U.S. DEPARTMENT OF ENERGY

Office of Science

Department of Energy Office of Nuclear Physics Reviewer Excerpts

on the

Annual Progress Review

of the

Super BigBite Spectrometer (SBS)

November 4-5, 2014

EXCERPTS FROM PANEL MEMBER REPORTS

The Annual Progress Review of the Super BigBite Spectrometer (SBS) project was held at Thomas Jefferson National Accelerator Facility (TJNAF) on November 4-5, 2014. Provided below are excerpts from the reports of the review panel members regarding their findings in response to the review criteria they were asked to address.

<u>The significance and merit of the project's scientific goals:</u>

Reviewer:
"The conclusions of last year's review that the proposed suite of measurements takes excellent advantage of the 12 GeV upgrade to make measurements to high Q^2 and improved precision measurements at lower Q^2 are reaffirmed. The data should provide new insight into the basic structure of the nucleon. The measurements are of high significance. The proponents should be encouraged to consider the significance of the measurements in the broadest possible context including having significant contact with theorists and organizing workshops."

Reviewer:

"The scientific program of the proposed Super BigBite Spectrometer (SBS) is focused mainly on two measurement techniques of the nucleon electromagnetic form factors up to momentum transfers Q2≈ 10 GeV2. They are possible due to the new 12 GeV capabilities promptly available at Jefferson Lab. Results from these measurements are likely to have a lasting impact on the nuclear physics field. The form factor measurements have a direct connection with the structure of the nucleon and the proposed program will probe this structure at scales not attempted before, which would lead the way to evaluations of theoretical models in a region where the data are expected to be sensitive mainly to the three-quark core."

Reviewer
"The goals are to understand details of nucleon structure and could well revolutionize our understanding of collective partonic effects in nuclear matter. These goals are shared through many communities in physics and deserve strong support."

Reviewer:
"Measurements of nucleon electromagnetic form factors are basic to our knowledge of nucleon structure. The SBS program, utilizing beams from the TJNAF 12 GeV accelerator upgrade in Hall A, will provide measurements of 3 of the 4 elastic form factors (GE(n), GM(n), GE(p)) out to a Q^2 of at least 10 GeV^2, significantly above the current range of ~ 3.4 GeV^2. The region above Q2=3D8 GeV2 is unexplored using the method of polarization transfer. While form factor measurements are planned in other JLAB hall experiments (GM(p) will be measured with the HRS), the SBS program will provide the bulk of the nucleon electromagnetic form factors to high Q^2.These elastic nucleon form factors taken together will add additional constrains on the Generalized Parton Distributions.

“Previous form factor results, have already helped substantiate theoretical developments and have included predictions for quark angular momentum behavior using the Ji sum rule. The new data will effectively triple the Q^2 range over which an essentially model independent flavor decomposition of the nucleon form factor is possible. The extension to higher Q^2, where quark core states are likely to manifest, may be sensitive to quark-di-quark degrees of freedom.

“Interest in the nucleon form factor measurements pushed to higher Q^2 by the SBS program remains high as re-affirmed by the recent PAC review. In addition to the core SBS program, A1^n measurements will be made, extending to larger values of x. SIDIS measurements, with more detailed information on the Collins and Sivers asymmetries (expanding significantly on the work at COMPASS and HERMES) are also anticipated and have a high scientific importance.”

<u>The feasibility and merit of the technical approach for delivering the science, and the technical status of the project, including completeness of scope and fabrication progress:</u>

Reviewer:
"Significant progress has been made on all systems. Many detector systems are in production. The magnet iron is in hand and machined for the requirements of SBS. New race track coils are ordered and the decision is made to order new saddle coils. The power supply is in hand. The magnet will not be able to be energized to full field until it is installed in the experiment hall. If the decision is made not to do a full detailed field map it would be advisable to carefully check the region adjacent to the slot in the yoke at full field since saturation may occur in the iron there.

