JLab experiment E12-09-019

Precision Measurement of the Neutron Magnetic Form Factor

and JLab experiment E12-17-004 GEn-Recoil

Preparation and GMn Run Plan

edited by B. Quinn, B. Sawatsky, and B. Wojtsekhowski,

The GMn experiment aims to measure the magnetic form factor of the neutron at very large momentum transfer up to 13.5 $(\mathrm{GeV/c})^2$ with high precision of 2-3%. This writeup is a draft document which will be updated/corrected. It provides a list of considerations for the experiment preparation and data taking. The following items will be outlined in the final document:

- Installation manpower
- The beam line
- The target system
- The LHRS detector package
- HV controls
- AC power for the BigBite and SBS electronics
- Plans for the moves to Hall A
- Plans for the moves during beam time
- DAQ electronics and software
- Data analysis software
- DC power for the all magnets
- Signal and HV cable lines
- Gas supply and gas lines
- The HCal detector

- GEM chambers of BigBite
- The alarm control display
- BigBite instrumentation
- Safety documentation
- The experiment web page
- Experiment shifts and RCs
- Coordination with GEn-RP

1 Manpower

The contact persons for the subsystems of the project are:

- Hall A beam line - TBD
- The target - D. Meekins
- The Moller polarimeter - S. Malace
- The Left HRS - R. Michaels
- The Left HRS detector - J. Segal
- The HV controls for SBS detectors - R. Michaels
- The SBS equipment - J. Butler
- The DAQ electronics and software - A. Camsonne
- The data analysis software - A. Puckett
- DC power for the spectrometer magnets - J.Segal
- Gas supply for GEM chambers - J.Segal
- HCAL detector - B. Quinn
- BigBite DAQ and analysis - M. Jones
- BigBIte Shower - A. Tadepalli
- BigBite hodoscope - R. Montgomery

- BigBite Gas Cherenkov - T. Averett
- BigBite GEM chambers - N. Liyanage
- GEn-RP detectors - B. Sawadzky

There are several main groups contributing in this project:

- Hall A/C technical and engineering groups
- Hall A/C spectrometer support group
- Hall A/C physics staff
- SBS collaboration and Hall A users
- GMn spokespeople

It will be best to have all equipment installed well in advance before beam time to allow a thorough test of the components as outlined in the next sections. It is assumed that all components (spectrometers, beam line, DAQ, and detectors) will be tested before the move to Hall A. The PREX beam time will end before May 6, 2020 and the GMn beam time will start on Feb 1, 2021, so there are just eight-nine calendar months after the radiation cools down for the PREX target. According to the initial plans, equipment installation requires about 195 work-days, which is by a large factor more than the number of work days in the projected installation period.

The detectors, data collection, and on-line analysis software of the experiments require several expert groups for parallel efforts in the preparation stage, as well as during commissioning and data taking. Assuming (from the SBS collaboration) six graduate Ph.D. students and four qualified postdocs, such a plan for preparation could be realized.

2 Preparation

2.1 The beam line components

The contact person is TBD. The following beam line items will be used in this experiment:

1. Beam charge monitors (the Unser monitor and BCMs)
2. Cavity-based beam position monitors and HARPs
3. Beam steering magnets
4. Beam rastering magnets

5. SBS dipole
6. SBS double-coil correctors
7. Møller beam polarimeter (for the GEn-RP part)

The target – The contact person is Dave Meekins. A link to the recent talk is here: `https://www.jlab.org/indico/event/336/contribution/12/material/slides/0.pdf`. The target will be in the standard Hall A scattering chamber and will have the following items:

1. Two cells for LH2 (1” diameter, 15 cm long) with a 6% Cu radiator on one of them
2. An LD2 cell (2” diameter, 15 cm long)
3. A spare cell (2” diameter, 15 cm long)
4. Al dummy cell with 10x windows, 15 cm long (The thickness of Al windows 1.75 mm)
5. Al dummy with a 6% Cu radiator (at the same z as the radiator for LD2, item 1)
6. A carbon hole target with a diameter of 5 mm
7. A carbon single foil at the central location
8. Nine carbon foils (0.125 mm) for optics (in 4 cm intervals along the beam)
9. BeO target
10. A beam path through open space

Møller polarimeter – The contact person is Simona Malace. The Møller polarimeter is only required for the GEn-RP component of the run and will only be used as part of Section 3.6. A nominal 5% precision on the measured beam polarization is assumed. We also assume that the full Møller measurement can be completed in one 8-hour shift for the necessary precision.

The GEn-RP Collaboration has assumed a beam polarization of 80% in its PAC proposal and the production runtimes outlined in Section 3.6.

The Left HRS – The contact person is Bob Michaels.

