Technical Review of the Hall-A SuperBigbite Spectrometer (SBS) Project

October 2, 2011

1. Introduction

A second technical review of the SuperBigbite Spectrometer (SBS) project in Jefferson Lab's Hall A was held on Friday, January 22, 2010. (A first technical review had been conducted on November, 17, 2008.) Following the SBS review in January 2010, the committee received responses to the recommendations from the Second Technical Review on July 13, 2011.

The members of the Review Committee (the Committee) were:

Paul Brindza
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Dave Doughty
Bernhard Ketzer
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The committee reviewed the "Progress Report on the SBS Project" from July 13, 2011 and answers to the follow-up questions on the physics program and technical features from September 19, 2011. The committee would like to thank the SBS proponents which carefully studied recommendations and addressed major items raised during the 2010 review. Since the Second Technical Review the SBS collaboration has made a major progress, especially in the area of Monte Carlo simulation benchmarked against both dedicated measurements and published data from the previous JLAB experiments.

Detailed discussion about the SBS layout, technical specifications for the key detector components and background environment can be found in the materials presented to the committee during the Second Technical Review of the SBS spectrometer. Follow-up questions and recommendations were summarized in the committee report from February 22, 2010.

It should be noted that this report uses words like comments, concerns, and recommendations in their standard English meaning, not with the specific meaning use in DOE review.

2. The SBS Project: Summary of the Second Technical Review

<u>The summary of the committee report from the Second Technical Review in January 2010 was:</u>

The SuperBigBite project in Hall A has been reviewed. The Technical Review Committee is impressed by the broad scope of the physics program and the anticipated performance of the spectrometer.

The SBS project is aiming at the combination of large solid angle coverage at forward angles with the highest luminosity achievable with the upgraded 12 GeV CEBAF. The SBS consists of a transverse field dipole magnet equipped with high-rate GEM tracking detectors. Calorimeters and Cherenkov counters will be used for triggering and particle identification.

The initial experimental program consists of three nucleon form factor experiments that have been approved by the JLab PAC. It is obvious to the Committee that the SBS will become the instrument of choice for a large variety of other important physics problems requiring small-angle coverage, high luminosity, and modest resolution.

The Committee finds that the SBS experimental design has a very high probability of meeting the experimental requirements. The high rate and high resolution capability of the GEM detectors make them the ideal solution for this application. The SBS Collaboration has the required expertise to carry out the project within the time schedule presented.

Remaining uncertainties in background rates and electronics performance can be reduced by performing experimental tests under similar conditions. This should be done as soon as possible since the results could lead to modifications of the segmentation scheme and the readout rates which need to be known before the start of mass production.

Below we'll review detailed responses of the SBS collaboration following committee recommendations and our feedback to the SBS responses.

3. The GEM Tracking System

3.1 GEM Detectors and PCB

Recommendations:

- In view of the very large production of GEM foils and readout PCBs by the CERN workshop, the Committee strongly recommends to set up a list of specifications and QA acceptance criteria (e.g. max. leakage currents, inner/outer hole diameter range, max. mask misalignment, etc.) before the start of mass production this year. Strict QA rules and documentation of acceptance tests at the institutes receiving the GEM foils and PCB boards should be set up and followed. Depending on the details of the QA requirements, the level of required contingency should be discussed with the CERN workshop. The quality of GEM foils and PCB components during the mass production process has to be closely monitored, and rapid feedback to the CERN workshop should be ensured.

The SBS team has established a list of specifications and QA acceptance criteria based on the COMPASS production guide, information coming from the RD51 Collaboration and experience acquired during the quality control and assembly tests of the full-scale (40x50 cm2) triple-GEM prototypes. The SBS collaboration intends to use the single mask GEM technology: production quality has reached a level comparable to the double mask technique and production is becoming cheaper and faster (based on the experience from CERN MPGD workshop and RD51 collaborating institutes). The QA procedures for single mask GEMs will not change with respect to the double mask technique. The INFN group will perform QAC for the components of the front tracker. The UVa group will employ experienced GEM expert who will perform QA tests at CERN before shipment of the GEM foils to the UVa. The lab at UVa will be equipped to make additional tests.