"Concerning the CDET system plans are well advanced. The scheme for shimming each slat with thin tape to achieve projective geometry seems labor intensive. The proponents should be encouraged to investigate simpler schemes such as mounting slats in suitable size groups and arranging the mount to the support frame to rotate the group. A realistic schedule for completion of CDET, including finishing the design, possible testing of prototypes, fabrication and testing should be developed and integrated into the WBS and PMP.

"Concerning the GEM trackers, R&D and prototyping is complete and production of the final modules has started. Studies of the prototype chambers have led to beneficial changes to the design including more careful production of the readout plane to assure proper etching of the kapton between the top and bottom readout strips and use of a gas barrier separate from the readout plane. Measurements on the prototype chambers show that the performance requirements can be met. Initial production experience indicates that component yield is good and that the fabrication and QA procedures lead to good finished modules.

"A persistent mystery is a systematic decrease in gain across the module in the direction of gas flow. Although the magnitude of the decrease can be minimized by increasing the gas flow it would be good to understand the cause of this phenomenon. Such behavior can be caused by a leak in the gas vessel. Monitoring water and oxygen content in the exit gas stream should provide an indication of leaks."

Reviewer:
"In practice the proposed SBS spectrometer with its associated infrastructure (targets and auxiliary detection systems) are well matched to the capabilities of the laboratory in terms of the needed luminosity, beam polarization, and scientific and technical personnel. In addition, the SBS collaboration has a strong record of doing these types of measurements and on the use of the proposed polarization techniques as well as on the design, construction, and operation of open, large solid angle spectrometers like the proposed SBS.

“The SBS project encompasses two main distinct experimental configurations: one in which the SBS is used as proton polarimeter (PP) and another in which is used as a neutron detector (ND). As a PP the SBS consists of the magnet followed by an array of GEMs and analyzers for tracking proton polarization and a position-sensitive scintillation coordinate detector (CD) as the front face of a hadron calorimeter (HCAL) for proton full identification. In the ND configuration the GEMs and analyzers are not needed and the CD detector acts as a charge particle veto for the hadron calorimeter. The electron arm in each case is also quite distinct of one another. A non-magnetic, large solid angle detector consisting of the CD detector followed by an existing calorimeter achieves the electron detection when the SBS is used in the PP configuration. On the other hand, for the neutron form factor measurements an existing magnetic spectrometer is used as the electron arm as a way of improving the accuracy of the scattered electron kinematical information. The two experimental configurations use their unique targets: an unpolarized liquid hydrogen target for the proton and a polarized 3He gas target for the neutron form factor measurements, respectively.

“The overall complexity of the SBS program is significant. The 48D48 magnet is at JLab and the yoke pieces have been modified for use as the SBS magnet. The Laboratory handles this part of the project and progress has been substantial and it appears that the remaining tasks will meet their deadlines. The SBS detector responsibilities all reside with outside universities. The GEMs fabrication project is in the hands of the University of Virginia (UVa) group and a subcontract has been awarded to UVa for the construction of the GEMs. Production of the GEMs has started and a rigorous testing procedure has been implemented that gives confidence in the quality of the final detector.

“The recent proposed CD detector adds significant technical capabilities to all proposed measurements but it requires a significant effort in terms of coordination and oversight. The design is at a well-advanced stage with a prototype already in place. The WBS2 schedule should now reflect this new detector with all its implications for manpower and costs.

“The hadron calorimeter, which is not included in the project WBS’s, is in the hands of the Carnegie Mellon University (CMU) group, a final construction plan is in place and no hurdles are foreseen except for the enormity of the tasks (24,000 scintillator channels). Other off-project detector tasks include the construction of a Front Tracker GEM system from the INFN group and the refurbishing of auxiliary detection systems (Gas Cherenkov, Calorimeters) from various outside expert groups.”

