Draft Closeout Report for the Super Bigbite Spectrometer (SBS) Program

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Introduction

The Super Bigbite Spectrometer (SBS) Program produced key components of the research equipment required to conduct a series of elastic nucleon electromagnetic form factor experiments. The experiments will use the electron beam from the upgraded 12 GeV CEBAF accelerator. The three experiments are:

- A measurement of the ratio of neutron magnetic to magnetic form factors, GMn/GMp, to Q^2 = 13.5 GeV^2 by determining the cross-section ratio for the two reactions d(e,e'n) and d(e,e'p) (E12-07-109).
- A measurement of the ratio of neutron electric to magnetic form factors, GEn/GMn, to Q^2 = 10 GeV^2 using the double polarization beam-target technique (E12-09-016).
- A measurement of the ratio of proton electric to magnetic form factors, GEp/GMp, to Q^2 = 12 GeV^2 using the double polarization beam-recoil-polarimeter technique (E12-07-109).

These experiments along with precise data from the recently completed proton magnetic form factor, GMp, experiment (E12-07-108) will determine all four elastic electromagnetic nucleon form factors, as well as making possible a flavor separation. Inherent in the SBS equipment is the flexibility to rearrange the equipment to suit different experiments. Two additional experiments have been approved by Jefferson Lab Program Advisory Committee for beam time. These experiments are:

- A measurement of semi-exclusive deeply inclusive scattering on a polarized neutron to study transversity (E12-09-18).
- A measurement of tagged deep inelastic scattering (E12-15-006) to study the mesonic component of the nucleon structure.

The SBS Program consisted of three separate, but interrelated Projects.

- The first Project, **SBS Basic (WBS 1)**, involved the acquisition of an existing magnet and the associated work of preparing it for use during the SBS research program. The effort included modifications to the magnet (including machining a slot in the yoke for beam passage), magnet power supply, front field clamp, beamline corrector magnets, magnet stand, magnet counterweight, floor plates and the design and development of the infrastructure needed to run the magnet.
- The second Project, **Neutron Form Factor (WBS 2)**, involved the construction of the PMT-based Coordinate Detector (CDet), beamline support, beamline shielding, rear clamp for magnet, electronics hut, GEM chamber frames and stand and the trigger electronics for the Hadron Calorimeter (HCal) to meet the requirements of the approved neutron form factor measurements.
- The third and final Project, **Proton Form Factor (WBS 3)**, involved the construction of forty GEM detector modules with associated front-end and DAQ modules to meet the requirements of the approved proton form factor measurement.

For each project, a breakdown table of the cost per year and the total cost are given in the "Cost Summary" section. Each project was completed by its completion date and all milestones for each project were completed. A table of milestones for each project is given in the "Schedule Summary" section. The Key Performance Parameters for each project were meet and details are provided in the "Key Performance Parameters" section.

Cost Summary

WBS1 Cost Table

	Budget	Expenditures	Labor	Expenses	Overhead
FY13	$838K	$411K	$57K	$258K	$96K
FY14	$643K	$517K	$91K	$286K	$140K
FY15	$212K	$663K	$18K	$474K	$171K
FY16		$147K	$30K	$68	$49
Total	$1694K	$1738K			

WBS2 Cost Table

	Budget	Expenditures	Labor	Expenses	Overhead
FY14 + items moved forward from FY15	$843K	$674K	$15K	$552K	$107K
FY15	$441K	$235K	$26K	$130K	$79K
FY16	$77K	$370K	$7K	$240K	$123K
FY17	$12K	$61K		$42K	$19K
Total	$1372K	$1340K			

WBS3 Cost Table

	Budget	Expenditures	Labor	Expenses	Overhead
FY14 + items moved forward from FY15	$1134K	$975K	$39K	$870K	$66K
FY15 + items moved forward from FY16	$553K	$455K	$16K	$409K	$30K
FY16	$62K	$234K	$46K	$143K	$45K
FY17	$32K	$91K	$24K	$38K	$29K
Total	$1781K	$1755			

