U.S. DEPARTMENT OF ENERGY

Office of Science

Office of Nuclear Physics Report

Scientific Review of the Proposal

"A Heavy Flavor Tracker for STAR"

February 25-26, 2008

Executive Summary

The U.S. Department of Energy (DOE), Office of Nuclear Physics (NP) completed its Scientific Review of a proposed detector upgrade to enhance the relativistic heavy ion physics research program of the STAR (Solenoidal Tracker At RHIC) Experiment at the Relativistic Heavy Ion Collider (RHIC). A panel of six experts convened at Brookhaven National Laboratory (BNL), Upton, NY, on February 25-26, 2008, and evaluated the proposal titled "A Heavy Flavor Tracker for STAR" and accompanying addenda documents submitted by BNL.

The Heavy Flavor Tracker (HFT) upgrade, comprising the Pixel Vertex Detector (PIXEL) and the Intermediate Silicon Tracker (IST) detector, is judged to be a worthwhile addition to the STAR detector. The scientific merit of the proposed research by reconstruction of D-mesons was deemed to be important by the review panel. STAR has the potential for making quality measurements that could yield significant physics results. The physics potential for the HFT in STAR is higher than competing instruments at RHIC since it provides more detail in the measurements through complete topological reconstruction of D-meson decays. Researchers will use the HFT to address important physics topics through measurements of D-meson flow, the ratio R_{AA}, and the ratio R_{cp}. In this regard, the STAR collaboration had identified science deliverables for the first three years of running with the HFT detector.

The impact of the D-meson program on its own could be limited since some scientific questions (e.g. "thermalization" and "energy loss" of heavy quarks) may have already been addressed by 2013 by the STAR, PHENIX (Pioneering High Energy Nuclear Interaction eXperiment) and the LHC (Large Hadron Collider) programs.

The STAR collaboration did not make a convincing science case for measurements that did not involve D mesons. On the polarized proton program, the review panel heard no discussion in the presentations of the proposed spin structure measurements. In this regard, the realization of the proposal's broad scientific goals was not apparent to the reviewers. These significant weaknesses need to be addressed by BNL management, and the STAR collaboration should pursue detailed simulation efforts to establish feasibility of physics topics beyond the D mesons.

The review panel thought that the STAR projections were rather qualitative and/or did not include careful assessments of backgrounds. The review panel advises the STAR collaboration to perform refined simulations that include realistic detector response, particle identification, and Time Projection Chamber space charge effects. These simulations should examine the sensitivity of measurements to the detector and structural thicknesses and establish a set of final HFT performance requirements.

The HFT collaboration is commended by the reviewers on making steady progress towards addressing a variety of technical issues on all aspects of the HFT upgrade. A number of comments and suggestions of previous BNL technical reviews have been considered and factored into the modified design presented in the proposal addenda documents. At a high level, the review panel believes the proposed HFT pre-conceptual design is appropriate.

The Monolithic Active Pixel Sensor (MAPS) technology choice for the PIXEL detector is ambitious and challenging with risks associated with the first large-scale deployment of a new detector type. The review panel identified six risk factors associated with the HFT that could limit or prevent the detector from achieving its science potential: the fabrication of the "Ultimate" MAPS, the impact of materials in the support structure and cooling system, radiation tolerance of the MAPS, event pile-up, and redundancy. The HFT collaboration will need to address these risk factors as it progresses with project plans.

Effective operation of the existing Silicon Strip Detector (SSD), located just outside of the proposed HFT, appears to be essential for the HFT to work as designed. Before the HFT construction is approved, BNL management in coordination with DOE must establish that, operationally, the SSD meets the high efficiency and performance required by the HFT.

The panel could not evaluate the commitments of the research groups who would lead and exploit the new capabilities, and thus it was unable to comment on the charge criteria pertaining to the required experimental and theoretical efforts. The DOE Nuclear Physics Medium Energy (ME) program supports groups to conduct research on the nucleon spin program at RHIC. The HFT spin program was not discussed, thus, presently there is no justification for the DOE ME program to be a stakeholder in the IST.

The STAR collaboration is requested to submit a 5 year (2009-2014) Research Management Plan (RMP) that defines the HFT research goals, responsibilities for each collaborating institution, and annual research milestones associated with the development of the HFT and the SSD scientific program. This plan should be submitted to the DOE NP (Heavy Ion and Medium Energy programs) for approval by March 31, 2009, and updated annually.

DOE Recommendations

I. The STAR collaboration should perform refined simulations for the HFT that include realistic detector response, particle ID, and TPC space charge effects. These simulations should include extraction of the proposed measurements, such as the v_2, R_{AA}, R_{cp} distributions, and p_T spectra of D mesons embedded in the generated events, and examine the sensitivity of measurements to detector thicknesses. A report articulating the results of these simulations should be submitted to DOE by April 30, 2009, including any influence of the simulation results on the proposed technical performance specifications. A set of HFT and SSD technical specifications will be assessed and validated at the first DOE Technical, Cost, Schedule and Management Review, and finalized prior to Critical Decision-2 approval.

II. The HFT collaboration should specifically address the impact on the proposed science inherent in the six risk factors identified at this review, including a failure analysis of each detector layer and submit, by April 30, 2009, a report to DOE articulating its findings. This will be valuable input to the development of a Preliminary Risk Assessment and Risk Management Plan which will be assessed at the first DOE Technical, Cost, Schedule and Management Review, and finalized prior to Critical Decision-2 approval.

