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Office of Science

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on the

Annual Progress Review

of the

Super BigBite Spectrometer (SBS)

November 7-8, 2016

EXCERPTS FROM PANEL MEMBER REPORTS

The Annual Progress Review of the Super BigBite Spectrometer (SBS) project was held at the Department of Energy complex in Germantown, Maryland on November 7-8, 2016. 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.

The significance and merit of the project's scientific goals:

Reviewer:

"We have been reviewing now for several years, progress in the development of the Super BigBite Spectrometer (SBS) setup which will provide a unique capability for experiments requiring high luminosity combined with large solid angle. We re-affirm that the main SBS program: measurements of the nucleon elastic form factors GE(n)/GM(n), GM(n) and GE(p)/GM(p) with the SBS out to large momentum transfers (($Q^{\wedge 2}$) of 10, 12, and 13.5 $(GeV/c)^{\wedge 2}$, respectively), continues to be of high scientific merit and hence remains as a high priority for the scientific community. In addition, there is strong interest in many of the proposed additional uses of the SBS setup (SIDIS and the novel TDIS presented more fully previously).

"The SBS nucleon form factor measurements aim at both high statistical and systematic accuracy and in combination will help reveal the constituent contributions and correlations that are key to understanding the QCD nucleon structure. This includes SU(2) based quark flavor separation for comparing u- and d-quark form factor contributions as well as measurements that reveal evidence for the influence of di-quarks. Large $Q^{\wedge 2}$ form factor measurements can also put constraints on light front wave functions (LFWF) which are related to the nucleon parton distribution amplitudes (PDA).

"The Dyson-Schwinger equations in a continuum QCD approach predict a zero crossing in the GE(p)/GM(p), whose position is sensitive to the underlying dynamics. Similarly a turnover and zero crossing of GE(n)/GM(n) is predicted, driven by correlations in the nucleon wave function. Details of the turnover in GE(n)/GM(n) can be tested with the SBS and some sensitivity to the zero crossing is expected for both ratios.

"A new frontier is the 3D imaging of quarks inside nucleons via transverse momentum (TMD) and generalized parton (GPD) distributions. The SBS has approved SIDIS transverse single spin asymmetry measurements that will address this physics. The fragmentation functions needed for their interpretation can also shed light on confinement and dynamical chiral symmetry breaking (DCSB).

"In short, there continues to be strong and considerable interest in the results to come from the SBS physics program. The theoretical community recently (April 2016) participated in a workshop in Trento where these and many other topics were discussed. Future such meetings (including even more practical items such as how to make state of the art radiative corrections, etc.) will likely continue to be beneficial for maximizing the impact of SBS data as it becomes available."

Reviewer:
"The conclusions previous reviews 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. It is encouraging to see that a workshop has been held including the theoretical community. It would be good to see this activity continue, perhaps with an annual workshop, to have a close and continuing connection with theorists."

Reviewer:
"The physics case for the SBS program is still compelling - measuring the structure functions for p and n at large Q^2 is necessary to understand the partonic structure of nucleons. Specifically, the role of diquarks and internal orbital motion are exciting possible outcomes from this program.

"The SBS Program is expected to start in Fall 2019, but JLab has already begun scheduling preliminary readiness reviews for SBS. The progress made by the scheduling and infrastructure groups on modeling setups is impressive."

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:

Reviewer:

"All SBS infrastructure items have essentially now been completed and are in storage at TJNAF. These items include the 48D48 magnet and its counterweight structure, the required field clamps and corrector magnets, various scattering chambers/snouts and the specialized beam pipe construction with its complex shielding elements, as well as many other pieces. Some final infrastructure items in WBS2 (detector support frames and electronics huts and shielding) are in the process of delivery and expected by December 15, 2016.

"Besides the attention paid to the technical requirements for all the individual items, a great deal of effort has been put into making sure the designs as implemented can easily accommodate all SBS experiments in all their kinematic settings.