Schedule Summary

WBS1 Schedule and Milestone Table

	Milestone	Scheduled Date	Completion Date
1 (1.1-01M)	Project start	10/1/2012	**10/1/2012**
2 (2-01M)	Magnet delivered to JLab	4/30/2013	**8/21/2013**
3	Power supply received	1/4/2014	**10/17/2014**
3	Magnet yoke modifications Completed	4/1/2014	**5/22/2014**
2 (1.2-10M)	Platform parts received	6/27/2014	**3/24/2015**
3	Assemble magnet in Testlab	7/1/2014	**9/4/2014**
3	Commissioning test of magnet in Testlab completed	10/1/2014	**10/29/2014**

3	Beampipe solenoid correctors received	1/5/2015	**12/11/2015**
3	Detector supports completed	4/1/2015	**3/24/2015**
2 (1.2-30M)	Beam-line parts received	9/24/2015	**11/30/2015**
1 (1.1-10M)	Project completion	1/29/2016	**1/22/2016**

WBS2 Schedule and Milestone Table

Level	Milestone	Scheduled Date	Completion Date
1	Project start	10/1/2013	**10/1/2013**
3	Finish testing of module prototype module	8/30/2014	**8/30/2014**
3	Scintillator ordered	9/30/2014	**9/15/2014**
2	CDET module design completed	11/30/2014	**11/30/2014**
3	Wavelength Shifting Fibers ordered	1/15/2015	**1/20/2015**
3	Scintillator shipped for machining	4/30/2015	**4/10/2015**
2	JLab receives exit field clamp	6/2/2015	**11/18/2015**
3	Begin preparation of WLS fibers	6/15/2015	**7/6/2015**
3	Begin construction of CDET modules	9/1/2015	**9/24/2015**
3	Assembled one CDET module	10/1/2015	**11/15/2015**
2	Electronics hut parts received	10/2/2015	**3/30/2016**
2	Trigger completed	10/4/2015	**3/15/2016**
3	Assembled one CDET plane	12/1/2015	**7/15/2016**
2	Coordinate Detector assembled	6/30/2016	**8/31/2016**
1	Project completion	1/29/2017	**1/23/2017**

WBS3 Schedule and Milestone Table

Level (ID#)	Milestone	Scheduled Date	Completion Date
1 (3.1-01M)	Project start	10/1/2012	**10/1/2012**
3	Order GEM Parts	10/1/2013	**10/18/2013**
3	UVa receives GEM parts	2/3/2014	**4/23/2014**
2 (3.2-01M)	First module assembled and tested	3/3/2014	**5/15/2014**
2 (3.2-10M)	UVa 5 GEM modules assembled and tested	6/2/2014	**12/23/2014**
2 (3.2-20M)	UVa 6-16 GEM modules assembled and tested	9/30/2014	**7/28/2015**
2 (3.2-30M)	UVa 17-29 GEM modules assembled and tested	3/2/2015	**3/30/2016**
2 (3.2-40M)	UVa 30-40 GEM modules assembled and tested	7/15/2015	**2/1/2017**
2 (3.2-50M)	1st order of Front End Electronics	10/1/2014	**3/5/2015**
2 (3.2-60M)	2nd order of Front End Electronics	10/1/2015	**3/5/2015**
1 (3.1-10M)	Project completion	2/1/2017	**2/1/2017**

Key Performance Parameters (KPP)

WBS 1

KPP in Program Management Plan.

The modified 48D48 Magnet (yoke cut, new coils, beam-line field compensating coil, and entrance field clamp) must be on the platform and be energized.

Demonstration of KPP:

The modified 48D48 Magnet has been placed on its platform. Separately it was energized to 200A (which is about 10% of the maximum current) with the magnet field measured (Fig. 1a shows the magnet with coils and Fig 1b is a copy of the table of the field measurements.). The 200A test is sufficient to demonstrate that the modified 48D48 Magnet performance is acceptable for SBS experiments.

Figure 1a SBS Magnet when being tested at 200A

	Current (A)	Probe 1 (Tesla)	Probe 2 (Tesla)	Probe 3 (Tesla)
62.5%	200	84.31mT / 843G	79.94mT / 799G	82.15mT / 821G
46.875%	150	63.23mT / 632G	59.97mT / 599G	61.62mT / 616G
31.25%	100	42.25mT / 422G	40.02mT / 400G	41.09mT / 410G

Figure 1b Table of field measurements at different locations in the SBS magnet opening at currents of 100, 150 and 200 A.

WBS 2

KPPs in Program Management Plan.