It will be used with the standard detection package which includes:

1. VDCs with FASTBUS 1877S TDC
2. S2m and S0 with fADC in VME (34 channels)
3. Gas Cherenkov with fADC in VME (11 channels)

4. Shower (pion rejector) with fADC in VME (64 channels)
5. BPM, BCP with fADC readout

The LHRS will be located at 90 degrees during most of experiment and for the last part should be moved to 70 deg (61.1, 64.4, 67.5, 70.7) and finally to 40 (39.0, 40.2). The DAQ of the LHRS should be ready for a single arm mode run for a check of the detector and optics/pointing and for a run with a readout of HCAL (HRS provides a trigger for a negative pion).

Re-installation of the detectors in LHRS – The contact person is Jack Segal.

The collaboration will provide the manpower for reconnection of 500 cables after the detectors are installed.

The HV controls – The contact person is Bob Michaels.

The experiment will use LeCroy and CAEN HV power supply:

1. HCAL - two crates
2. BigBite Shower - LeCroy, two crates, 27 modules, negative 1461N
3. BigBite GEMs Number, type of crates?
4. BigBite Timing Hodoscope CEAN HV crate,
5. BigBite gas Cherenkov - GRINCH LeCroy, four modules, positive 1461P

AC power for SBS electronics – The contact person is Jessie Butler.

There will be several locations which require AC power:

1. The main bunker with BigBite, HCAL relay racks, total 75 kW
2. The HCAL mezzanine, 10 kW
3. The HCAL DAQ in main bunker, 15 kW
4. The SBS GEM bunker, 15 kW
5. The BigBite front-end, 10 kW
6. The BigBite DAQ (weldment) in the main bunker, 30 kW
7. The BigBite GEM bunker, 10 kW

Plan for the equipment moves prior to the beam time – The contact person is Jessie Butler. There are a number of big items to move. A time line and space allocation in Hall A are needed. A link to the recent talk is here:
`https://www.jlab.org/indico/event/336/contribution/11/material/slides/0.pdf`.

1. The SBS iron slabs
2. The SBS coils
3. The SBS frames
4. The HCAL four parts
5. The HCAL movable frame parts with a mezzanine
6. The BigBite detector package
7. The BigBite electronic weldment
8. The relay racks of HCAL
9. Movable carts for the cable lines
10. The beam line magnetic shielding for configuration 3 (per the A.Gavalya's table).

GEn-RP equipment moves prior to the beam time – The contact person is Jessie Butler. GEn-RP will require the following GEn-specific components moved and staged in the Hall. The SBS GEMs and Recoil Proton detector assemblies will need to be installed on the SBS carriage with sufficient time to run cosmic checkout prior to beam operations. They will remain installed and cabled until GEn run is completed.

All items on the list below will need to be test fit, and detectors will be cabled and checked with cosmic prior to beam operations.

1. SBS rear field clamp (needs to be removed after GEn-RP run).
2. Recoil Proton detector assemblies (2x)
   Each assembly includes 1 hodoscope array, and 2 UVa GEM planes.
   These assemblies can move to the Hall as a unit.
3. "Inline" SBS Frame (that supports the inline GEMs and analyzer plate)
4. GEMs (2x INFN + 6x UVa GEMs)
5. Analyzer plate (must be inserted after commissioning of the beam/BB/HCAL and removed after GEn-RP run)
6. Shield "wall" between SBS and beamline

7. Shielding (Pb bricks) for the SBS dipole gap

8. Active analyzer array (Collaboration will deliver this to the Hall).

Talks by Robin Wines, Brad Sawatzky at this link have additional details:
`https://hallaweb.jlab.org/wiki/index.php/E12-17-004-ERR-29May2019`
Section 3.6 outlines the GEn-specific installation and deinstallation plans during beam.

Plan for the equipment moves during the beam time – The contact person is Jessie Butler. There are a number of big items to move. A time line and space allocation in Hall A are needed.

1. The BigBite angle change
2. The SBS angle change, including beam line re-alignment
3. The HCAL move
4. The BigBite removal from the left side of Hall A
5. The beam line magnetic shielding for configuration 4.

The DAQ electronics and software The contact person is A. Camsonne.

DAQ needs several powerful computers, very fast internet links, and a large number of CPUs in VME and FASTBUS. Specifically:

1. Fast DAQ computers:
2. CPU:
3. Internet system:

The DAQ components will be located in three shielded bunkers:

1. The main DAQ bunker is located on the left side of Hall A in the large angle area. This bunker will be used for most of the DAQ electronics and all HV supplies.
2. The small bunker near BigBite (on the large angle side) will be used for the VME based GEM readout.
3. The midsize bunker on the large angle side of SBS will be used during the GEn-RP run for the VME based GEM readout of a large tracker system.