Introduction

On February 25-26, 2008 the Research Division of the Office of Nuclear Physics (ONP) completed a Scientific Review of a proposed detector upgrade of the STAR Experiment at the Relativistic Heavy Ion Collider (RHIC). A panel of six experts (Dr. Carl Haber, Lawrence Berkeley National Laboratory; Dr. Ronald Lipton, Fermi National Laboratory; Dr. Vince Cianciolo, Oak Ridge National Laboratory; Dr. Harold Jackson, Argonne National Laboratory; Prof. Jianwei Qiu, Iowa State University, and Prof. Dr. Johannes P. Wessels, Institut fur Kernphysik, Universität Münster, Germany) met at Brookhaven National Laboratory (BNL) and evaluated the original proposal entitled "A Heavy Flavor Tracker for STAR" and addenda documents that significantly updated sections 4.12-4.19 of the proposal.

Dr. Gulshan Rai, Program Manager for the Heavy Ion Nuclear Physics Program, chaired the review, and Dr. Eugene Henry, Director for the DOE Nuclear Physics Research Division, Dr. Brad Tippens, Program Manager for the Medium Energy Nuclear Physics Program, and Dr. Helmut Marsiske, Program Manager for Nuclear Physics Instrumentation, were also present.

The main goals of the RHIC research program at BNL are the discovery of the novel ultra-hot, high density, state of matter predicted by the fundamental theory of strong interactions and the elucidation of the spin structure of the nucleon. The STAR experiment is one of two highly successful, large-scale experiments operating at RHIC.

The STAR collaboration proposes to construct the Heavy Flavor Tracker (HFT) to significantly upgrade its detector's tracking capability. The HFT has been under research and development (R&D) for several years. It consists of the Silicon Pixel Detector (PIXEL) and the Intermediate Silicon Tracker (IST). The HFT, operating in conjunction with the existing Time Projection Chamber (TPC) and the Silicon Strip Detector (SSD), should permit direct topological identification of heavy-quark mesons and baryons by reconstruction of their displaced decay vertices with a resolution of approximately 50μm in p+p, d+A, and A+A collisions at RHIC. The main aim of the HFT upgrade is to identify open charm (D-mesons and Λ_c baryons) and beauty (B-mesons) decays within the acceptance ($\eta<1$) of the TPC. This extended capability provided by the HFT upgrade is also formulated in BNL's 5-year (thru ~ 2011) mid-term strategic plan for RHIC.

The STAR collaboration identified three deliverable science goals for the first three years of RHIC running with the HFT upgrade: (1) precision p_T spectra of D^0 and $v_2(D^0)$ in A+A collisions; (2) p_T spectra of D^0 in p+p collisions; and (3) Λ_c measurements in A+A collisions. In addition to these three immediate goals, the collaboration identified many other important measurements that could be achieved with the HFT upgrade.

The primary purpose of this review was to evaluate the scientific merit, significance, and feasibility of attaining measurements utilizing the proposed HFT (PIXEL + IST) detector upgrades. The Office of Nuclear Physics needed to understand what important progress in scientific knowledge will occur after the new capabilities become operational. In carrying out this charge, each panel member was asked to evaluate and comment on:

- The significance of specific scientific questions identified by the community and laboratory which they believe can be addressed by data acquired during the first three years of operations;

- The feasibility of the approach or method proposed to carry out the proposed program;

- The impact of the planned scientific program on the advancement of nuclear physics in the context of current and planned world-wide capabilities; and

- The experimental and theoretical research efforts and technical capabilities needed to accomplish the proposed scientific program.

The result of this review would establish the scientific need for the new capabilities, and in turn, validation of the critical technical performance parameters necessary to assure that the science can be accomplished. In addition, collaboration plans would be examined to establish the commitments and resources of principal investigators and their research groups who will support and exploit the future new capabilities.

The review consisted of formal presentations made by the proponents of the HFT proposal. The agenda included a question and answer session and closed executive sessions for panel deliberations. The review was concluded by the Heavy Ion Program Manager who conveyed his preliminary analysis of the reviewers' common as well as critical opinions in a close-out session with BNL and STAR management.

The panelists were also asked to submit their individual evaluations and findings in a "letter report" covering all aspects of the charge letter. The executive summary and the accompanying DOE ONP recommendations are based largely on the executive session deliberations and information contained in these letter reports. A copy of the charge letter (Appendix A), the agenda (Appendix B), and excerpts from the panel reviews are included. This report is organized according to the five charge elements and adopts the format of findings, comments, and recommendations.

The significance of specific scientific questions identified by the community and laboratory which they believe can be addressed by data acquired during the first three years of operations.

Findings:

A proposed scientific program was presented in the Heavy Flavor Tracker (HFT) upgrade proposal and verbally articulated by the STAR collaboration proponents at the review. Altogether 15 topics were identified most of which required the capability to topologically reconstruct D-meson and charm baryon decays, B-meson decays, or the capability to measure semi-leptonic decay channels of D- and B- mesons via electron identification. The proposed technological solution for the required capability is the development and construction of two tracking detector upgrades to the STAR experiment, collectively described as the HFT. The combination of the new HFT, the existing Silicon Strip Detector (SSD) and the Time Projection Chamber (TPC) is expected to determine the position of displaced or hadronic decay vertices to better than 50 μm within 2π coverage in ϕ and a rapidity coverage of ± 1.0 unit. The two new HFT detectors were described as the Pixel Vertex Detector (PIXEL) and the Intermediate Silicon Tracker (IST).