Reviewer:
“The approach is to scatter electrons off nucleons and nuclei, with simple triggers to select events for further analysis. The triggers are based on 2-body kinematics, either detecting a single scattered electron or an electron in coincidence with another particle such as a neutron or the absence of a particle. In principle these are simple geometrical coincidences, but the signal represents a tiny fraction of the triggered events. I am still interested in seeing an analysis of a "real" event stream to see how the signal is picked

out. Last year I was more confident in their ability to do this, but the parallel Fastbus approach that relies on operating a complex system at extremely high luminosities represents a real challenge. Discussions with the "experts" convinced me this is possible with a simple time stamp technique, but it is complex. I re-emphasize that that it would be much better to find a way to eliminate Fastbus in favor of the JLab flash ADC boards used in other parts of the experiment.

“I find the SBS group to be well managed, enthusiastic, and innovative. Their goals, to measure the GEn, GEp, and GMn form factors are important to understanding the internal structure of nucleons, and may well elucidate the role of internal orbital structure. Again we did not have a presentation on trigger and daq, but we did get a draft of the document describing these aspects of the experiments. The document is not complete, but has basic information on subsystems. It should eventually include an overview that presents real data rate numbers, with clear breakdown of hits per trigger per detector.

“We uncovered an interesting difference in the culture of experiment simulation, with our view at RHIC simulating "real" events into our detector system, while at JLab, the simulations concentrate on individual processes or subsets of final states. This makes it difficult to understand backgrounds and I think compromises our ability to see realistic detector responses, especially in a very high luminosity environment.

“For the CDet, I note that they have a separate gain normalizer card that will allow cancellation of both PMT gain variations and NINO channel variations leading to a very uniform detector response, if they choose to use it this way. I also like the idea of having 1 longer bar in each set of 16 so that you can sight along it to align with the target.

“For the GEM electronics, I note that the choice of INFN electronics is a good way to save manpower costs since ony one electronics system need to be mastered. The GEM schedule and progress look good.

“I found that techniques developed for HCal construction to be innovative and very clever. Using cosmic rays to get close to the gain matched high voltage for the PMTs, and then using elastic scattered electrons makes this calibration problem elegantly simple.”

Reviewer:
“The basic infrastructure for the SBS, prerequisite for the several configurations envisioned for both preparatory calibrations as well as physics measurements are contained in the scope of WBS1 and (a few parts of) WBS2.

“Since the last review, there has been significant activity on all fronts with equipment taking shape, major orders placed or received, with some items undergoing acceptance testing. The final engineering/fabrication push is anticipated during FY15. The committee is pleased to hear of all this good progress and the projection to completion of this "SBS basic" part of the project in a timely and cost effective manner.

“In particular we heard that: 1) the 48D48 magnet yoke pieces obtained from BNL have been machined, assembled as the SBS magnet and acceptance tests performed at low (200A) excitation with available coils; 2) new race track coils were ordered/received and a decision made to go ahead and order new saddle coils (in the award process at time of review); 3) the new SBS magnet 2200A power supply has been delivered to Hall A and will be tested during during the next Hall A access period in January; 4) the counter-weighted SBS support structure, to be positioned by a combination of hydraulic cylinders and Hillman rollers, has passed design review and is in fabrication; 5) the exit beam pipe magnetic field correction design meets the < 1000 G-cm integral field requirement and is versatile, accommodating the different SBS settings by utilizing both layering of shielding material on the pipe as well as having two independent iron dipole corrector magnets; and finally 6) a vacuum "snout" is in fabrication to be used with an existing scattering chamber, design of the field clamps is complete (awaited final coil decisions) and analysis for the pole shims is underway. Projecting toward the completion of tasks, due to a window in the Hall A experimental installation/ running schedule, sufficient workforce resources appear available to meet remaining WBS1(2) engineering/design deadlines in the next months.

