STAR FMS Review Report

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1. Introduction

This document is the Committee Report of the review of the STAR Forward Meson Spectrometer (FMS) Project. The review was called by the STAR Spokesperson and was held at Brookhaven National Laboratory on Sept. 1-2, 2009. The committee membership is given above. The Charge from the STAR Spokesperson to the Committee and the Review Agenda are attached as Appendices to this document.

The Executive Summary of this document presents the main recommendations of the review committee. The Narrative Section provides a discussion of the main recommendations, plus additional, secondary recommendations.

2. Executive Summary

The committee commends the FMS team for developing this unique detection system, which adds important new physics capabilities to STAR, and for completing the FMS project and bringing the device into operation. The committee also thanks the participants in the review. The review presentations and discussions were wide-ranging and informative.

The findings and recommendations of the committee fall into several categories:

Physics Performance:

The committee finds that the physics potential of the FMS is high for the study of the low-x gluon structure of hadrons and for nucleon spin measurements in the forward direction, particularly with transverse polarization. However, the committee finds that the FMS has not yet met that potential. Most notably, it is unclear to the committee:

- what will be achievable from the Run 8 dataset, whose results are urgently awaited by the RHIC community and beyond;
- what the real physics impact is of the Zener diode instability problem;
- why data-taking was not established for 500 GeV p+p collisions in Run 9;
- what the real importance is of a shower maximum detector to meet future physics goals

The committee recommends that planning for future transverse running include a focused and quantitative discussion within the PWG framework, with documentation of luminosity requirements vs. physics sensitivity. The FMS analysis must be integrated into the PWG framework.

The committee recommends the following priorities for the FMS team, with highest priority first: completion of Run 8 analysis; completion of Run 9 analysis; development and implementation of upgrades.

Management, Run Planning, Operations
The FMS is a STAR subsystem and must be fully integrated into STAR operations and planning. To that end, several documents should be prepared and their procedures implemented, as specified below.

Hardware Status and Integration
Full integration into STAR slow controls for HV should be established. Plans should be developed and documented addressing the Zener diode instabilities, magnetic field measurements, and clock distribution upgrade.

Calibration and Online
Full integration into STAR databases and online monitoring should be established. The calibration process must be open and documented on a continuous basis. Ongoing communication between the FMS group and the STAR Calibrations Coordinator is required, especially in the areas of calibration, online resources, and monitoring.

Software and Offline
All mapping and calibration parameters should be available in STAR databases. A strategy should be developed in consultation with the S&C group for embedding and Monte Carlo calculations, taking into account resources and knowledge in the rest of the collaboration. The committee strongly encourages the FMS team to use shared and open analysis software.

Documentation and Implementation
In order to address these issues, the committee recommends that the following planning documents be prepared, and the procedures presented in them implemented, as soon as possible:

- *Project Management Plan*: required workforce, responsibilities, timelines, and requirements, including responsibilities and authority of the FMS Subsystem Manager.
- *Run Plan*: physics-driven requirements for online calibration, gain matching, and QA; strategy for online calibrations; plans for monitoring and addressing the Zener diode instabilities.
- *Slow Controls Plan*: requirements for integration into STAR slow controls.
- *Software Plan*: plan for full integration of core FMS software into the STAR software framework and organization.

We discuss the content of these documents further in the Narrative section.

3. Narrative

Physics Performance
The Committee commends the FMS team for completing the project and bringing this important new device into operation. It opens compelling new physics avenues to STAR by extending electromagnetic calorimetry into the forward region, providing full azimuthal coverage over $-1 < \eta < 4$. This large solid angle coverage of STAR is one of its strengths and provides unique capabilities for exploring physics with particle correlations. It is clear that there is high potential for physics involving both the low-x structure of matter and spin physics, most notably the transverse spin program that has been pioneered by many of those in the FMS group.

Understanding the structure of hadrons at low x, including the possible existence of a Color Glass Condensate, is crucial to the heavy ion physics program and can play a strong role in motivating the EIC program. The FMS is clearly the best way to study this physics at the present time.

