing resolution of at least 100 *ps* and more than double the momentum range for particle identification. The MRPC module production is the responsibility of the Chinese collaborators.

Summary of Primary Findings

The STAR TOF detector is expected to significantly augment the scientific output of the STAR detector. The detector will provide improved particle identification capabilities to STAR and open up new avenues for studying new states of matter created in the high energy and density environment of RHIC. For example, due to its PID capability, the STAR TOF can extend the jet quenching studies (one of the major discoveries at RHIC) to include fluctuations and correlations. The STAR TOF would also allow a lepton program extending to heavy flavor particles that could potentially contribute to clarifying the quark-gluon plasma signature.

The detector is essentially a United States/Chinese venture, with the Chinese fabricating the detector modules and the United States fabricating the mechanical support and the electronics. Successful detector and electronics prototypes, tested in-beam at RHIC, lower the technical risks in the project. There is room for optimizing the performance of the system, as well as making final design choices that will ease the maintenance and testing of components.

The proposed Department of Energy (DOE) investment in the project is $4.78 million, including 24% contingency. The panel believed the proposed budget to be appropriate and feasible. There were a number of issues that could cause minor fluctuations in the proposed cost, and these need to be addressed prior to the start of the project, including verifying BNL burdens, costing of labor, costing of spares, sufficient Quality Assurance (QA) procedures and levels of project management.

The schedule appears feasible but is aggressive. However, a more thorough schedule contingency analysis needs to be performed and it is recommended that the schedule float be increased by one quarter. A procurements strategy and definition of mechanism for transferring funds to collaborating universities will also optimize the project schedule performance.

A management team was proposed that reports directly to a BNL Project Manager who will act as the interface with DOE. The Contract Project Manager is located at Rice University and the Project Engineer is located at BNL. A U.S./Chinese Coordinator will act as liaison with the Chinese institutions. This project is of relatively short duration, but will require a non-trivial amount of project management in coordinating the project tasks distributed amongst a number of institutions throughout the world. Effective management tools, frequent communication and enforced reporting mechanisms will be required to keep the project on track. Oversight by BNL management is seen as a necessary and valuable component to project success.

Contents

Introduction

On August 22-23, 2005, the DOE Office of Nuclear Physics (NP) held a Technical, Cost, Schedule and Management Review of the STAR TOF project at BNL. The review committee consisted of five external consultants: Professor Russell Betts (University of Illinois at Chicago), Dr. David Lee (Los Alamos National Laboratory), Professor Ricardo Alarcon (Arizona State University), Dr. Cheng-yi Chi (Nevis Laboratories), and Dr. Crispin Williams (European Organization for Nuclear Research). Dr. Jehanne Simon-Gillo, Director of the NP Facilities and Project Management Division, chaired the review and Dr. Gulshan Rai, Program Manager for Heavy Ion Physics, also attended.

The primary purpose of the Technical, Cost, Schedule and Management Review is to evaluate the proposed technical scope, cost and schedule baselines, and the effectiveness of the management structure of the project. The significance and merit of the proposed scientific program is assessed in the context of the Nuclear Science Advisory Committee (NSAC) Long Range Plan for Nuclear Science and the national nuclear physics program. In order to perform the review, each panel member was asked to evaluate and comment on any relevant aspect of the BNL STAR TOF project. However, the focus of the STAR TOF Technical, Cost, Schedule and Management Review was on understanding:

- The significance and merit of the STAR TOF project;
- The status of the technical design, including completeness of technical design and scope, feasibility and merit of technical approach;
- The feasibility and completeness of the proposed budget and schedule, including availability of manpower;
- The effectiveness of the proposed management structure; and
- Other issues relating to the STAR TOF detector.

A copy of the charge letter is included in Appendix A.

Prior to the review, the STAR TOF Management Team provided background material to the panel reviewers, including copies of the proposal that was submitted to DOE and the draft Project Management Plan. The two day review was based on formal presentations given by STAR TOF staff and separate follow-up discussions with the reviewers. The second day included a closed session in which STAR TOF staff responded to questions posed by the panel on the first day, an executive session during which time the panel deliberated and prepared draft reports on their assigned areas of focus and a brief closeout with STAR TOF management and staff. The panel members were asked to submit their individual evaluations and findings in a “letter report” covering all aspects of the STAR TOF Project. The executive summary and the accompanying recommendations are based largely on the information contained in these letters reports. The agenda of the meeting is included in Appendix B.