“The SBS magnet and its successful implementation and operation figures prominently of course in nearly all aspects of the SBS basic infrastructure design. It was important to hear that the project was advanced enough so that contingency funds could be used to order new saddle coils. Along with the new racetrack coils (which ease rotation of the magnet) the new saddle coils increase the physics solid angle by allowing closer proximity of the detectors to the magnet. Add in the new power supply that has now been delivered, this is effectively a new magnet system which should operate well for the SBS program. Solidifying the coil geometry has also allowed for the final field clamp and other impacted designs/fabrication to go forward. Regarding the exit beam pipe magnetic field compensation scheme, while simulation tests indicate that the "integral field" requirements can be met with the two bucking magnet and pipe insulation scheme, there may also be impact on the beam size/shape, affecting the effective clearance of the exit pipe. Beam transport calculations may be used to investigate if this is an issue.

“The SBS magnetic field needs to be known for various experimental purposes: 1) particle tracking through the spectrometer to determine kinematics and signal; 2) spin tracking through the spectrometer in order to extract the physics observables (e.g., through spin manipulation); 3) the impact of any residual magnet fields on the target polarization. Hence, continued effort should be made to quantify the magnetic field characteristics. Full field excitation of the SBS magnet will likely not take place until it can be installed in Hall A at which time in situ field measurements (including the pole tip region adjacent to the slot) can be made to spot check simulations. Any significant disagreement may prompt a more complete mapping. In the meantime, existing BNL field maps along with low excitation test results can be used to substantiate the simulation values. Eventually with beam, a "sieve" slit generating known kinematical trajectories for elastic scattering can be used to additionally confirm all the field components (dispersive and non-dispersive). Zero field/straight track trajectories will be used to measure the detector alignment.

“Following recommendations of the previous SBS review, significant progress has been made on the scintillator implementation of the coordinate detector to be used in all of the SBS nucleon form factor experiments. A technical report was issued and an internal JLAB review took place in early 2014. In the final design, the CDet planes are readout via WLS fiber inserted into a central hole running the length of 5mm x 4 cm x 51cm bars of extruded scintillator and connected to 16 channel MAPMTs.

“While a mechanical prototype was constructed, helping to iron out several construction issues, it still seems that the assembly plan may be somewhat tedious and hence unreliable. It may pay to consider simpler "mini-block" schemes for achieving the desired projective geometry.

“One of the original concerns was whether the optics would deliver a sufficient number of photoelectrons. A test during the summer of 2014 gave ~ 10 pe/MeV although details of the geometry and other parameters were not given. Surely in terms of uniformity of light collection along the strip, a mirrored end on the WLC fiber should help and is likely important considering all the other efforts (electronically) to match the strip/channel response.

“At the anticipated rates, the DAQ system as presently envisioned requires use of a parallel (synchronized) FASTBUS readout in triplicate in order to achieve reasonable dead times. This is in addition to sparsification and event buffering. Because of its potential impact, it is of the highest priority for this scheme to be realistically tested in a "slice" of readout electronics.

“There has been great progress in the GEM chamber technical developments and startup of production style chambers. A possible remaining issue is the gas flow effect on the gain uniformity across the chamber. Hopefully the plan for accommodating a higher flow rate will be successful and easy to implement.

“For such a large installation of chambers of relatively new technology it is likely that standard (budgeting) rules of thumb may not apply. It is recommended that additional chambers be constructed so that at least a full plane (including electronics) is available for swap into the experimental setup.

“A new segmented hadron calorimeter (HCAL) is needed for the SBS program. The overall design settled upon is a modified version of that used (HCAL1) at the COMPASS experiment. For SBS, a significant improvement in the timing (resolution down to ~ 0.5 ns or better) is required for the experiments in order to reduce backgrounds. COMPASS modules brought to Carnegie underwent optimization studies compared with sophisticated GEANT4 simulations to investigate details of the timing response (e.g., effects of faster Wave length shifting (WLS) fiber along with faster PMT response, etc.).