- The Committee recommends investigating the possibility to reduce the number of spacer strips between GEM foils which will result both in a smaller dead area and a smaller amount of material.

Revised version of the GEM chamber design resulted in a significant reduction of spacer strips (by about ~50%), leading to a smaller dead area.

- The Committee also proposes to investigate the possibility to increase the technical personnel for the construction and system integration aspects of GEM chambers and electronics for ST and TT at the University of Virginia.

The level of technical support at the UVa has been re-evaluated. Additional manpower (GEM expert joining UVa, part-time post-docs, graduated students) has been identified in the UVa group, which seems to be adequate for the chamber production within the time schedule presented.

- The cost estimate for the construction of GEM trackers seems to be adequate. The Committee recommends to make sure that the cost estimates for the GEM foils and readout circuits include the contingency for the final yield, based on the QA procedures, and to review the cost estimate for the gas system which seems to be on the low side.

The SBS team intends to use the existing gas delivery system of Hall A (without modifications). The current cost estimate for the GEM gas system includes only additional piping and flow meters that will be necessary for integration into the Hall A system. No financial resources for the major upgrade of the Hall A gas system are currently allocated in the project budget.

3.2 Readout of the GEM Modules

Recommendations:

- Noise performance studies of the chamber with UV strip orientation, and therefore varying strip lengths, and an analysis of its impact on resolution and efficiency are of a great importance before the start of mass production. Special tests to estimate S/B performance should be also foreseen for the ST and TT chambers, where four strips are connected into a single readout channel (longer effective strip length mean higher capacitance, i.e. more noise).

All GEM chambers with UV strip orientation have been dropped. This configuration allows the simplest layout of electronics. The impact of UV projections on the system redundancy at high occupancy has not been evaluated yet in details.

- In view of the high background levels (~ 500 kHz/cm^2) in the GEp(5) spectrometer, the Committee recommends that the 3-sample readout method of the APV25 be adopted as the default solution for all trackers (FT, ST, TT). This will increase the bandwidth requirement and data rates from tracking stations to the DAQ which, however, seems to be consistent with the plans for the Hall A DAQ upgrade.

The SBS team has adopted the recommendation of using the three-sample readout of APV25 for all trackers in the proton arm of GEp(5), and this has been incorporated into Monte Carlo simulation.

3.3 Background Considerations for GEM Detectors

Recommendation:

- The Committee strongly recommends that the response of a GEM detector to low-energy photons should be measured using a prototype detector and electronics. The results should be compared to the GEANT modeling to confirm that the background levels in the Monte Carlo simulation are realistic. The expected level of occupancy in the GEM detectors, using an APV time window of 250 ns and an average number of strips in cluster per MIP particle ~ 3.5, seems to be exceedingly high.

The photon-detection efficiency was measured using a prototype GEM detector and a 137Cs source, and was found to be in good agreement with the GEANT4 MC simulation performed by the SBS collaboration. A small five-plane GEM prototype has been constructed, and will be tested in beam in the fall 2011.

Conclusion:

The choice of the GEM technology for the SuperBigBite spectrometer fulfills the most stringent performance requirements imposed by the high background levels of the GEp(5) experiment. The design of the detector modules is well advanced and appears to be sound and without major flaws. The full size triple–GEM prototypes of 40 x 50 cm^2 were constructed and tested in 2011. In discussions with the CERN workshop, it was confirmed that the workshop has sufficient capacity to produce the required number of GEM foils and PCB readout boards for the SBS project in the next few years.

The SBS collaboration has addressed major concerns summarized in the Second Technical Review. The committee is impressed with the recent progress in the design and construction of GEM detectors and Monte Carlo simulation improvements.

The Committee is confident that both groups can benefit significantly from the recent GEM technological advances existing in CERN and from other RD51 collaborating institutes and should be able to construct the proposed GEM-based tracking system within the proposed schedule.

4. The Other Components of the SBS Spectrometer

4.1 SBS Magnet

Recommendations:

- Execute a letter property transfer of the 48D48 magnet, spare coils, and power supply with BNL to secure the ownership of the magnet for JLab.