"The decision in WBS2 a few years back to switch to making a dedicated scintillator based charged particle coordinate measuring detector (CDET) seems to have been a good one. The detector has two planes with a modular construction of groups of scintillator paddles read out with wavelength shifting (WLS) fiber. All told there are 2352 channels and the detector will be used in both GE(p) (in front of ECAL) and GE(n)/GM(n) (in front of HCAL) experiments. It is commendable that the CDET assembly was completed August 2016 and projects to be finished ahead of schedule with all key performance parameters satisfied.

"The success of the SBS GE(p) physics program relies on a large area multi-plane tracker using Gas Electron Multiplier (GEM) technology. Completion of the needed 40 GEM chambers (WBS3) is expected January 2017 with 8 spare modules to be completed by May 2017. This has been a sizable and technologically challenging effort. It is impressive that the component yield and number of assembled chambers passing QA has been high throughout the project. For readout, the full order of FEE for the chambers has been delivered (with a few more orders expected to serve as spares and/or relieve cabling issues); the status of other aspects of the full electronics readout were less clear.

"A setup of 5 chambers is now configured in Hall A for in-beam tests, a very important step to ascertain the GEM chamber performance under more realistic conditions and give a chance to develop track finding and calibration software. While each chamber is QA'ed after assembly, further tests with cosmic rays (or periodic repeat of source/performance benchmarks) may help convince one that the chambers are not degrading over time prior to their actual use with the SBS, predicted now to be be several years hence.

"The front tracking GEM chambers (a off project item supplied by INFN) are expected to be completed by May 2017. Progress and delivery within specifications look to be very promising, with ongoing cosmic ray testing taking place in Rome.

“There are other important "off-project" dependencies, comments on several of these in turn next:

“HCAL
“Following initiation of fabrication in March of 2015, progress on HCAL module production has advanced and has largely adhered to the anticipated schedule. At present, 75% of the 288 required modules have been completed, with 169 of those already delivered to TJNAF. Completion of the hadron calorimeter (HCAL) module assembly is expected by February 2017, with work on the crane-able assemblies to begin in spring 2017 and a fiber optics based pulser system to be installed in summer 2017. The fabrication of this subsystem dependency seems to be well in hand and anticipated to be ready for use when needed for the SBS. A caution to the above is the question if the HCAL iron, effectively “channels” stray magnetic fields, potentially causing a problem with PMT performance. A simulation/test of this possible problem should be performed.

“ECAL
“Following recommendations from the last review, a write up of the C16 “proof of principle” beam test of thermal annealing for the electromagnetic calorimeter (ECAL) lead glass was generated and construction of a C200 prototype for the thermal annealing studies was initiated. During last summer an e-mail review (with a subset of the SBS review panel members) took place centered around these write-ups along with a newly generated document outlining 3 options for dealing with the ECAL radiation damage: use of Pb glass with UV curing, with thermal annealing, or the use SPACAL from Brookhaven National Laboratory.

“Following that mini-review feedback, the thermal annealing solution was presented as the path forward at this review, with the thermal annealing solution with UV curing as a backup. In conjunction with these activities, work on a "C200" prototype to identify and implement scalable solutions for thermal annealing was initiated. A summary of that work and a preliminary CDR report were generated as pre-brief materials for this review.

“The super module (3x3 Pb glass block assemblies) ECAL concept appears to answer many questions regarding a scalable design for the ECAL thermal annealing. Comparison of C200 test setups with simulated results from the COMSOL program have helped considerably for understanding and improving details of the super module structure with optimal heating and cooling. This has been a very encouraging development and seems now to have convinced all (including committee members) of the approach.

“In the current test implementation, the desired temperature profile along the length of the lead glass is achieved and correctly simulated in COMSOL giving important confidence in the design process. Continued tweaking of design components is ongoing to optimize thermal gradients and mechanical performance; no show-stoppers are known or anticipated.