“The working HCAL prototype "proto2" was completed in May 2014 and an initial timing resolution of about 340 ps was measured with a cosmic ray test stand, already better than the requirement. Detailed design of the HCAL was completed in July 2014 (a decision had been taken along the way to base the module production fabrication at Carnegie). Besides improvements in construction techniques/materials derived from building the prototype, a choice of laser-cut rather than injection molded light guides was made because of the superior attenuation length (this may also improve the timing slightly, closer to the ~ 265 ps calculated in the simulations).

“At present, many components are accumulating at Carnegie with module HCAL assembly scheduled to start in March 2015. Components include extruded scintillator (from FNAL), wavelength shifter assemblies (from St Gobain) and final design light guides (CMU). Pre-fabrication of many items (chopping scintillator and absorber plates into pieces has already begun and is well along in some cases. A "design review" is expected to be held in December. It is important that it also serve as a module "production review." The preview we heard of the status indicates many components are on hand/fabricated with further fabrication and assembly procedures under good control.

“The BigCal calorimeter is needed in particular for electron ID in the GEp(5) experiment. The calorimeter (loaned to BNL) has of course been used before in JLAB experiments and is well characterized (e.g., from GEp(3)) in terms of energy and spatial resolution performance. Its return and stacking rearrangement required for the SBS program (ECal consists of 2000 Pb/Glass bars) are not anticipated to have any issues (the collaboratin has access to 6000 PMTs to select from). However, GEp(5) running conditions are expected to cause significantly more radiation damage (crystal darkening) than heretofore experienced. Detector recovery ("curing") via UV is well known and there has been some experience with such procedures with BigCal as used in Hall C. The demands of GEp(5) may push this to an extreme in terms of damage and needed recovery timescale.

“The new idea presented at this review was that the radiation damage could be corrected by running the detector (individual lead glass modules) at elevated temperatures for continuous annealing. A bench top test indicated a damage reduction factor of nearly 60% could be obtained in ~ 8 hours at a temperature 225 deg C. Implementation of this proposed ECAL annealing scheme on the scale of the full detector assembly will no doubt take some further development (idea is to have a gradient along the modules so that the PMTs don't see the full temperature elevation).

“The collaboration should test the continuous thermal annealing concept with a several detector element test assembly operated and monitored in a beam/radiation environment before proceeding to the final detector design. Issues include viability of implementation including mechanical, temperature and readout stability.

“Among the first likely SBS experiments, GEn will require ~ x6 improvement over the previous use of the ^3He polarized target. Plans to meet that goal include a 60 uA beam current and a 50% increase in target length. In order to ensure good FOM performance various technical improvements are also needed, including better performing pumping cells and driven gas movement. In addition, metal end windows need to be used to withstand the high beam currents without degradation of the polarization of the stored gas. We heard of recent promising results in the needed technical developments, but because of the long lead time and high impact, integration of 3He technical milestones into the SBS monitoring process would likely be good to help keep the SBS program on track."

<u>The feasibility and completeness of the budget and schedule, including workforce availability:</u>

Reviewer:
"The overall budget across all 3 WBS major categories is in good shape with less than half of the funds remaining to be committed and 60% - 100% of contingency remaining. All on-project items have generous schedule float.

"Concerning the CDET system a realistic schedule for completion of CDET, including finishing the design, possible testing of prototypes, fabrication and testing should be developed and integrated into the WBS and PMP.

"Concerning the rear GEM tracker the decision to implement CDET with scintillator has reduced the number of GEM modules needed. This results in additional schedule float for the rear tracker so the completion date should be easily met. All major items for module construction have been purchased or committed. The only major budget item remaining is the readout electronics. The decision has been made to use the MPD readout produced at INFN. This readout is already being produced for the front tracker so the cost is well known.

"Workflow documents with required manpower and time have been produced for both the rear tracker and front tracker. Adequate manpower is identified for construction for both projects. The target production rate for the rear tracker of 2 modules per month was achieved last month. This rate easily allows the project to be completed on schedule."