1. The main performance parameters of the CDET are:
   - I. Coordinate resolution < 3.0 mm
   - II. Time resolution < 2.0 ns
   - III. Rate capability of 500 kHz per bar with deadtime < 10%
   - IV. Efficiency > 95% per plane
2. The pole shims must be in hand with dimensions verified.
3. Exit field clamp pieces must be in hand with dimensions verified.

4. The final trigger configuration will be a ready to use integrated hardware and software package. It will be considered complete when it has been successfully tested with pulsers and cosmic rays.

Demonstration of the KPPs:

1. The main performance parameters of the CDET:
    - I. A detector thickness of 5 mm was achieved which projects to a coordinate resolution of 1.5 mm.
    - II. Timing resolution of 1.25 ns was achieved (see Fig. 2a).
    - III. Deadtime of 2.5% is given, since timing pulses for the amp/discriminator cards are less than 50ns wide. The PMTs are capable of handling rates up to 1MHz.
    - IV. In cosmic tests, efficiency > 99% was achieved (see Fig. 2b).

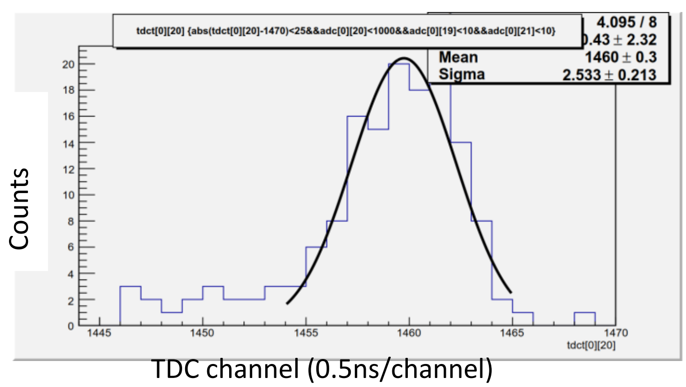

Figure 2a) Timing resolution of the CDet. The sigma is 1.25ns.

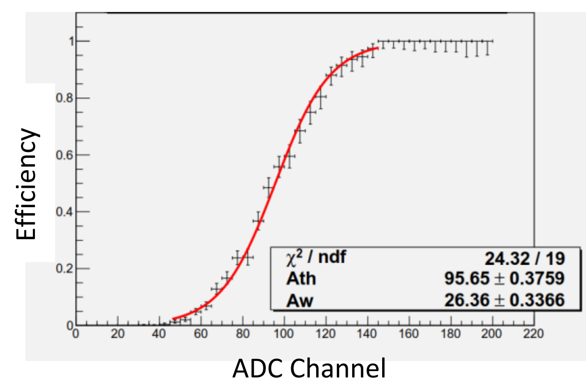

Figure 2b) Efficiency of TDC timing cut versus ADC threshold. The efficiency reaches > 99% at ADC channel=140. The minimum ionizing particles deposit a mean energy of ADC channel=300.

2. Verification of pole shim dimensions was done by JLab Hall A engineers as standard part of Quality Assurance.
3. Verification of exit field clamp dimensions was done by JLab Hall A engineers as standard part of Quality Assurance.
4. The electronics for the trigger have been purchased and undergone acceptance tests.

WBS 3

KPPs in Program Management Plan.

1. All GEM modules must be constructed such that:
    1. all foils have an average dark current of less than 5 nA per 20 x 5 cm2 section at 4100 V on the full module

2. they have a gain of at least 5000 at the operational voltage of 4000 V in a gas mixture of 70% Argon and 30% CO_2
3. they have a track efficiency of at least 95%, averaged over the module, in cosmic tests
4. All GEM modules with their attendant electronics must be assembled in their frames and tested with cosmics. GEM electronics and DAQ must be attached to the above GEMs and functional in an integrated data-acquisition system.
5. The APV25 front-end read-out boards must be tested for low noise level performance and the equivalent noise charge must be less than 3500 e (RMS), averaged over the module.

Demonstration of the KPPs:

All GEM modules are constructed:

(*Note: The voltage of 4250V is used instead of the high voltage in the original KPP, because of the decision to used GEM foils produced by single mask compared to double mask which was an older technique. The decision was approved by the Associate Director of Physics Rolf Ent.)*

I. As shown in Fig. 3a, all foils have average dark current of less than 5 nA per 20 x 5 cm^2 section at 4250 V on the full module.
II. As shown in Fig. 3b, modules have a gain of at least 5000 at the operational voltage of 4250 V in a gas mixture of 70% Argon and 30% CO_2.
III. As shown in Fig. 3c, modules have a track efficiency of at least 95%, averaged over the module, in cosmic tests.