The observation of large transverse single-spin asymmetries at large x_F in the forward region at STAR has rejuvenated research into the origin of this phenomenon, first seen at much lower CM energies, and now in a regime where the observed cross sections indicate that perturbative QCD should apply. The FMS provides the capability to extend asymmetries for π^0s and other mesons to higher p_T for comparison to pQCD-based calculations, as well as to explore jet-like correlations that can shed light on possible Collins and Sivers effects. Theoretical studies of the Sivers effect motivated by this work and other measurements have pointed to QCD predictions that color charge interactions should lead to a sign change for the Sivers effect in gamma+jet and Drell-Yan production. These both lead to future directions for research with the FMS.

Finally the FMS provides coverage to the low-*x* region for studies of the gluon spin contribution to the proton's spin, a region that must be constrained experimentally to determine the integral contribution.

While the prospects for this detector are strong, the committee is concerned that its full potential is not being realized in a timely fashion. Several technical issues were raised with the detector performance during Runs 8 and 9 that, at best, make the analysis of the data difficult. During Run 8, magnetic field effects led to trigger thresholds that were, on average, much higher than intended. There were also very large variations in the tube-to-tube gains. Together, these problems make calibration difficult, and mean that the effective acceptance of the triggered data is less than anticipated. It appears that it will be necessary to utilize minbias data to fill in the kinematic region below the trigger turn-on. We note that a large fraction of the d+Au minbias data was recorded during the period when the FMS phototube voltages were changing daily. Furthermore, the kinematic reach of the minbias data is still unknown. During Run 9, problems were found with Zener diode instabilities that led to large, time-dependent variations in the gains for the affected large cells. The impact of these instabilities on the quality of Runs 8 and 9 data is unclear. It is also unclear whether or not these instabilities will provide a fundamental limit to the future physics reach of the FMS. The detector was not operated during much of the recent 500 GeV running period. The STAR magnetic field reversal during the 200 GeV running demonstrated that, while magnetic field effects have been reduced dramatically after Run 8, they remain significant. For all of these reasons, it remains unclear to the committee what portion of the physics goals are achievable from Run 8. This is a serious concern because the FMS measurement of the low-*x* gluon structure of the Au nucleus was the primary STAR goal for Run 8, and played a major role in defining the entire RHIC Run 8.

The committee was told that it is unlikely the dynamical origin of the large transverse single-spin asymmetries that have been seen in large-x_F π^0 production can be determined with the data that have been recorded to date. Several potential future measurements to address this goal were presented, including extending the π^0 measurements to 500 GeV and exploring asymmetries for jets, forward Λs, gamma+jet, and Drell-Yan. A shower-maximum detector is required to do π^0 and photon physics with the FMS at 500 GeV. Such a detector may or may not be required to measure gamma+jet at 200 GeV. The jet and Λ measurements motivate the proposal to add a Forward Hadron Calorimeter. The Drell-Yan measurement would require additional forward tracking. The general connections between the proposed upgrades and the various measurements are clear. However, detailed, quantitative estimates of the luminosity required to achieve specific physics sensitivities are incomplete. For example, an estimate was shown of the backgrounds for direct photons at 200 GeV with the existing FMS configuration. From this, an estimate was presented of the figure-of-merit required to perform the gamma+jet measurement. But the kinematic coverage and expected precision of the asymmetry measurement, after realistic background subtraction, was not discussed. It was also noted that backgrounds to the gamma+jet measurement might be reduced by the addition of either a shower-maximum detector or the Forward Hadron Calorimeter, but the expected impact of these upgrades on the background level and the required running time was not discussed.

Recommendations:

- Planning for future runs should be more focused and quantitative. The impact of the gain variability from the Zener diode bases on the future program also needs to be evaluated and addressed.
- Efforts of those working on the FMS must be integrated into the Physics Working Group structure of STAR. Intermediate progress reports on analyses, discussions of algorithms, etc., should be regular parts of open meetings where all those working with the FMS can participate, share ideas, and learn from each other. Working details should be posted on a routine basis to the STAR central Web site (Drupal or protected area) and announced using standard mailing lists. Frequent updates should be presented during the appropriate weekly PWG meetings so that feedback from the entire PWG can be incorporated into the analyses at all stages.
- It is clear that the group working with the FMS detector has a very full plate. Careful choices and priorities must be set to best utilize the full workforce available. The STAR collaboration and the entire RHIC community have a large investment and strong interest in the data already taken. It is unlikely that d+Au collisions will be run again prior to the 2012 deadline for DOE Performance Milestone DM8, which involves the determination of the low-*x* gluon density in cold nuclei. It is also important to determine the quality and reach of the existing data in order to assess the full impact of the proposed future upgrades. For these reasons, the committee believes the highest priority should be assigned to the timely analysis of the Run 8 data, and that analysis of the Run 9 data should take precedence over planning for future upgrades.