Reviewer:
"The project has been divided in three main WBS: WBS1 concerns magnet and infrastructure, WBS2 deals with the detector systems needed for the neutron form factor measurements (CD detector, HCAL trigger, and other detector infrastructure), and WBS3 deals with the detector systems for the proton form factor measurements (GEM tracker). The division of WBS2 and WBS3 is somewhat arbitrary and the new CD detector implies significant overlap with not so clear distinctions respect to budget, schedule, and manpower.

"The budget and schedule for WBS1 appears on track with a completion date expected at the end of FY15 with about 41% of the budget remaining to be committed with 60% of the contingency left. The WBS2 acquisitions and procurements are expected to be done by the end of FY15. At present, 39% of the WBS2 budget remains to be committed and 90% of the contingency remains. The WBS3 completion date is July 31, 2017, and at present 34% of the budget remains to be committed and 100% of contingency is still available.

"Critical path items in each of the WBS were identified corresponding to high-risk items in each WBS but because of the overall float they do not appear to be critical to the schedule. Other critical instrumentation like electron and hadron calorimeters, polarized 3He and high power hydrogen targets, are not contained in the presented WBS's.

“The workforce availability for the individual WBS elements seems adequate to complete the project. An overall workforce plan was not presented formally.”

Reviewer:
“Much of the equipment for this program either exists or is provided by supplemental funding through operation budgets and appears adequate to the task. I repeat that the experiment is significantly easier if the Fastbus is replaced by the JLab flash ADC system.

“The budget is inadequate to have a dedicated target and the polarized 3He gaseous target is apparently to be shared between Hall A and D.”

Reviewer:
“In general the on-project budget and schedule as presented appear to be in good shape with reasonable expenditures and associated contingency remaining in the various WBS categories. Costs for "dependency" projects were not presented but appear to be largely ok with the projects on track.”

<u>The effectiveness of the management structure and the approach to ES&H:</u>

Reviewer:
"The management effectiveness has improved significantly. Recommendations from last year's review were acted on and closed. Comments were also implemented or responses given. PMP and RMP plans have been updated and an integration document produced."

Reviewer:
"JLab does the project management and a new Project Manager (PM) was appointed early in 2014. The new PM inspires confidence in the likely success of this project. He is clearly in touch with all aspects of the program, from the physics, through the infrastructure and detectors, and to the analysis of results.

"To keep track of the project the PM works closely with Hall A management and the collaboration through regular meetings. As recommended in the last review the Project Management Plan was updated together with the Research Management Plan and the project team responded to all recommendations from the previous review. At present, no contracts to universities remain to be awarded and all project activities adhere to the protocols in the JLab EH&S manual."

Reviewer:
"I believe that the new project manager and the obvious increased attention from lab management overall make this a well-run program with a high probability of success."

Reviewer:
"At the suggestion of the last review committee, integration of the dependency projects into the SBS planning structure was presented and summarized in a list with rough timelines and schedule float. While it appears that nothing has gone seriously out of whack there could perhaps be a big benefit from a relatively small additional effort of adding more timely and meaningful milestones to help in tracking progress. This might give additional structure to the (already successful) various meetings between project management, Hall A and the collaboration/coordinating committee."

Other issues relating to the SBS project:

Reviewer:
"The tracking of progress and development of integration plans has improved markedly since last year. The collaboration should continue to track status and progress in all aspects of the upgrade."

Reviewer:
"This is an exciting users-driven project that goes after the most basic nucleon structure information in an unexplored energy region. University groups, all with solid records in the proposed experimental technique and significant expertise in detector construction, are responsible for most of the components of the detector project apparatus. JLab plays a key role in fostering an environment in which experimental ideas as this can emerge."

Reviewer:
"The [panel] would like to express their thanks to the presenters and TJNAF management for a lively and hospitable review. We hope to see the SBS project continue to progress to timely completion. The SBS science program is compelling, feasible and likely to produce high impact physics results from the beam energy upgrade at TJNAF."