1. Pixel Vertex Detector

A two-barrel pixilated (30 μm pitch) silicon detector (called PIXEL) is designed to provide high spatial resolution coverage of the collision interaction region of STAR. The inner and outer PIXEL barrels are located at a radial distance of 2.5 cm and 8 cm, respectively, about the beam axis. The PIXEL technology concept was shown to be well advanced, with plans existing for the evolution of the detector sensor elements (Monolithic Active Pixel Sensor – MAPS), on-chip readout schemes, and off-chip readout electronics. The addenda to the HFT proposal noted that the final PIXEL detector for STAR will be procured as a two-stage development process with the readout system requirements tied to the stages of the MAPS development effort at the Institut Pluridisciplinaire Hubert Curien (IPHC), Strasbourg, France. The revised development plan requires a first set of prototype sensors (Phase-1) to have digital outputs and a 640 μs integration time. These “slow” sensors will be used to construct an engineering prototype detector system for deployment in STAR during the summer of 2010. The prototype system will employ the mechanical design to be used for the final PIXEL detector and a readout system that is designed to be a prototype for the final Phase-2 sensors. The Phase-2 sensor, code named “Ultimate”, will contain all of the attributes of the Phase-1 sensor but with the pixel arrays incorporating on-chip data sparsification and clocked faster to give a shorter integration time (< 200 μs). First prototypes of the “Ultimate” fast sensors are expected to be delivered in 2010 followed by the integration of the final Phase-2 sensors into the complete PIXEL detector in the 2012 time frame.

2. Intermediate Silicon Tracker

A barrel with a single-layer silicon pad-type (1 mm x 500 µm pad pitch) detector (IST) is designed to provide a track pointing resolution of ~ 400 µm on to the outer surface of the PIXEL detector. Additionally, the IST provides redundancy in case of inefficiency of either the SSD or the IST sensors. The IST detector is located at a radial distance from the beam axis of 14 cm interposed between the PIXEL and the SSD detectors. The addenda to the HFT proposal noted that the IST design has changed from the old layout with three silicon layers at two radial locations (original HFT proposal configuration) to a new layout which employs one layer of silicon at one radial location. The development plan requires significant R&D to develop an IST prototype ladder, readout electronics, and Data Acquisition System (DAQ). The integration of the PIXEL, IST, and SSD detectors, and the requirements of another ongoing upgrade called the Forward Gem Tracker (FGT) is a challenge.

With the PIXEL and IST upgrades, the potential scientific program as presented to the review panel is summarized in Table 1. The proposed program can be viewed according to heavy ion and proton spin observables derived from charm and bottom hadron decays. They include the:

- study of heavy quark thermalization and energy loss (via R_{AA}, R_{cp}, and v_2);
- gluon momentum distribution in Gold nuclei (via $R^{Au}{}_{g}(x, Q_2)$);
- cross–sections of charm- and beauty-hadrons in heavy ion and proton collisions; and
- study of proton spin structure (via A_{LL}, A_{TT}, and A_T heavy flavor asymmetries).

Comments:

STAR has had a successful program in heavy ion (HI) and polarized proton physics at RHIC, participating in the discovery of the strongly-interacting Quark-Gluon Plasma (sQGP), and the initial results for the contribution to the proton spin by gluons, $\Delta G(x)$, within the kinematic range x ~ 0.03-0.3. The HFT is the last in a series of planned mid-term upgrades designed to extend and enhance the scientific reach of STAR.

The reviewers evaluated the merit, significance, and the feasibility of the 15 proposed measurements listed in Table 1. The annotations in each row record the reviewers' consensus regarding each criterion. "No" indicates the proposed measurement was unsuccessful in passing a criterion. "Plausible" signifies the material presented was reasonably persuasive, but further study or analysis is needed.

The reviewers believe the proposed detector system (HFT), in conjunction with the STAR detector enhanced with the DAQ 1,000 upgrade, will be capable of performing topological reconstruction of D mesons produced in Gold collisions at RHIC. This capability will allow the measurement of centrality-binned p_T spectra and elliptic flow for D mesons. Based on these measurements, the STAR collaboration identified the following science deliverables for the first three years of running with the HFT detector:

- With 500 million minimum bias events of Au+Au collisions at 200/A GeV measure v_2 (elliptic flow coefficient) of D^0 in the p_t range from 600 MeV/c up to a p_t of larger than 5 GeV/c. The expected absolute error on the measurement will be 0.009 for the p_t bin from 600 to1,000 MeV/c and 0.007 for the p_t bin from 3.75 to 4.25 GeV/c.
- With the same 500 million events, measure the p_t dependence of R_{cp} of D^0 mesons in the p_t range from 1 GeV/c to 10 GeV/c. R_{cp} statistical errors are expected to be 5% in the p_t bin range 1.75-2.25 GeV/c and 16% in the p_t bin range 7.5-8.5 GeV/c provided the open charm suppression is the same as for light quark mesons.
- With p+p collisions at 200 GeV, measure the p_t dependence of D^0 production and achieve a precision of 17% for the p_t bin between 7-8 GeV/c. The total D^0 production cross section will be measured with a precision of better than 15%. The combination of p+p and Au+Au data will enable the determination of R_{AA}.
- With 1,000 million minimum bias Au+Au events, perform impact parameter selected v_2 and R_{AA} measurements. In the centrality bin with the largest v_2 signal, 40 – 60%, the statistical error in the D^0 production is expected to be less than 2.5% in each p_t bin, with p_t = 0.5 GeV/c, in the p_t range from 1 to 4 GeV/c. Finite reaction plane resolution will dominate the v_2 errors, the maximum error being about 10%.
- Measure a Λ_c spectrum with about 14,000 identified Λ_c in the p_t range of 2-10 GeV/c.

Of these, the D^0-related deliverables appeared most credible and were endorsed by the reviewers. These measurements could provide new scientific information on the production mechanism for charm mesons, thermalization, and parton energy loss.

The competing program in the PHENIX experiment has limitations on solid angle coverage and cannot fully reconstruct D mesons. Some reviewers believed the measurements of heavy quark hadrons in PHENIX may be subject to systematic errors due to the unfolding of production and decay distributions, whereas the STAR measurements of D^0 flow should be largely free from these systematic errors.

However, the HFT proponents argued D^0measurements will be made over a wider p_T range 0.5-15 GeV, but it was not obvious from the available information that reconstruction at the upper p_T range was achievable. The reviewers also believed that while the D^0 measurements seemed technically feasible, their sensitivity to the science objectives remain to be demonstrated. Given the ability to reconstruct significant D^0 signals, STAR should also be able to reconstruct significant samples of D^{+-} and D^*. Although the group made its case for STAR's capability to achieve the central goals of measurements of R_{AA} and elliptic flow of D mesons, the review panel felt that the case could be sharpened by increasing the sophistication of the simulations and associated analysis and advises increased efforts to both refine the physics simulations and to further quantify the sensitivity of these measurements to the science goals. Overall, the D-meson science program (i.e., 4 out of 15 proposed topics) achieved either a "Yes" or a "Plausible" rating in Table 1.

Beyond the D-meson program, the HFT proposal discussed B meson hadronic decays and proton spin measurements. This program was perceived as significantly weaker because either the science topics were not discussed at the review, or that feasibility was not convincingly demonstrated. In this regard, 11 out of 15 topics achieved a "No" rating in Table 1.

The STAR collaboration did not make a convincing case for heavy flavor physics that does not involve D mesons. The review panel thought that all the STAR projections were rather qualitative and did not include careful assessments of backgrounds. The proposed detector might have the capability to reconstruct states such as Λ_c baryons and B mesons; but without more careful study of the significance of the signals, their impact on the physics proposed by STAR was unclear to the reviewers.

On the nucleon spin program, the review panel heard no discussion in the presentations of measurements of unpolarized parton distributions ($R^{Au}{}_{g}(x, Q_2)$), although there was a brief mention in the proposal text. The omission of this and any discussion of spin structure measurements (A_{LL}, A_{TT}, and A_T) in the scheduled presentations was taken as an indication that these topics were not considered sufficiently advanced for consideration. A double-spin asymmetry measurement in heavy-flavor production detected with displaced electrons was briefly presented. While this measurement could provide a strong signal if ΔG is large and negative, its feasibility remains to be demonstrated.

The prospects for probing proton spin structure using spin-dependent heavy flavor production appeared less encouraging to some reviewers in part due to recent developments. Recent measurements at RHIC of spin asymmetries for neutral pions and also for 2-jet events indicate a small value for ΔG, suggesting that the signal in heavy flavor production will be very weak. Furthermore, calculation of the "analyzing power" of heavy flavor production is not reliable because of the uncertainties in the theoretical models for the reaction. Thus, without further information, expectations are that such heavy-flavor measurements will be very difficult.

In summary, the review panel believes the HFT is a worthwhile addition which is well matched to the STAR detector. It will address important physics topics through measurements of D-meson flow, the ratio R_{AA}, and the ratio R_{cp}. The physics potential for this instrument could be much higher than competing instruments at RHIC since it provides more detail in the measurements through complete topological reconstruction of D-meson decays.

TABLE 1

Evaluation of the proposed scientific measurements presented in the HFT proposal and/or at the review. The first column ("Ref") indicates the proposal section number and whether the measurement was presented at the review ("Rev"). Columns 3-6 reflect the four review criteria. The annotations in each row (i.e. measurement) record the reviewers' consensus regarding each criterion. "No" indicates the measurement was unsuccessful in passing the criterion or that material was not presented. "Plausible" signifies the material presented was reasonably persuasive but further effort or analysis is needed.