6. As part of the track efficiency study with cosmics, each GEM module is assembled with its attendant electronics.
7. The noise level for each APV25 front-end read-out board is less than 3500 e- (RMS), averaged over the module. As shown in Fig. 3d, the average noise level is 2280 e-.

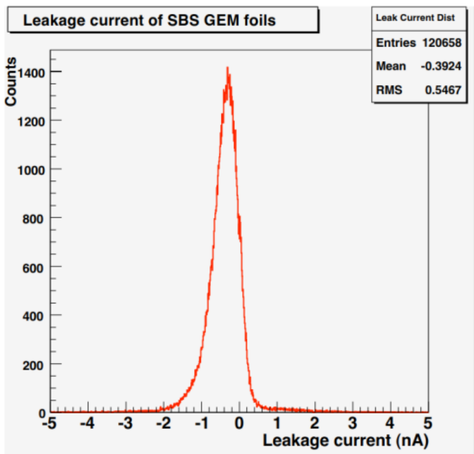

Figure 3a) The leakage current for all sectors of one module at 4250V.

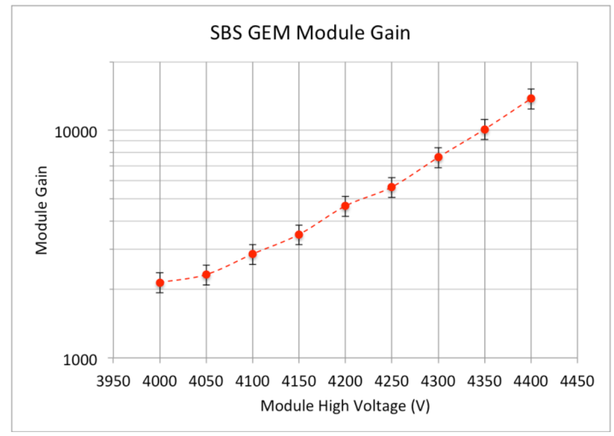

Figure 3b) Module gain versus high voltage. Reach gain of 5000 at 4250V.

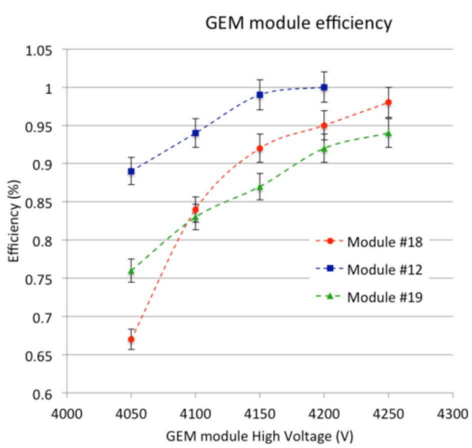

Figure 3c) Tracking Efficiency versus GEM high voltage for cosmic ray tests for three modules. The modules reach >95% at 4250V.

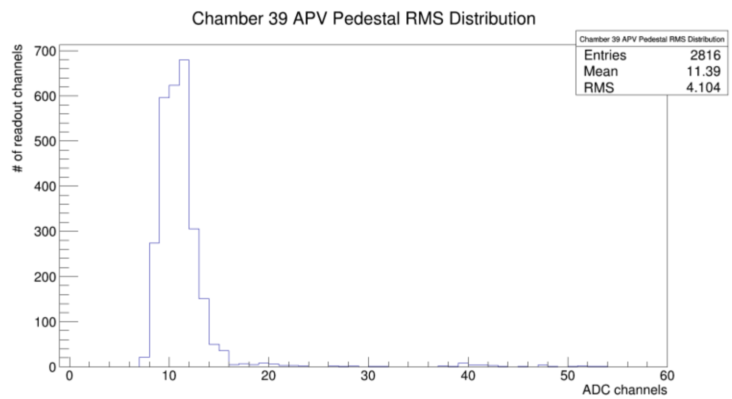

Figure 3d) The pedestal RMS for all readout strips in one module. An ADC channel is 200 e-, so the mean of the pedestal RMS is 2280 e-.