DOE Recommendations

- Investigate the possibility of using additive gases such as SF_6 or C_4F_{10}, which could have the effect of reducing the onset of streamers and improving the operational characteristics of the detectors.
- Add test pulse function to the TINO board.
- Accelerate the NINO chip decision.
- Investigate the possibility of performing thermal cycling (HASS) lifetime tests on the boards.
- Develop detailed system integration plans and testing procedures to be reviewed by expert peers, prior to the start of electronics fabrication.
- Develop a project procurements strategy for the electronics and incorporate into the schedule, as well as adequate times to allow for funds to be transferred from BNL to collaborating institutions.
- Perform a schedule contingency analysis and maximize schedule float prior to the start of the project. The completion date should be delayed to 1st Quarter 2009 to increase schedule float by three months.
- Increase the level of project management particularly during the initial stages of the project.
- The mechanism for transferring funds to the universities should be identified and preparations should be made as soon as possible, prior to the start of the project.
- The project management plan needs to be updated to address the issues identified in this review. After submission of the final plan to DOE and with DOE approval, the project is ready to proceed.

Merit and Significance of Project

Findings:

The RHIC program is a flagship of the U.S. nuclear physics program, which over the past few years has provided remarkable new insights into the structure and properties of bulk hadronic matter. The initial studies of pp, dAu and AA collisions over a range of energies and species have uncovered a range of phenomena which indicate an unexpectedly strongly interacting form of matter, possibly consisting of deconfined quarks and gluons.

The STAR TOF upgrade will provide new capabilities relevant to many of the questions posed by the present state of phenomenology and understanding. The upgrade will provide e, π, k and p separation in the momentum region between those available through dE/dx measurements in the STAR TPC. This new capability will add to the single particle and event by event performance of the apparatus and allow more discriminating tests of current models of freeze-out and hadronization, in-medium energy loss processes as well as give access to wide acceptance studies of vector mesons and heavy flavors.

Comments:

The detailed study of this new state of matter is of high significance and importance. Accordingly, the studies which must now be carried out at RHIC will be increasingly focused and require more precise, selective and differential measurements which demand both improved detector and accelerator performance, such as the STAR TOF upgrade.

The upgrade project will be carried out by an effective collaboration between U.S. and Chinese scientists and will exploit advances in detector technology which make possible the cost-effective construction of large area, high resolution timing detectors.

The panel members noted that in order to realize the proposed scientific goals of the project, 100ps in timing resolution over the whole acceptance is required.

Recommendations:

- None

Technical Status

Detector and Mechanical Subsystem:

Findings:

The Detector and Mechanical subsystem includes tray assembly and testing, the high voltage system, gas system, Start Detector and infrastructure.

The MRPC module production is the responsibility of the Chinese collaborators. The modules are to be tested in China prior to shipping to the United States The responsibility of the U.S. project includes the delivery of 120 assembled and tested trays of detector modules and electronics, plus spares, and the installation of up to 48 trays into STAR. The installation and commissioning of the remaining trays into STAR are dependent upon the RHIC shutdown and running schedules, and are therefore outside the scope of the project.

The gas mixture proposed for the detector system is 95% Freon 134a + 5% isobutane. Isobutane and SF_6 can suppress the probability for large avalanches called "streamers". The currently used gas (with no SF_6) has a very short efficiency plateau before the onset of "streamers" (maybe 200V). The project team is hesitant to use SF_6, as a leak of the gas could degrade the performance of the STAR TPC.

The resistive high voltage layer of the MRPC's is made with carbon-loaded adhesive tape made by Department of Electrical and Electronics Engineering (EEE) in Japan. This was presented as having a resistivity of 100 kOhm/square. This will have the effect of spreading the induced charge footprint to a size of 1 cm or more.

Comments:

The project team is to be commended for the professional quality of the prototype tray used in the STAR experiment. The successful operation of this detector represents a significant achievement. However, the testing of the trays with cosmic rays is an important aspect and critical to determining whether the tray is acceptable before insertion into STAR. Adequate attention should be given to ensure this testing is ready to start as soon as the first trays come off the production line.