Ref.	**Proposed Measurement**	**Scientific Merit/ Impact**	**Feasibility/ Sensitivity**	**Current/ Planned context**	**Technical/ Capabilities**	**Comments**
2.3 Rev	Spectra, D^0s	Production Mechanism	Yes, but no sensitivity analysis was presented	Unique at RHIC		Reviewers have confidence in the topological reconstruction of the hadronic decay channels. Charm cross-section from electrons not demonstrated
2.3 Rev	Spectra, B (B spectra obtained by using subtraction method)	Production Mechanism – but is less critical than Charm measurement	No	PHENIX through the semi-leptonic decay channel		
Rev	B semi-leptonic B -> J/ψ (~500 events) B -> D + pion	See above	No			
Rev	R^c_{AA}/R^b_{AA} (~1000 events)	Test pQCD/ CFT	No			During discussions, STAR believes this measurement is probably not feasible
Rev	D^+, D^-, D_s	Hadron Chemistry	Plausible			3-body decay channel. Should be easier if particle identification works well. Measurements will help clarify the total Charm cross-section and the semi-leptonic channels.
Rev 2.5.3	$\Lambda c/D^0$	Formation of Baryons	No			Clarify the baryon/meson puzzle observed in light hadron production
2.4.1 Rev	Elliptic flowv_2 D^0 (0.5-15 GeV/c)	Thermalization	Plausible case made, but detailed simulations, with well motivated cuts are required.			c.f. PHENIX V_2 from electrons, Phi-meson flow, J/ψ. Flagship measurement. Demonstrate reproduction of generated distributions.
2.5.1 Rev	R_{AA} and Rcp (D^0s) (Bs)	Energy loss	Plausible for Ds. Feasibility with the proton beam needs to be demonstrated from a rate perspective.	PHENIX		Based on topological reconstruction. D^0 Plausible < 10 GeV. B's not possible.
Rev	Charm hadron Correlation functions (~600 pairs, P_T~1-3 GeV)	Drag coefficient	No			One sentence on slide presentation and brief Q&A response. Angular correlation – showed theoretical plots – no sensitivity analysis was presented, the measurement S/N is low, complications can arise in back-to-back correlation due to fakes and gluon splitting.
2.6	Di-lepton	Chiral Symmetry	No	PHENIX		
2.7	A_{TT} and	Transversity	No	PHENIX		One sentence in proposal

	A_L (charm associated W)					Might not be competitive with the electron channel – suffers from fragmentation function. No forward backward detectors.
2.7	Asymmetry from Bottom production		No			No discussion on this topic was presented
2.7	A_{LL}	ΔG	No		Radiation Damage, Signal-to-Noise (S/N deterioration.	Displaced electrons from Charm and Bottom at high P_T, charm x-sec falls rapidly. Mixture of processes – thus cannot get at the pure shape. Cannot determine sign of ΔG But if negative large, then this measurement is important. PHENIX will also measure it
Rev	Asymmetry via γ+jet		No			No discussion was presented at the review.
2.8	R^{Au}_g Cold Matter	Gluon Distribution (Q, x)	No			No discussion was presented at the review.

The feasibility of the approach or method proposed to carry out the proposed program.

Comments:

Heavy Ion Program:
The review panel believes the HFT is well matched to the STAR detector. It will address important physics topics through measurements of D-meson flow (v_2), the ratio R_{AA}, and the ratio R_{cp}. These measurements were identified as milestones for the first three years of running with the HFT detector for $p_T < 5$-8 GeV/c. How well the measurements can be performed in the p_T range up to 15 GeV/c needed to complete the proposed D meson program remains to be demonstrated. The science capabilities of the HFT may be undervalued compared to other competing instruments at RHIC.

GEANT simulations were presented showing that D^0 signals could be reconstructed in Au+Au collisions, which allow the measurement of p_T spectra and v_2. Based on similarity of decay lengths, measurements of other D meson states should also be feasible.

The presentations and documentation lacked specificity as to how some of the proposed measurements could advance the scientific agenda. The panel was unable to evaluate the feasibility for the proposed measurements on Λ_c baryons, B meson, di-leptons, and the D-D meson angular correlations.

At the anticipated RHIC II luminosities, track reconstruction in the TPC will be subject to systematic effects caused by the build-up of space charge. The reviewers suggest that simulations be performed to show how space-charge affects the D meson measurements.

The reviewers encourage the STAR collaboration to pursue detailed simulation efforts to establish feasibility of physics topics beyond the D mesons.

Spin Program:
The review panel heard no discussion in the presentations of the proposed proton spin structure measurements (A_{LL}, A_{TT}, and A_T). The driving physics behind the 500 GeV spin physics program is the W production. It was difficult for the review panel to evaluate that driver from the singular statement in the proposal: "Measurement of the spin asymmetry A_L in charm-associated W production." The panel was unable to assess the success of the $p+p \rightarrow W^{\pm} + c + X$ physics program and the utility of the HFT upgrade. A clear path moving from the identification of a W and a charm-state candidate was not presented.

Development of a Research Management Plan (RMP):
The STAR collaboration is requested to submit a 5-year (2009-2014) Research Management Plan (RMP) that defines the HFT research goals, responsibilities for each collaborating institution, and annual research milestones associated with the development of the HFT and the SSD scientific program. This plan should be submitted to the DOE NP (Heavy Ion and Medium Energy programs) for approval by March 31, 2009, and updated annually.

The RMP plan should also respond to the comments under the section addressing the experimental and theoretical research efforts needed to accomplish the proposed scientific program.