“A critical decision point for the annealing method was identified to be August of 2017.

While many of the concepts in terms of scalability and performance for the full ECAL detector show very good promise, it is important to continue to test and finalize issues as quickly as possible, as many aspects of the full ECAL construction (parts procurement) already begin in early 2017. Further, while general criteria for success of the fully stacked ECAL in thermal annealing mode are that it operates with appropriate temperature profiles and mechanical stability over week long type test running periods, specific detailed pass/fail criteria should be developed to ensure success.

"As a follow up to the C16 test, it is suggested that any investigations that would further solidify the conclusions from those results would of course strengthen the thermal annealing underpinning beyond the test of principle already carried out.

"^{3}He target
"As mentioned elsewhere (management), it is very important that the design review and subsequent freezing of the design took place close to milestone schedule. This has allowed JLAB to identify and contribute critical design and engineering help to push this project forward. Details of the associated technical achievements were presented, including finalizing the basic target design with metal endcaps, laser pumping scheme and various studies to measure the separate contributions to the intrinsic relaxation time of the target in order to ensure that relaxation caused by the beam (~30 hours) dominates. The ^{3}He target is a schedule driver for the GE(n) measurement and hence milestones associated with the remaining technical challenges will need to be closely watched and monitored.

"Trigger and DAQ
"For the GE(p) experiment, the ECAL discriminator outputs drive the Level 1 trigger; geometrical information available from ECAL and HCAL flash ADCs is added at level 2. Various schemes to subsequently reduce data volume (beyond zero suppression), particularly for the GEMS,
involve localization via crude tracking and timing information allowing coincident selection of x and y time slices. A timing diagram was requested and then presented, which helped all parties to better understand the flow of data and its manipulation vs. trigger and other timing decisions. Significant progress has been made, although there is clearly more to do (waveform fitting software, geometrical and x,y hit time selection). Given this, the committee suggested that the trigger/DAQ organization and responsibilities chart be updated and attention paid to allocation of a sufficient workforce.

"Gas Cerenkov and GRINCH
"These off project dependencies seem well in hand and are progressing nicely. No further comments."

Reviewer:
"Excellent progress has been made in the past year. It is very encouraging to see several parts of the project completed or near completion within budget. WBS 1 is complete and WBS 2 and 3 are expected to be completed by mid-2017.

“Off project dependencies have shown remarkable progress in the past year. The front tracker, HCAL and GRINCH are all expected to be completed in 2017. The EMCal, a major concern in last year’s review, presented a convincing, scalable design supported by measurements and modeling. The ^{3}He target design has advance greatly since last year. This is still the longest lead time item however so progress and milestones still need to be monitored carefully.

“As the construction phase is nearing completion the experimenters need to develop a plan for transitioning to operation and analysis. In the interim before running well thought out plans for storage and monitoring of the equipment are needed.

“The rear tracker group is commended for installing and operating an array of modules in the hall. They are encouraged to continue to use the array not only to gain experience in operation of all elements but also to develop the software needed for operation and analysis.”

Reviewer:
“Many components of the SBS system, including CDET, magnets, and infrastructure, are now complete and in storage at JLab. Others are nearly complete and expected in the next few months - Grinch, HCAL, the rear GEMs, and the front tracker GEMS. Electronics for the trigger and daq is on hand. All GEM electronics is now at UVa for testing. The remaining items, including the ECAL for GE(p) and the polarized 3He target for GE(n), have made great progress since our last review.

“The SBS group investigated 3 options for GE(p) ECAL : heat-annealing PbGl, UV annealing PbGl, and rad-hard SPACAL. The SPACAL option was rejected based on its assumed poorer resolution and the group's unfamiliarity with this detector. The UV option was selected as a backup, having intermediate resolution and known issues. The heat-annealing option was deemed best because it would produce a constantly-clear detector of excellent resolution, even though it has the highest implementation risk.