- Transfer of the SBS magnet, spare coils, and power supply to JLab should occur as soon as funds can be obtained for shipping and storage. The 48D48 magnet (and its power supply) is an excellent general purpose device and will be a valuable asset for JLab for many uses including its obvious value to the SBS project.

- A JLab representative should be dispatched to BNL to inspect the 48D48 DC power supply(s) to ascertain the suitability for continued use at JLab as part of the SBS Spectrometer. DC Power Supply documentation, spare parts inventory, and overall power supply condition should be determined by on site first hand inspection.

- The SBS magnet should be operated with all coils in series for best spectrometer stability and accuracy.

- The magnetic modeling of the 48D48 magnet as modified for the SBS that has been performed using "Mermaid" should be cross-checked against a fresh TOSCA model. The field plots shown during the presentations show some evidence of a grainy mesh especially in the angled beam pass through the channel. According to the presenters this was a result of limitations of the Mermaid installation. A TOSCA model with higher resolution would provide confirmation of the efficacy of the beam pass through shielding and the field in the gap including fringe fields.

- The SBS optics that was presented was based on model fields to represent the SBS dipole. The results presented indicate that the SBS magnet optics, resolution, and acceptance are well matched to the experimental requirements. The optics calculations and evaluation of the resolution and acceptance should be repeated with calculated 3D fields from a high resolution TOSCA model or at least the present Mermaid model. Using actual calculated SBS magnet fields will necessarily include the effects of the field gradient along "Z", a complete fringe field description, and information about actual fields along the beam pass through.

Written assurances have been received from BNL regarding the availability of the 48D48 magnet. A new power supply for the magnet has been added to the SuperBigbite budget, so that the magnet will be operated with all coils in series. TOSCA calculations are continually being refined.

Conclusion:

The SBS project team has address all questions related to the 48D48 magnet, magnet acquisition, Tosca modeling and optics simulation. The results presented clearly demonstrate that the optics will meet all SBS requirements. The SBS project team is to be commended for procuring a new power supply capable of powering the 48D48 in series. The committee is satisfied that the SBS team has addressed all magnet and optics issues and we are very impressed with the current SBS Progress Report.

4.2 The Electromagnetic Calorimeter

Recommendations:

- Provide calculations of the energy and spatial resolution with the 20 cm Al absorber taking into account the average radiation damage.

An adequate response is provided. Detailed simulation of the energy and position and resolution of the electromagnetic calorimeter remain sufficient under the operating conditions of the GEp(5) experiment.

- Evaluate the impact of the resolutions on the general performance including tracking and trigger rate. Clarify the impact of the expected energy resolution not meeting the requirement on page 107.

A response is provided. It appears that the resolution is a constraint and may reduce the efficiency to the signal for acceptable trigger rates.

- The calorimeter resolution affects the trigger efficiency at a given trigger rate. What reduction of the statistics due to the trigger rate constraints could one anticipate, if one uses the new calculations of the energy resolution and makes reasonably conservative assumptions about the DAQ capabilities?

According to the 2010 DAQ scheme and increased rate of the calorimeter, the DAQ rate will be of the order of 3 kHz. Such a rate is still below the level of 5 kHz considered acceptable in the report. An additional study of DAQ was presented by I. Rachek and B. Wojtsekhowski using the sparsification mode of the FastBus TDC 1877s and evaluated readout speed. The proposed DAQ system will allow us to take data at a 10 kHz rate with 10-20% dead time.

- Provide evidence or arguments that a 5 fold increase in the UV light intensity will increase the rate of curing by a factor of about 5.

According to analysis of the radiation rate and annealing rate, the SBS collaboration allocated 12% of the time (one hour per eight hours) for the UV annealing process (see page 30 of the ”Progress report on the SuperBigbite Project”). The UV curing of the lead glass will be tested this year at high light intensity. The results of the new measurements will be important to confirm underlying assumptions.