According to panel members, running with streamers degrades time resolution and could generate aging problems. In addition, particle hits not close to the center of the pad will fire two pads and thus increase occupancy; slewing corrections are more difficult when charge is shared between two pads and thus time resolution is degraded. There was discussion at the review regarding demonstrated techniques that indicate that an increase in the resistivity can combat the degradation of time resolution. Producing the high voltage layer with a LICRON spray available from Techspray in Texas is apparently such a technique. The Chinese production centers are set up to produce MRPC's using the Japanese tape although various Chinese students from the University of Science and

Technology of China (USTC) have been building MRPC's using LICRON over the last year or two. The panel suggested that the project team evaluate the tradeoffs associated with potential improved performance of fabricating the MRPC's using LICRON or a similar coating versus the impact to the cost and schedule of the project.

With the current choice of proposed gas, variations in individual operating points of the MRPC's will make system integration and operation with a single high voltage supply challenging. Nevertheless, the panel believed that the gas system, cooling system and mechanical support designs seem feasible.

The Start Detector design is based on existing technology and seems feasible as well.

Recommendations:

- Investigate the possibility of using additive gases such as SF_6 or C_4F_{10}, which could have the effect of reducing the onset of streamers and improving the operational characteristics of the detectors.

Electronics Subsystem

Findings:

There is about $2.1 million in the electronics board purchase and fabrication budget excluding contingency. The total board count is ~2300 boards excluding the spares and includes five different board designs: 1114 amplifier/discriminator boards (TINO), 1114 time-to-digital-converter boards (TDIG), 6 dual-fiber interface-to-STAR Data Acquisition (DAQ) boards (THUB), 8 start detector-to-TDIG boards (TPMT), 134 TDIG to THUB distribution boards (TCPU).

The proposed TOF electronics will use the A Large Hadron Collider Experiment (ALICE) High Performance Time to Digital Converter (HPTDC) chip in the TDIG board as the timing digitizer. The TDC clock will be generated by the 40 MHz crystal in the master THUB board and distributed to the HPTDC through the slave THUB boards. The clock distribution is accomplished through copper cables. With the exception of the TINO, THUB and TDIG boards, other boards have been designed and prototyped, with only minor, if any, modifications needed before proceeding to fabrication. (TDIG boards have been designed and prototyped and 8 boards operated successfully in STAR in Run 5 (FY05) producing the required timing performance. TDIG was the only readout board used in the Run 5 TOF prototype. TINO was designed and prototyped but not yet tested at the time of the review. A TINO board was examined by the reviewers.) The project intends to manufacture two of the boards, TDIG and TCPU, with a Small Business Innovative Research (SBIR) company, Blue Sky Electronics.

The TINO board represents the most risk to project cost and schedule. The design incorporates the Conseil European pour la Recherché Nucleaire (CERN) NINO chip as an amplifier/discriminator of the MRPC detector instead of Maxim amplification. This board is proposed to be installed and tested in the RHIC Run 6 with a subsequent decision as to whether to use the NINO chip or fall back to the existing prototype design. The completion of the final TDIG board is on the critical path. The proposed TINO board does not have a test pulse input. In addition, the TINO and TDIG are going to be embedded in the TOF tray. Access is expected to be difficult.

Detailed board fabrication procedures, material (components) management and Quality Assurance (QA)/testing plans were not presented. Additionally, the overall system integration and testing plan was not presented.

Comments:

In the board manufacturing process, it is important to identify boards which could prematurely fail. The panel thought it essential to have a test pulse input for the board level and system level design and testing.

The NINO chip decision is on the project critical path. Any acceleration in the decision timing will clearly benefit the project.

The plan for electronics system integration and testing must be developed in the early phase of the project before the start of fabrication. Approximately $500,000 has been set aside for testing prior to the existence of a plan. The panel believed that the cost of the five boards, including contingency seemed appropriate.

Recommendations:

- Add a test pulse function to the TINO board.
- Accelerate the NINO chip decision.
- Investigate the possibility of performing thermal cycling (HASS) lifetime tests on the boards.
- Develop detailed system integration plans and testing procedures to be reviewed by expert peers, prior to the start of electronics fabrication.