Recommendations:

I. The STAR collaboration should perform refined simulations for the HFT that include realistic detector response, particle ID, and TPC space charge effects. These simulations should include extraction of the proposed measurements, such as the v_2, R_{AA}, R_{cp} distributions, and p_T spectra of D mesons embedded in the generated events, and examine the sensitivity of measurements to detector thicknesses. A report articulating the results of these simulations should be submitted to DOE by April 30, 2009, including any influence of the simulation results on the proposed technical performance specifications. A set of HFT and SSD technical specifications will be assessed and validated at the first DOE Technical, Cost, Schedule and Management Review, and finalized prior to Critical Decision-2 approval.

The impact of the planned scientific program on the advancement of nuclear physics in the context of current and planned world-wide capabilities.

Comments:

The proposed new capabilities of STAR were not compared to those being developed by the PHENIX collaboration. Therefore, the panel could not evaluate the broader yet unique impact of the HFT upgrade.

The impact of the D meson program alone could be limited since the scientific question on "thermalization" of heavy quarks may have already been addressed by 2012-2013 by the STAR non-HFT efforts, as well as the PHENIX and the LHC program. An extensive body of "v_2" measurements already exists with differences among them. The proposal did not explain how the D meson measurements will be significantly more informative.

Heavy flavor energy loss in Au+Au collisions at RHIC has been observed and is larger than expected. Understanding this large energy loss may be facilitated by detailed studies of the particle mass dependence which requires separating the c- and b-quark components.

Both STAR and PHENIX collaborations have made indirect measurements of D^0 production based on non-photonic electrons. The p_T distribution of the electrons is insensitive to its parent D (or B) meson's p_T distribution. The reviewers think the STAR collaboration has made a good case for the need of the direct reconstruction of charm mesons. Specifically, the R_{AA} (D) and R_{cp} (D) measurements proposed by STAR should complement the PHENIX measurements in so far as the STAR measurements should be an improvement over measurements made via semi-leptonic decays, since the D meson will be identified and separated from B decays.

The proposed B meson measurements, via semi-leptonic decay channels, and di-lepton measurements will be coming late relative to similar PHENIX measurements. A broad program was presented at a superficial level in the proposal, but was not discussed in detail during the review. As mentioned earlier in this report, the review panel believes more simulations will be needed to establish the viability of these other measurements.

Measurements similar to those proposed for the HFT will also be carried out by the LHC collaborations on a similar or earlier timescale. The review panel believes measurements at RHIC and the LHC are complementary since the hot nuclear medium produced at LHC energies will be quite different than at RHIC energies**.**

Some reviewers think the HFT might have a capability to probe the spin structure of the nucleon. Since there is no competing polarized proton facility, measurement of heavy meson asymmetries through displaced electrons may provide an important contribution to the subject of nucleon spin. However, a complete understanding of the features of charm meson production will be needed in order to make progress. According to one reviewer, another potential capability is the first measurement of the gluonic Sivers function. Such a measurement could impact the spin program at COMPASS and at a possible future electron-ion collider. However, all of these aspirations are speculative, and the impact of the HFT upgrade on the spin program remains unsubstantiated.

Recommendations: None

The experimental and theoretical research efforts and technical capabilities needed to accomplish the proposed scientific program.

Experimental Research Effort

Comments:

In the context of the comments made under the Significance and Feasibility sections of this report, the reviewers advise that further simulations are needed, as well as the need for the development of a viable research program beyond the D mesons and a spin measurement program. The review panel could not evaluate the commitments of the research groups who would lead such efforts and consequently offer no comments on the experimental efforts needed. The development by the STAR collaboration of a Research Management Plan (RMP) mentioned above should address this shortcoming.

The HFT has the potential for a number of proposed measurements. This will require a concerted effort to realize an effective experimental program that fully exploits the resulting data.

Theoretical Research Effort

Comments:

In general, to realize the goals of the proposed HFT measurements requires clear linkages of the experimental observables to solid theoretical calculations. The required theoretical developments were not presented in detail in the proposal or the review. The reviewers, however, believe the B meson measurements require additional theory input and careful simulation. The calculation of the "analyzing power" of heavy flavor production is undependable because of uncertainties in the theoretical models for the reaction. The theoretical path to extracting $|\Delta G(x)|$ from A_{LL}^{QQbar} is still under development.

The review panel could not evaluate the commitments of the theory research groups who would lead necessary efforts to realize the scientific goals of the HFT program. Similar to the comments on the experimental research effort, the STAR collaboration's RMP should also incorporate a plan for the relevant theoretical effort.

HFT Detector Upgrade - Technical

Findings:

The STAR group has proposed an integrated design, based on an innovative inner silicon PIXEL detector, an intermediate silicon pad-type IST detector, and the existing SSD. The SSD and IST are required to extrapolate the coarse TPC tracks into the pixels. They could also provide fast timing resolution, allowing selection of hits that correspond to the correct bunch crossing within the pixels. Much work remains to be done on the mechanical layout and integration with other detectors to reduce incompatibilities.

The IST is a more conventional device than the PIXEL detector. A single layer of pad detectors is proposed which utilizes APV25 chips developed for the Compact Muon Spectrometer (CMS) at CERN. The IST will work in tandem with the SSD layers to provide track extrapolations from the TPC into the PIXEL. The design of the IST has changed fairly recently, going from two layers with short strips to a single layer with pads.

Technical Comments:

The collaboration is commended by the reviewers on making steady progress towards addressing a variety of technical issues on all aspects of the HFT upgrade. A number of comments and suggestions of previous BNL technical reviews have been considered and factored into the modified design presented in the proposal addenda documents.