Management, Run Planning, and Operations

With the completion of the FMS construction project, the FMS is now a STAR subsystem. As such, it needs to be fully integrated into STAR and operated for the use and benefit of the entire collaboration.

Commissioning of the FMS took quite a long time during Run 8. As a new detector, this was perhaps to be expected. Even after the commissioning was complete, the distribution of cell gains was far from uniform. It also took quite a long time to commission the FMS during Run 9. The opportunity to take a significant data set during the 500 GeV running period was lost. The FMS was on during most of the 200 GeV running period, but the phototube high voltages were only 'frozen' and the FMS triggers elevated to physics status during the last ~2 weeks. This will complicate the analysis of data that were recorded earlier in the period.

Recommendations:

- The *Project Management Plan* should describe the workforce that is needed, the responsibilities of the individual group members, the requirements of the various tasks, and the expected timelines. It should also define the responsibilities of the FMS Subsystem Manager. It should be prepared in close consultation with STAR Management, and needs to be approved by STAR Management.

- The *Run Plan* should be written well before the next run and implemented to minimize the necessary commissioning time. It should describe FMS maintenance between runs, commissioning of the FMS and its triggers at the beginning of runs, routine operations after the commissioning phase is complete, and calibration of the data after the run; include a detailed plan for setting phototube high voltages; identify the team that will be responsible for the online calibrations, and the strategy that the team will use; and include the diagnostic and QA measurements that will be performed to verify that the detector is operating as desired.
- During the commissioning period, the team should post frequent status results on the diagnostic and QA measurements, making their best effort to make them accessible via standard methods (STAR central Web service, cross-reference in the RunLog, etc …) and discuss them via the FMS subsystem hypernews list. The team should also give routine reports on the diagnostic and QA measurements during the daily "10 o'clock" STAR Operations meetings.
- Operation of the FMS in FY10 should be evaluated, in consultation with STAR management and the relevant PWGs. Considerations in favor include the possible physics measurements and equalization of gains to accelerate commissioning in Run 11, while potential radiation damage may argue against.

Hardware Status and Integration

The detector and its electronics are now complete. The detector itself is composed of 1264 recycled lead-glass cells from at least three sources, including four different phototube/base combinations. This has led to a complex high-voltage (HV) control system with components from multiple commercial and university sources. The BNL-built LED system is expected to operate stably for the life of the detector.

To date, the FMS high voltage system has been operated outside the standard STAR Slow Controls system. This makes monitoring difficult for the shift crew in the Control Room, and precludes logging of the high voltage status in the standard STAR Slow Controls database. The committee was told that it should be relatively straightforward to integrate the Penn State and Yale portion of the high voltage system, which handles the small cells, into the STAR Slow Controls. The large cells, which are powered by LeCroy 1440 systems, may require some additional software development in order to provide subsystem experts access to special commands that have proven useful when dealing with Zener diode problems.

There are no mechanical issues with the detector system. Replacement of phototubes or bases is extremely difficult, and any annealing that may become necessary due to radiation damage will be difficult and time consuming. In light of this, careful consideration should be given to operating the detector in high radiation environments. It would also be worthwhile for the FMS group to consider contingency planning, in case annealing does prove to be necessary at some future date. The magnetic shielding added for Run 9 has significantly reduced the field dependence seen during Run 8.

Recommendations:

- The HV Control system should be incorporated into the STAR Slow Control (SC) framework, according to the requirements specified in the *Slow Controls Plan*. HV values should be changed only by FMS experts in consultation with the Period Coordinator and Trigger Board. It is expected that no HV operations will be required of the shift crews.
- The FMS has until now logged all high-voltage values onto local disks. We recommend that this logging be accomplished through the SC database operations in the future. We appreciate that the LED system provides the most robust verification of gain stability. We recommend that the

group develop a plan for dealing with Zener instabilities during running, which should be documented in the *Run Plan*.