Budget and Schedule

Findings:

The project proposes to start 1st Quarter 2006 and complete 4th Quarter 2008 with the total cost of the project to be $4.78 million, expended over 3 years. The total project contingency is 24% and was estimated according to the Lockheed method, incorporating estimated risks.

The success of the project is critically dependent on the Chinese collaborators delivering MRPC modules that function according to specifications and according to agreed upon milestones. However, the schedule does not appear to include electronic components procurement and delivery time. Moreover, project schedule and milestones do not include major safety and project reviews, or critical path decisions (such as TINO board decision).

The project team estimates that ~ 18 Full Time Equivalent's (FTE) are required to complete the fabrication of the project.

Comments:

The panel believed that the estimated cost of $4.78 million seems reasonable. However, a number of costing issues need to be resolved, which could impact the final costs. These include fully capturing BNL burdens, ensuring that scientific labor is costed according to DOE guidelines, and re-evaluating the overall costs, the number of spares, QA procedures, and the manpower and project management necessary to implement the project. The project contingency of 24% may be adequate, considering the low technical risks of the project and the fact that most components have been prototyped. However, the project team should ensure that a consistent approach was used throughout the project.

The schedule appears feasible but is aggressive. However, major decisions and project reviews can have an impact on the project schedule. Delays in procurement and the allocation of funds are notorious for producing schedule delays. The schedule should include component purchasing lead time.

The project team can respond to schedule delays by adding more shifts per day or more assembly tables. However, a project schedule contingency analysis has yet to be performed.

The panel expressed concern regarding project person-power and cautioned that it may be low for an "assembly type of construction project", including the production facility at the University of Texas (UT). Two FTE undergraduate students to do all of the assembly and moving the trays from one room to another, getting parts, setting up, doing QA, etc. for 40 hours a week may be demanding. It is planned that a full-time technician will be busy monitoring all of the processes, keeping the documentation, and training new people.

Recommendations:

- Develop a project procurements strategy for the electronics and incorporate into the schedule, as well as adequate times to allow for funds to be transferred from BNL to collaborating institutions.
- Perform a schedule contingency analysis and maximize schedule float prior to the start of the project. The completion date should be delayed to 1^{st} Quarter 2009 to increase schedule float by three months.

Management and Project Documentation

Findings:

A management structure has been established for a mass production project with tasks being performed at different institutions in the United States and China. The project is divided into sub-systems and individuals have been identified at the different institutions for overseeing the sub-systems.

The project management is done by a coordinated effort between the project manager and the project engineer (Project Office), located at different sites. Each of them will work at the 15% level.

Project management will be responsible for quarterly reports that will be reviewed by the BNL and the DOE project managers. Sub-systems managers will report monthly to the Project Office.

With the exception of Rice University, the collaborating universities are assuming maintained levels of research funding relative to FY 2005 for the lifetime of the project. Rice University is assuming the addition of a postdoc to their research grant for the lifetime of the project.

Comments:

The collaboration with the Chinese institutions seems well-defined and strong. The Chinese contribution is vital to the project and will impact the ability of the United States portion of the scope to succeed. The Chinese Liaison will be important in ensuring effective communication between the U.S. and China, and will need to work closely with the TOF project office to ensure that the schedule is maintained.

The identification of the STAR Lead Engineer as the STAR TOF Project Engineer is essential to the project success and this individual will be an asset to the project. He brings the necessary project management expertise to the project team. However, the roles, responsibilities and lines of authority within the project management organization were not apparent and need to be clearly defined. Reporting mechanisms and management tools need to be defined and in place.

Brookhaven should take the lead in completing Memorandum of Understanding’s (MOU) with collaborating institutions that articulate and confirm institutional roles, responsibilities and resources, prior to the start of the project since the project is international and multi-institutional, with an aggressive schedule, and a significant number of different types of electronics boards to produce. The project will have to adhere to DOE approved baselines. The level of oversight in ensuring success should not be underestimated.

Change control table needs to be updated to include corrections regarding wording on cost and schedule and to clarify the roles of STAR Management, the change control board, DOE Headquarters, DOE Site Office and the BNL Project Manager.

Project deliverables and acceptance specifications need to be updated in the context of project complete and anticipated optimum performance.