At a high level, the reviewers believe that the proposed HFT solution is appropriate. The physics requirement for minimal material to limit multiple scattering drives the requirement for the two thin inner PIXEL layers. The CMOS MAPS technology choice for the PIXEL sensors is challenging with risks associated with the first large-scale deployment of a new detector type. The panel believes the groups involved have world-class expertise and have a good chance of success.

The current PIXEL design assumes the availability of MAPS with 200 μs integration time, which appears to be acceptable, but given the limitations imposed by event pileup, shorter times remain a desirable objective. The development and implementation plan for the MAPS devices, now using the "Phase-1" device for a prototype, followed by the "Ultimate" sensors and sharing much of the data acquisition and control framework is a positive development. The PIXEL mechanical structure, and in particular the insertion support design, also appears to be promising.

The primary function of the IST is to provide a hit redundant with the SSD for extrapolation of TPC tracks into the pixels. The IST design has been changed from a 2-layer strip device to a single layer of pads. The reviewers noted this is a relatively recent but positive change. The IST design optimization has yet to be completed, including whether or not liquid cooling is needed.

The set of technical performance parameters presented by the HFT collaboration are a good start in defining the performance of the HFT, but will require validation through simulations.

Several significant risk factors where identified at this stage of the project:

1. The proposed PIXEL detector is a challenging device. It is dependent on the successful development of high readout speed, and shorter integration time (100-200 μs) MAPS devices by IRES Strasbourg with good yield.
2. The construction of a low mass support structure which incorporates power distribution, system cooling and cabling. Further detailed physics simulations are required to understand the optimization of the thin and fragile MAP sensors and the impact of services (e.g. power, readout, cooling) which could dominate the overall material budget of the HFT tracker.
3. Radiation tolerance of the MAPS devices needs to be carefully studied. This could become an issue in proton running where radiation doses may be well above those considered in the HFT proposal. The reviewers' assessment of the radiation hazard was hindered by the absence of scientific information regarding the utility of the HFT in the 500 GeV spin program. Given the wide range of running conditions expected at RHIC-II, establishing the radiation exposure and the performance degradation of the PIXEL device is a high priority issue that must be addressed. This includes the disposition of the PIXEL being easily removable and replaced. The commissioning of a new set of MAP sensors annually struck some reviewers as a challenging prospect.
4. Event pile-up and beam bunch resolution in proton running could be an issue. Some reviewers were not persuaded by the statement that the RHIC spin program would be able to handle multiple interactions within the same beam crossing.
5. The IST design is considerably less developed than the PIXEL detector. The proponents need to develop a better understanding of support and cooling issues. In particular they need to understand the physics and technical tradeoffs associated with a possible choice of liquid cooling, which will increase the mass of the IST layer. The impact of additional mass on the performance of the tracker, particularly at low momentum should be simulated.
6. The HFT performance relies on achieving graded pointing resolution and high efficiency starting from the outside (TPC) and tracking inward towards the PIXEL. The design has little redundancy in tracking layers and thus all three detectors (SSD+IST+PIXEL) must individually perform at high efficiency. The operations and efficiency of the existing detector, SSD, is an ongoing concern from a previous technical review. The HFT proponents should conduct a failure analysis of the HFT concept, including the SSD, that is

based on more detailed simulations and determine the impact on the proposed science goals.

The identification, analyses and mitigation of all risks associated with the HFT will be essential as the project moves forward towards fabrication. As noted at this review and the BNL Technical Advisory Committee Review (January 30-31, 2007), much depends on the on-going MAPS R&D program of the IPHC group in France and the degree to which their MAPS development is driven by the STAR requirements. Thus, it will be imperative to define when and how the MAPS design "freeze point" will be captured to achieve the desired research goals.

Each of the six risks identified at this review will be monitored at future Critical Design (CD) and review points to ensure that they have been satisfactorily addressed, eliminated, or managed. However, the impact of these risks on the scientific program should be analyzed in detail now and continued throughout all stages of the HFT project.

The effective operation of the SSD appears to be absolutely essential for the HFT concept to work as designed. Technically, the SSD is outside the scope of the proposed HFT project. Therefore, before the HFT construction is approved, it should be demonstrated that, operationally, the SSD meets the high tracking efficiency and performance required by the HFT.

Recommendations:

II. The HFT collaboration should specifically address the impact on the proposed science inherent in the six risk factors identified at this review, including a failure analysis of each detector layer and submit, by April 30, 2009, a report to DOE articulating its findings. This will be valuable input to the development of a Preliminary Risk Assessment and Risk Management Plan which will be assessed at the first DOE Technical, Cost, Schedule and Management Review, and finalized prior to Critical Decision-2 approval.

Other issues relating to the proposed upgrades, such as a plan that identifies, as specifically as possible, research groups and leaders who will support and exploit the new capabilities to address the proposed scientific program.

Findings:

The HFT project centers around the efforts of two main teams, LBNL on the inner PIXEL detector and MIT on the IST.

The review panel was provided with a work force profile for the HFT project in the form of a spread sheet which listed in detail the members of each institutional group participating in the HFT project.