Conclusion:

The SBS team has addressed questions related to electromagnetic calorimeter. The only remaining question is if the time allocated for the lead glass curing sufficient. The results of the new measurements planned for 2011 would be important to confirm underlying assumptions. The results of the new measurements have not been yet presented to the reviewers. The calorimeter resolution affects the trigger efficiency and the level of background in the final Gep sample. The SBS report indicates that the expected losses are relatively small - up to 20% due to the dead time of the DAQ if the trigger rate is increased from 3kHz to 10kHz because of a reduced energy resolution of the calorimeter ("Progress Report on the SBS Project", page 27). The background increase is described as "acceptable" ("Progress Report on the SBS Project", page 25). It would be helpful to provide the final evaluation of the expected signal and background statistics taking into account all the factors discussed.

4.3 The Hadron Calorimeter

Recommendation:

- The CDR indicated that the timing resolution of the hadron calorimeter will be improved from 1.5 ns to 0.4 ns. Although the hadron calorimeter is removed from the MIE application, its performance remains important. It was not clear if the proposed 4-fold improvement in the timing resolution was essential for the project, and if so what the plan was to achieve such an improvement.

In GEp(5) and GMN experiments, time resolution of 1.4 ns (COMPASS result) is sufficient. Much better time resolution of HCAL is essential in the GEn experiment for the suppression of inelastic events. There are three factors which will allow us a 4-fold improvement in the time resolution: shorter emission time of the wave shifters, shorter rise time of XP2262 PMT and high resolution TDC which will be used for HCAL. A time resolution of 0.4 ns was achieved in the hadron calorimeter of E864 (NIM A 406 (1998) 227 258) with the lead-scintillating fiber scheme. By using a fast scintillator and a fast wave shifter, the SBS collaboration expect to reach a similar result.

Conclusion:

The original plan was to build an iron-scintillator sandwich calorimeter with a WLS readout. The referenced calorimeter from experiment E864 was built using a SPACAL technology. The latter calorimeters might be intrinsically faster because they do not use the additional light radiation in the wave-length shifter, which adds an additional timing smearing and reduces the light output. The SPACAL calorimeter is also denser, using lead, and has a better energy resolution than the iron-scintillator sandwich. This may also contribute to a better timing resolution. Improving the timing resolution of the proposed calorimeter by a factor of 4 might be possible, but will likely require considerable R&D efforts.

4.4 Electronics, Triggering, and Data Acquisition

Recommendations:

- Develop a plan for routing the signals from all boards in the backplane to the FPGAs that is consistent with the expected data rates.

The "Progress Report on the SBS project" presents plans for three possible solutions: an aggressive solution which involves doubling the data rate on two serial lanes, a fallback solution using all four serial lanes, or a very conservative solution which involves splitting the electronics. It is likely that one of the first two solutions will work fine, and even the last solution has cost implications which are not onerous ($85,000). The committee has no remaining concerns in this area.

- Clarify the consequences of the multi-mode readout of the APV25S1 chip for event size and data acquisition rates.

The calculations included in the report indicate that readout of the APV25S1 chip, processing and data readout should not be a problem. We have two additional comments concerning as-yet untested features of this readout and processing chain. First, if the "retriggering" mode of operation does not work the only penalty will be a little bit of dead-time. Also, based on other simulations of which we are aware, the processing in the MPD should be done in well under the 500 microsecond budget.

- Specify the mechanical details of the FEC electronics, in particular the support for the electronics and the routing of the cables.

The details and figures provided address this concern.

- Examine the signal quality of the GEM chambers as a function of cable length to make sure that the GEM performance is not compromised by the 7 - 10 meter cable run.

The signal quality tests indicate that this should not be a problem as long as the lengths are kept under 15 m.

<u>Conclusion:</u>

- The committee is satisfied with SBS responses, which address all concerns in the recommendation report on electronics, triggering and data acquisition. If the "retriggering" mode of operation, which is considered technically feasible but not implemented yet, does not work the only penalty will be a little bit of dead-time.

5. Tracking and Event Reconstruction

<u>Recommendations:</u>

- Clarify the pattern recognition in the CD, taking into account showers in the 20 cm thick Al absorber in front and the backsplash from the calorimeter.

Detailed MC simulation of the coordinate detector has shown that the SBS analysis will yield a spatial resolution that is sufficient for the track selection in the GEMs of the front tracker of the hadron arm.