- The group should develop a plan to measure the local field variation to help understand gain shifts seen with different magnetic field configurations.

Calibration and Online

The instability of the Zener diodes makes online monitoring of the FMS critical. The LED-system provides a powerful tool for continuous monitoring of the gain stability. The FMS group has developed software to monitor the gain stability via the LEDs and to do online reconstruction of π^0s, but currently none of this information is available to the shift crews. Integration of the FMS monitoring software into the official STAR online monitoring software is necessary.

At present, it is not known whether the Zener diode instability problem is stable or getting worse with time. The committee was told that approximately 5% of the large cells experienced the problem during Run 9. If that number remains approximately constant, it may suffice to mask those channels out of the trigger. If the number of problem channels appears to be increasing, more aggressive action may be required in order to stabilize the system.

Monte Carlo simulations have been used to understand the calibration results, but the committee did not obtain a good picture of how well the simulations reproduce the data or the quality of the calibration obtained if the calibration procedure is applied to Monte Carlo data. These comparisons should be documented.

Recommendations:

- The *Run Plan* should specify the physics-driven requirements for online calibration and gain matching to obtain the needed calibration quality and trigger uniformity, along with the calibration procedures. The effects of the Zener diode instability on the calibration process should be accounted for, and procedures developed to accommodate it.

- The *Run Plan* should specify the physics-driven requirements for online monitoring, i.e. what should be monitored, with the necessary statistical precision and latency. It should also specify the needs for FMS fast offline production so more detailed studies on the quality of the recorded data can be carried out.

- Instructions for the shift crew should be developed for the next running period, to ensure the shift crews are used efficiently.

- It is necessary for the FMS group to have regular communications with the relevant PWGs on the calibration process and progress of the FMS commissioning. Calibration tables must be included in the STAR database, to enable reproducibility of data analysis. The process to achieve these goals should be established in close coordination with the STAR S&C core support team.

Software and Offline

The committee acknowledges the considerable efforts made to date which have brought the FMS to a level where calibration and analysis are possible by central contributors to the project. The transition from a project to a fully operational detector requires integration of the detector sub-system data access and common analysis software into the standard STAR framework, to allow organized and efficient access by the full collaboration to calibration procedures, calibration constants, and analysis code.

During the review a broad overview of the software, calibration and analysis schemes was described; however, a comprehensive description of the software was not presented. Very little of the software and code are available in a standard STAR manner and there is no code repository apart from the rudimentary code available as integrated in the OnlinePlots (aka PPlots). The Committee was told that tar ball-like archives could be provided if requested, but it is unclear how such a scheme can provide a manageable approach to integrating detector information in an analysis combining other STAR sub-systems. Since the code is not publicly available in its entirety there is no clear way for the collaboration to verify or improve on algorithms for calibration, cluster reconstruction, or end-user analysis. Hence, access to increased resources is self-limited (human and computational resources) and quality assurance and regression testing are limited to the current FMS workforce.

None of the code uses standard application programming interfaces (API). In addition, the database approach is based on text file input (about six external files) whose inter-dependency is kept in check by home-made scripts. Such an approach is not suited to timeline synchronization between multiple detector sub-systems, nor does it allow the standard framework to evolve within a distributed computing environment. The absence of abstraction eliminates the possibility for virtualization, load balancing and performance scaling.

The method of releasing online and offline calibrations and the approval procedure for such releases was unclear, resulting in a lack of traceability for changes in the calibrations. As analysis opportunities broaden, this modus operandi is not desirable as it appears un-scalable in nature. In contrast to the standard STAR Database approach, the FMS calibration release is designed around a central and one-to-one communication process. The Committee finds that convergence and data readiness planning in light of FMS deliverables is not currently possible within an integrated STAR computing plan for data production, re-production and calibration convergence.

Statements were made on the need for immediate data processing and turn around, but no clear resource requirements were provided. Similar statements were made on the inadequacy of the OnlinePlots to deliver a framework for monitoring, but the event rate quoted as needed was within a factor of two of the nominal (un-tuned) event rate known to be currently achievable.