“The presentation of results on how to scale the heat-annealing option to the 1710 cell size of the full detector was impressive. It appears that the scaling problem has been solved using a combination of a heating tape on the front surface and a heating coil on the rear light guide with an insulating layer separating the cooled PMTs from the hot zone. The group is using COMSOL™ software to model their system, using heating tests of PbGl and light guides to tune the simulation parameters. A full test of heat-annealing a sample of PbGl under realistic radiation conditions was not performed, but approximations to this appear to be close enough to the expected situation to allow the project to proceed. I was originally very skeptical that this option could scale to the full calorimeter, but I am now optimistic that a scalable solution has been devised.

“The polarized 3He target appears to be in much better shape than for the last review. Cates has achieved a 78% polarization in the lab. His use of dual-direction pumping using 240W from two lasers is sufficient to saturate the polarization of the gas. He has shown that the combination of metal and glass works and does not depolarize the gas too quickly. The target is pumped continuously in use and the laser power needed is just to offset the intrinsic relaxation time of the target, estimated at 40 hours, and beam related relaxation time, approximately 30 hours, of the polarization. He is expecting to produce a 3 liter model for tests by mid-2017 and the full 6 liter target by Jan 2019.

"The trigger for the GE(p) experiment is the most demanding on the electronics. It is based on a level 1 trigger formed from hits above threshold in the ECAL. The rate for this trigger appears to be near 500kHz. A level 2 trigger uses both ECAL and HCAL with geometrical reauirements to select elastic scattering. Data from the HCAL is sent to 250 MHz Fast Ananlog-to-Digital Converters from which it is fed to an 8μs long pipeline and into a trigger processor to search for hits above threshold. Data from the HCAL is used in coincidence with the ECAL L1 trigger and the geometry of hits in both these detectors to form a level2 trigger which fires at up to 5 kHz, an upper limit set by the readout of the GEM electronics.

"The GEMs have front-end-electronics that have a 300 ns shaping time. These signals are sampled every 25 ns, with the analog amplitude stored in a 4 μs long pipeline. The raw data is first transferred to the multi-purpose-digitizer (MPD) where it is 0 suppressed. The remaining data represents about 60% occupancy, because of the 300ns shaping, which is then passed to the sub-system-processor (SSP). The level2 trigger must arrive at the SSP in less than 4μs to make sure the data for the triggered event is still in the pipe. Data from the GEM in the region suggested by the HCAL and ECAL hit locations, ie, the geometry of the event, is then selected in the SSP, where the appropriate wave forms are fit and their leading edges determined. Those hits whose leading edge times meet the time coincidence with the level2 trigger are passed on to the event builders. All zero suppressed data from ECAL and HCAL is sent to the event builders after a L2 trigger

"The software for waveform fitting for the GEMs and for comparing x,y hit times for ECAL and HCAL is not yet written - it is just an idea at this point. This is of course crucial to reducing the data volume and the trigger rates. I am glad that they produced a real timing diagram although I have not yet received a copy. It should be drawn to scale for clarity, since there are many different delays and pipes involved. I understand that the round-robin multi-Fastbus-crate readout has been tested.

"I thank the group for providing the GE(p) trigger description. Adding the timing diagram and data flow diagram will make this a much clearer document. I am a bit unclear on how much of the trigger/daq electronics exists, but I have the impression that most of it is available already, with only a few modules being sought to simplify the operation."

The feasibility and completeness of the budget and schedule, including workforce availability:

Reviewer:
"The three SBS work breakdown categories (WBS) are all either completed or near completion at the time of this review. WBS1 was completed as expected in January 2016, while WBS2 with all milestones already met is expected to be completed in January 2017. All GEM front end electronics are delivered to the University of Virginia and are undergoing additional testing; assembly of the last 10 GEM modules for WBS3 is expected this month, projecting an early completion date in February 2017 for WBS3. With $26,000 contingency remaining for WBS3 (although there are some FY17 workforce and materials expenditures) the sum over all WBS presently sits at -$4k so it is likely that the entire WBS part of the project will be completed close to budget and schedule. This is of course very commendable, particularly as this sizable (yet relatively small) project was in competition in recent years with other much larger scale upgrades needed for 12 GeV JLAB.