Recommendations:

- Increase the level of project management particularly during the initial stages of the project.
- The mechanism for transferring funds to the universities should be identified and preparations should be made as soon as possible, prior to the start of the project.
- The project management plan needs to be updated to address the issues identified in this review. After submission of the final plan to DOE and with DOE approval, the project is ready to proceed.

Appendix A: Charge Memorandum

Thank you for agreeing to participate as a committee member for the Technical, Cost, Schedule and Management Review of the STAR Time-of-Flight (TOF) detector (~ 4.6 million actual year dollars) for the Relativistic Heavy Ion Collider (RHIC). This review is scheduled for August 22-23, 2005, at Brookhaven National Laboratory (BNL). A list of the members of the review panel and anticipated Department of Energy (DOE) participants is enclosed.

Each committee member is being asked to evaluate and comment on any relevant aspect of the STAR TOF project. However, the purpose of this review is to assess all aspects of the project's conceptual design and associated plans -- technical, cost, schedule, management, and environment, safety and health. The following main topics will be considered at the review:

a. The significance and merit of this proposed project;
b. The status of the technical design, including completeness of technical design and scope, feasibility and merit of technical approach;
c. The feasibility and completeness of the proposed budget and schedule, including availability of manpower;
d. The effectiveness of the proposed management structure; and
e. Other issues relating to the STAR TOF detector.

In addition to the above, the committee will be asked to evaluate drafts of project documentation, including the project proposal and management plan. Each committee member is asked to review the above aspects of the STAR TOF project and write an individual "letter report" on his findings. These "letter reports" will be due at DOE two weeks after completion of the review. As Chairperson, I will accumulate the "letter reports," and compose a final summary report based on the information in the letters.

We take care to keep the identity of the reviewers confidential in the summary report. It would be convenient if you would prepare your response in a form suitable for transmittal to the proponents devoid of potentially identifying information. The cover letter may include other remarks you wish to add.
I will be chairing the review. The first day will consist of presentations by the laboratory and executive sessions. The second day will include executive session and preliminary report writing; a brief close-out will occur at 2:00 p.m. Preliminary findings, comments, and recommendations will be presented at the close-out.

The Laboratory has been asked to provide relevant background materials prior to the review. This documentation, along with an agenda, will be distributed in the near future. If you have any questions about the review, please contact
Dr. Jehanne Simon-Gillo at (301) 903-1455, or E-mail: Jehanne.Simon-Gillo@science.doe.gov. If you have any questions regarding local travel or lodging, please contact Cora Feliciano at BNL at (631) 344-3908 or E-mail: feliciano@bnl.gov.

I greatly appreciate your efforts in preparing for this review. It is an important process that allows our office to understand the project and its readiness to proceed with fabrication. I look forward to a very informative and stimulating visit.

Sincerely,

Jehanne Simon-Gillo
Acting Director
Facilities and Project Management Division
Office of Nuclear Physics

Appendix B: Agenda

STAR Time-of-Flight Barrel (TOF)
Technical, Cost, Schedule, Management Review Agenda

Room 2-160, Physics Dept., BNL
August 22-23, 2005

Monday, Aug. 22

8:30	Executive Session	
9:00	Project Overview	T. Hallman (15+5)
9:20	Scientific reach of the STAR TOF	Z. Xu (30+5)
9:55	Performance Requirements; MRPC technology choice; prototype performance	G. Eppley (25+10)
10:30	*Break*	
10:45	TOF Electronics	J. Schambach (35+10)
11:30	Readout Electronics Production and Testing	L. Bridges (20+10)
12:00	*Committee Working Lunch*	
1:00	Mechanical Construction & Installation	W. Llope (35+10)
1:45	MRPC Module construction in China	H. Huang (20+10)
2:15	Project Management Plan; Cost and Schedule	G. Eppley (45+15)
3:15	*Break*	
3: 30	Construction Project Plan	R. Brown (35+10)
4:15	Executive Session	
7:00	*Committee Dinner*	

Tuesday, Aug. 23

8:30 Visit to STAR detector

9:30 Q&A, followed by break-out sessions if needed

11:00 Executive Session, Report writing

12:00 *Committee Working Lunch*

1:00 Continued report writing

3:00 Close-Out

3:30 Adjourn