The Committee has similar concerns about the offline analysis packages. Different analyses do not share a common pool of reusable classes or codes, introducing the risk of divergence, as suggested for example in the cluster algorithm.

Simulation is handled using HBOOK and PAW, middleware packages which are obsolete and no longer supported by CERN, putting software evolution at risk as the facilities evolve. The Committee is concerned that knowledge built around PAW is not marketable in the current HENP landscape, putting students involved in the software development at a disadvantage for future opportunities. The simulation package relies heavily on the existence of the CERN libraries, which, in itself, would place the FMS at the same level as other sub-systems. However, with the FMS code being maintained independently, it is not clear if migration to a new operating system or CPU architecture would at all encompass the needs of the FMS.

Alternative packages for analysis, relying on the ROOT framework, were also presented. While these are a step in the proper direction and serve as a proof of principle for software evolution, this approach has the risk of further developing homemade schemes outside the general common framework.

Recommendations:

- We recommend the FMS software team participate fully in STAR planning for online and offline disk storage, IO needs, processing needs and response time needed in support of monitoring and calibration. Monitoring will require a combination of approaches, to be developed jointly with the STAR S&C core team.

- The need for efficiency corrections via "embedding" was stated, but no concrete plans were presented to develop code. This should be done in collaboration with other STAR analysis projects.

- Several plans for the evolution of the software toward its integration into a common STAR framework were presented and discussed. We strongly recommend that a single approach be adopted and documented in the *Software Plan*, which includes a timeline and required workforce for full integration of the FMS software into the STAR standard framework. We recommend that the FMS team work within the established organizational structure of the S&C activities, developing plans and requirements in a timely fashion. A strategy should be developed for embedding and Monte Carlo calculations, taking into account resources and knowledge in the rest of the collaboration.
- The committee strongly encourages the FMS team to use shared and open analysis software.

4. Appendix I: Charge to the Committee

The STAR Forward Meson Spectrometer (FMS) project has now completed construction and has gained significant experience running the detector. To aid in full integration of the FMS into the STAR experiment, the Review Committee is charged by the STAR Spokesperson to carry out a comprehensive review of the FMS subsystem, including the following:

- hardware status, performance, and upgrade requirements
- online calibration
- integration into STAR DAQ, Trigger, Slow Controls, and Online Databases
- offline software status and integration into STAR Offline systems
- subsystem management and organization

The committee will submit a written report to the STAR Spokesperson.

5. Appendix II: Review Agenda

Tuesday Sept 1

9:00-9:10 N. Xu: Scope of the Review

9:10-9:50 (25+15) L. Bland: Forward physics and the FMS

Physics accomplishments to date; physics goals and detector requirements; overview of status and plans for detector operations and physics program

9:50-10:30 (25+15) A. Gordon: Detector performance, operational experience, hardware status

10:30-11:00 (20+10) C. Perkins: Electronics and trigger algorithms status and plans

11:00-11:20 Break

11:20-11:40 (15+5) L. Eun: Cockcroft-Walton HV system

11:40-12:20 (25+15) A. Ogawa: Online and offline software overview, status and plans

Integration into STAR DAQ, Trigger, Slow Controls, Online Databases, and Monitoring; Offline software status and integration into STAR Offline systems

12:20-14:00 Committee working lunch

14:00-14:30 (20+10) L. Nogach/designee: Calibrations and offline reconstruction

14:30-15:10 (25+15) E. Braidot: Event reconstruction and simulations: status and plans

Includes status of Run 8 and 9 analyses

15:10-15:50 (25+15) S. Heppelmann: ROOT-based analysis for the FMS

15:50-16:10 Break

16:10-16:30 (15+5) L. Bland: FMS upgrade plans

16:30-17:10 (25+15) L. Bland: FMS project summary and management plan

subsystem management and organization; STAR resources required for future operations; plans for full integration into STAR systems

17:10-18:00 Committee discussion; homework requests

Wed Sept 2

9:00-10:00 Presentation and discussion of homework

10:00-12:00 Committee discussion and report writing

12:00-12:30 Closeout