Comments:

The reviewers believe the main HFT project teams have relevant experience and expertise in the PIXEL and IST detector technologies. The LBNL effort on the inner PIXEL layers is "state-of-the-art" in both material reduction and in the application of MAPS in heavy ion collisions. The reviewers acknowledge the LBNL group's leadership role over many years in the R&D of thinned MAPS concepts and the institution's expertise in composite materials engineering and fabrication infrastructure that the PIXEL group intends to exploit. The MIT effort relies on the silicon experience developed for the PHOBOS experiment at RHIC, which will be directed at the IST. The IST has been reduced to a single-layer concept which the reviewers believe makes this project "all-the-more manageable and doable with the resources and time available."

However, a plan that identifies, as specifically as possible, research groups and leaders who will support and exploit the new capabilities to address the proposed scientific program was not presented. A critical workforce needs to be built up within the STAR collaboration which is committed to developing the scientific program and supporting activities of the HFT over the next 5 years. The SSD is an existing system which requires a dedicated STAR effort to ensure that the performance levels required in conjunction with the HFT are achieved through either repair or upgrades.

The MIT research group's activities on the proposed IST is funded by the DOE Nuclear Physics Medium Energy (ME) program which supports the polarized proton beam spin program at RHIC. The proposed spin program was not discussed at the review and all four spin topics received a "No" rating for feasibility in Table 1. Thus, the justification appears weak for the DOE ME program to be a stakeholder in the IST.

The panel could not evaluate the commitments of the STAR research groups who would lead and exploit the new capabilities. For the purpose of this section, the HFT collaboration's response to the development of a Research Management Plan should adequately address this charge element to ensure the HFT will be calibrated and ready to conduct "Day 1" physics.

Appendix A: Charge Memorandum

The Physics Research Division of the Office of Nuclear Physics is organizing a Science Review of the Heavy Flavor Tracker (HFT) proposal for the STAR detector upgrade at the Relativistic Heavy Ion Collider (RHIC). This panel review will take place at Brookhaven National Laboratory (BNL) on February 25-26, 2008.

The primary purpose of this review is to evaluate and articulate the merit and significance of the proposed scientific program for the HFT for the STAR detector at RHIC. Specifically, this office has requested a critical appraisal of what important progress in scientific knowledge will occur within the first three years after the new capabilities become operational. In carrying out this charge, each panel member will be asked to evaluate and comment on:

- The significance of scientific questions identified by the proposal and Brookhaven National Laboratory which they believe can be addressed by data acquired in the first three years of upgraded detector operations;

- The feasibility of the approach or method proposed to carry out the proposed program;

- The impact of the planned scientific program on the advancement of nuclear physics in the context of current and planned world-wide capabilities; and

- The experimental and theoretical research efforts and the technical capabilities needed to accomplish the proposed scientific program.

Based on these criteria, a successful result of this review should include a) justification of a compelling scientific need for the new capabilities, and in turn, b) validation of the critical technical performance parameters necessary to assure that the science can be accomplished, and c) approval of appropriate scientific research goals and milestones. The review should also assess the viability of the proposal's workforce, identifying as specifically as possible, research groups and leaders who will support and exploit the new capabilities to address the proposed scientific program.

Dr. Gulshan Rai, Program Manager for Heavy Ion Nuclear Physics, will be the chair of this review assisted by Dr. Brad Tippens, Program Manager for Medium Energy Physics. Please coordinate with Dr. Rai on matters concerning the proposal and other material to be provided by BNL to the reviewers. The first day of the review will consist of presentations by the proponents of the HFT proposal followed by executive sessions. The second day will include report writing and a brief close-out. The panel members have been instructed to contact Liz Mogavero at BNL at (631) 344-3940 or E-mail: mogavero@bnl.gov regarding logistical information. Word processing and secretarial assistance should be made available during the review.

I greatly appreciate your efforts in preparing for this review. It is an important process that allows our office to understand the scientific need for the projects as well as their feasibility. I look forward to a very informative and stimulating review.

Sincerely,

Eugene A. Henry
Director
Physics Research Division
Office of Nuclear Physics

Enclosure

cc: Timothy Hallman, BNL
Steven Vigdor, BNL
Michael Holland, BHSO/BNL
Brad Keister, NSF

Appendix B: Agenda and List of Reviewers

Physics Building, Room 2-160
BNL, February 25-26

February 25, 2008

09:00	Introduction	Tim Hallman (20+10)	(Hallman_Tim.ppt)
09:30	Physics Motivation	Nu Xu (30+10)	(Xu-Nu.ppt)
10:10	Break		
10:25	Performance	J. Thomas (30+10)	(Thomas-Jim.pdf)
11:05	Project overview	H.G. Ritter (20+10)	(Ritter-Hans-Georg.ppt)
11:35	Panel Discussion	(30 minutes)	
12:05	Working Lunch		
13:40	IST	B. Surrow (20+10)	(Surrow-Bernd.pdf)
14:10	PIXEL	H. Wieman (20+10)	(Wieman-Howard.ppt)
14:40	HFT Mechanics	E. Anderssen (20+10)	(Anderssen-E.ppt)
15:10	Panel discussion	(30 minutes)	
15:40	Break		
16:00	Executive Session		
19:30	Dinner		

February 26, 2008

8:30	Homework results and follow-up discussion
11:00-16:00	Committee work (working lunch)
16:00	Closeout
16:30	Adjourn

Review Panel

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