- Simulate the full chain of track reconstruction in the first SBS tracker, starting with the signal readout, taking into account the realistic pulse lengths and cluster widths.

Major progress has been achieved in this area. A full Monte Carlo of the experiment has been developed with the data generated within the framework of GEANT4. These data were then used as input for the full chain of the track reconstruction in the SBS tracker: detector response, signal processing and the analysis algorithms. The precise spectrum was studied using GEANT3. The pulse shapes generated using GEANT4 were cross-checked against actual experimental data. Further optimization using the programmable APV25s appears feasible.

- Demonstrate the expected tracking efficiency and the level of contamination by false tracks using an algorithm for hit recognition and projection matching.

Considerable progress has been made in developing the tracking algorithms and evaluating the tracking efficiency and the level of background. During the GEp(5) experiment the expected strip "raw occupancy" will be of ~70%, which makes tracking a very challenging task. The SBS collaboration defined "raw occupancy" as the probability of a hit with the small amplitude threshold (about 5% of the typical full amplitude). Using pulse shape analysis and applying several kinds of background filters, the actual occupancy which plays a role in tracking is estimated to be about 10%.

- We would like to understand what the impact would be on the tracking efficiency and false track probability if the UV chambers were kept in place. Normally, redundancy and different projections do help a lot. What was the major reason why the UV chambers were removed?

In the GEM tracker MC data we used the long strips - the split of the strips was not implemented. It will be the first upgrade to make if the occupancy is too high. The impact of UV projections has not been fully evaluated yet. We started from a configuration which allows the simplest layout of electronics.

- Remaining uncertainties in background rates and electronics performance can be reduced by performing experimental tests under similar conditions. This should be done as soon as possible since the results could lead to modifications of the segmentation scheme and the readout rates which need to be known before the start of mass production.

The SBS team has tested a small prototype GEM chamber during the recent PREx run in Hall A in June of 2010. The data are currently being analyzed. A test run of the GEM hodoscope at the electron beam from the tagger at Mainz has been done in September 2011. Analysis is underway.

Conclusion:

The committee is very impressed by the major progress achieved by the SBS team in the development of the full Monte Carlo simulation for the SBS/GEM tracker. The data generated within the GEANT4 framework was used as an input for the full chain of the track reconstruction: detector response, signal processing and development of pulse-shape analysis algorithms.

In the high background environment of the GEp(5) experiment, the overall tracking efficiency of ~90% has been achieved. The experiment discussed (GEp(5)) measures the cross-section asymmetry to the beam helicity flip and is not very sensitive to uncertainties of the tracking efficiency. The expected contamination by false tracks is expected to be smaller than 5%. It has to be noted that the expected "raw strip occupancy" is ~ 70%, which makes tracking a very challenging task. The SBS collaboration has developed pulse shape analysis and apply several kinds of background filters. This allows to reduce "actual occupancy" which plays a role in track reconstruction down to ~ 10%. The committee would like to suggest to study the effect of the pulse-shape background filters on the real data (e.g. from experimental tests in Hall A or the electron beam in Mainz).

The "raw strip" occupancy of ~ 70% has been calculated for long strips. It will be the first upgrade to split the strips in the middle of the module if the occupancy is too high.

6. Cost, Schedule, Manpower

Recommendations:

- The SBS Collaboration should develop a bottoms-up cost estimate for the project. Include all required components and activities. Make sure that realistic yields for delicate production items are taken into account.

A new and detailed funding profile has been worked out as part of an Major Item of Equipment (MIE) proposal to DOE. The budget was reevaluated following a bottom-up procedure. It includes modifications to the magnet and its support structure, development of the GEMs and all other aspects of the project.

In FY12 a contract is planned to be signed with CMU for the construction of the hadron calorimeter. The Hadron calorimeter, which will also be used in non-SBS experiments, has not been included in the MIE proposal, but will be funded directly by JLab.

- If DOE funds are available next year, do you aim to have the SBS ready for data taking in 2017 (as follows from Fig. 10.2 of Progress Report)?