"Because of the initial re-structuring of the SBS project, several important components have and are being carried out at outside institutions and are treated as off project dependencies. These include major items such as the ECAL, HCAL, GRINCH, front tracker GEMS and the polarized ^{3}He target. There has been good progress on all fronts since the last review, while ECAL and the ^{3}He continue to drive the schedule due to short term and long tern technical design and implementation issues, respectively. The ECAL is projected to be ready for installation by May of 2018 while the ^{3}He target is projected to be ready for installation January of 2019.

"Details of the workforce and budget for the dependencies were not presented at the review, although the support appears to be adequate. For ECAL, the NSF supplement to the HNCP-UP grant at North Carolina Central University effectively supports the additional hardware and workforce effort of the heat annealing option (although the funding for the UV curing fallback option --- likely not needed -- would seem to revert to JLAB). In the case of the ^{3}He target, JLAB has supplied additional design and engineering support to this project in conjunction with the conceptual design review (3/16) and subsequent conceptual design freezing (10/16), which will now switch to actual final implementation/design efforts. The latter is very welcome news as pushing this project to final design with available resources was seen as a significant roadblock."

Reviewer:
"The schedule and budget for on-project activities appears to be in good shape."

Reviewer:
"The work force table (his slide 10 - slide numbers would help here) shows only fractions of FTEs from each institution. It is not clear who is in charge of the whole operation: the person listed in the official org chart is not even listed here. This needs clarification, although I have great confidence in the group. I am confident that the required software will be developed soon and that this trigger/daq concept will prove more than adequate to

the task at hand."

The effectiveness of the management structure and the approach to ES&H:

Reviewer:
"The PM management and meeting structure, including weekly collaboration meetings and weekly Hall A management meetings, coupled with various separate weekly subsystem meetings, appears to have worked well. Over a month long time scale these meetings provide input to Rolf Ent and monthly reports to DOE, with feedback to review progress and raise any important issues. In addition, the SBS collaboration meets annually for several days.

"In general it is good to see that JLAB and SBS project management have stepped up to monitor schedule and resource issues regarding the SBS dependencies and to intercede where appropriate. This has caused the SBS project and its anticipated physics output to remain on track.

"The decision by TJNAF to conduct a readiness review for the GM(n) experiment is an encouraging development as it puts SBS physics running on the calendar (although it is clear this is still likely ~ 3 years off). A challenge for the project is to hold all this together: delicate components such as the GEMs now already fabricated, workforce still committed to finishing the project dependencies and people who are anxious to get at the physics once beam on the apparatus starts taking data.

"All activities at JLAB regarding SBS are carried out under the relevant EH&S protocols. Equipment and detectors delivered to JLAB also receive appropriate scrutiny. As noted above, the readiness review begun now for what is likely to be the first SBS experimental configuration is now in queue to be scheduled. Overall all these steps appear to have been effective so far with a promising future outcome expected."

Reviewer:
"The project manager is commended for excellent progress in the last year. He has coordinated on and off project activities over the year to successfully move the project forward. It is also encouraging to see that Jefferson Lab now is willing to stage the readiness reviews."

Other issues relating to the SBS project:

Reviewer:
"… the experimenters should work out a transition plan to assure a smooth startup of operations and timely data analysis and extraction of physics."

Reviewer:
"As noted above the off-project dependencies, HCAL and the ^{3}He target are now driving the schedule and introducing delay. I reiterate that the experimenters and laboratory should work together to develop a plan to minimize the delay."