Yes, the aim is to have GEP(5) equipment ready for data taking in 2017. According to the proposed time line, the four front GEM chambers will be used in the A1n experiment in 2014. The GMN experiment should be ready to take data in 2015 and allow the first chance for the GEM chamber test behind the SBS magnet. The GEN experiment should be ready to take data in 2016.

Conclusions:

A new and detailed funding profile has been worked out as part of an MIE proposal to DOE. The Committee's general impression is that the large components of the project have been accounted for and are included in the cost estimate in a realistic fashion. The contingency ranged between 10% and 30% with most items listed at 20%. This level of contingency seems to be adequate. However, based on the available information, it is difficult for the committee to judge if this level of contingency is sufficient for the number of small-scale items discussed in the current budget spreadsheet.

The manpower available for the project looks sufficient. The Collaboration has the required expertise (or access to it) in the critical areas of GEM chamber and electronics fabrication. The level of technical support at the University of Virginia has been increased. The Committee notes that the members of the Hall A staff play crucial roles in the SBS Project and engineering support is planned to begin shortly at JLab.

The schedule presented aims at having GEn experiment ready to take data in 2016 and GEp(5) equipment should be ready for data taking in 2017. This schedule depends critically on the availability of DOE funds. Assuming that these funds will be available, and assuming that the Hall A staff will be available to work on the SBS Project the Committee did not see any reason why the schedule could not be met.

7. Summary

The SBS project is aiming at the combination of large solid angle coverage at forward angles with the highest luminosity achievable with the upgraded 12 GeV CEBAF. The SBS consists of a transverse field dipole magnet equipped with high-rate GEM tracking detectors. Calorimeters and Cerenkov counters will be used for triggering and particle identification.

<u>The Committee finds that the SBS experimental design has a very high probability of meeting the experimental requirements:</u>

- The choice of the GEM technology for the SuperBigBite spectrometer fulfills the most stringent performance requirements imposed by the high background levels of the GEp(5) experiment. The design of the SBS GEM tracker is well advanced and appears to be sound and without major flaws. The manpower available for the project looks sufficient. The Collaboration has the required expertise (or access to it) in the critical areas of GEM chamber and electronics fabrication.

- The SBS project team has addressed all questions related to the 48D48 magnet, magnet acquisition, Tosca modeling and optics simulation. The results presented clearly demonstrate that the optics will meet all SBS requirements.

- The electromagnetic calorimeter is critical for triggering and the event selection. The Collaboration has a good experience with the detector to be used. The plan is to push this calorimeter to the limit of radiation damage and to compensate the damage by very frequent annealing runs. Following an earlier recommendation the Collaboration had plans to test this procedure in 2011 – no results are available yet.

- The hadron calorimeter was supposed to use an established technology. However, for one of the measurements, the timing resolution has to be improved by a factor of 4. The Committee points out that, while certainly possible, this may require to carry out an R&D program.

- The SBS project team has addressed all concerns in the recommendation report on electronics, triggering and data acquisition.

- Since the Second Technical Review the project has gained significant strength especially in the area of Monte Carlo simulation benchmarked against both dedicated measurements and published data from the previous JLAB experiments. The committee is very impressed by the major progress achieved by the SBS team in the development of the full Monte Carlo simulation for the SBS/GEM tracker: detector response, signal processing and development of pulse-shape analysis algorithms. The committee would like to suggest to study the effect of the pulse-shape background filtering algorithms on the real data.

The initial experimental program consists of three nucleon form factor experiments that have been approved by the JLab PAC. It is obvious to the Committee that the SBS will become the instrument of choice for a large variety of other important physics problems requiring small-angle coverage, high luminosity, and modest resolution. One should point out that these three experiments planned put stringent requirements on different part of the apparatus. None of the challenges individually appears to be a showstopper. Meeting them all in the common apparatus will require considerable efforts from the Collaboration.

Since a better understanding of the detector resolutions and rate limitations have been achieved it would be appropriate to review the expectations of the proposed experiments and provide a relatively compact summary.

The SBS Collaboration has the required expertise to carry out the project within the time schedule presented. A new and detailed funding profile has been worked out as part of an MIE proposal to DOE. The Committee’s general impression is that the large components of the project have been accounted for and are included in the cost estimate in a realistic fashion.