The DAQ software needs to be developed and ready for readout for the following detectors:

1. The BigBite - Shower (FASTBUS), Hodoscope (VME), GEM (VME), GRINCH

2. The SBS HCAL

3. GEn-RP GEM system

4. GEn-RP scintillator systems (recoil proton hodoscopes, active analyzer array)

The data analysis software – The contact person is Andrew Puckett. The team also includes the contact persons: S. Barcus (for HCAL online displays and calibration) and E. Fuchey (for BigBite online displays and calibration). The analysis of BigBite momentum will use the tracker and energy/PID using the shower and HCAL. The software should also allow us to do the following:

1. On-line displays for coincidence data
2. Track-finding in BigBite.
3. Track momentum determination.
4. Optics of BigBite calibration.
5. Projecting q-vector to HCal (for neutron and proton).
6. BigBite Shower calibration, and HV settings optimization.
7. HCal cluster-finding with fADC and timing information.

The analysis of the proton energy and coordinates in HCAL includes the following:

1. HCAL cluster selection.
2. Amplitudes - energy coefficients using elastic protons.
3. HV settings optimization.

GEn-RP additions to the GMn software – Development of GEn specific detector and physics modules for online monitoring and physics extraction (gain setting, timing checks, PID, yields, and asymmetries) will be overseen by W. Tireman and supported by B. Sawatzky, M. Kohl, and A. Puckett.

The needed GEn-RP additions to the GMn software are modest. They include online displays for the PMT-based Recoil Proton hodoscopes and Active analyzers, and GEM tracking support for the SBS GEMs. The SBS GEM software will be 'clones' of the software modules used for the BigBite GEMs with appropriately updated geometry configurations.

DC power for the spectrometer magnets – The contact person is Jack Segal.

The SBS magnet considerations are:

1. A 2.2 kA power supply with a remotely controllable polarity switch.
2. Some of the flat coils will not be connected for the GMn run.
3. Four power supply units for two dipole correctors with remote polarity flip.

The BigBite magnet considerations are:

1. A 1 kA power supply.
2. Central ray angle survey and calibration of all positions in advance
3. Magnet and detector angles measurement by collaboration (in addition).
4. Fast disconnection of all detectors prior to HCAL efficiency calibration.
5. Multiple changes of the spectrometer angle and distance from the target.

Low power cable lines – The contact person is Jack Segal. The team includes A. Camsonne, K. Gvavno, E. Fuchey, S. Barcus.

There will be multiple lines for HV and signals cables between front-end and the DAQ bunker.

1. Cable trays and movable carts
2. 13 multi wire HV cables (75-meters 0.5" diameter) and 4 RG59 HV lines to HCAL.
3. 600 100-meter long RG58 signal lines between HCAL and DAQ.
4. A fast and short cable line for the trigger signal from HCAL.
5. 243 RG59 HV lines to the BigBite shower.
6. 4 multi (48 each) wire HV cables for BigBite timing hodoscope.
7. 4 multi (24 each) wire HV cables for BigBite Cherenkov counter.
8. 16 RG59 HV lines for GEM chambers.
9. 46 RG59 HV lines for the Active analyzer and RP detectors.

There will be multiple ethernet lines from the main bunker to BigBite and HCAL

1. 23 optical fibers for GEM MPDs to the front-end bunkers

Gas supply for GEM chambers – The contact person is Jack Segal. The system of gas mixing and distribution is under design/construction by DSG. The team includes Marc McMullen, E. Cisbani, and K. Gvavno. There will also be a large number of long 0.25" diameter gas lines for the GEM chambers:

1. To the BigBite a total of 16 pipes
2. To the SBS a total of 46 pipes

HCAL detector – The contact person is Brian Quinn. The team includes S. Barcus and J.C. Cornejo. The HCAL considerations are:

1. The 288-channel detector includes four segments stacked one above another.
2. For the cosmic trigger, two scintillator counters will be placed above the HCAL.
3. Clean air flow will be provided to each HV base to push out the He contamination.
4. The detector mounted on the platform which can be moved within the steel floor area.
5. The front-end electronics located in three relay racks on the mezzanine behind HCAL.
6. The LED pulser system will be used for a fast check of the detector operation.
7. The DAQ electronics and HV supply are located in the DAQ bunker.
8. The HV and signal lines will be in movable cable tray carts.

Shower detector of BigBite – The contact person is A. Tadepalli.

The shower considerations are:

1. The 244 channel lead-glass calorimeter
2. Shower electronics in the front-end relay racks
3. The HV crates in DAQ weldment
4. Two sets of long cables for the signals and HV.
5. The two-layer detector provides a trigger signal to DAQ and off-line PID.
6. The shower center location serves as a key element of the track search.
7. Calibration of the blocks will start with cosmic rays and will be finalized with elastic electron scattering from a proton with the recoil proton detected in HCAL.

Timing hodoscope detector of BigBite – The contact person is R. Montgomery.

The hodoscope considerations are:

1. The highly segmented hodoscope provides a precision timing for the TOF measurement
2. The 2x2x60 cm paddles are viewed by two PMTs
3. The front-end NINO cards with low threshold of 2 mV
4. The level translators are between front-end and DAQ
5. The VME based TDC with 50?? ps time resolution
6. The CAEN HV crate CAEN SY1527, modules A1932A

GRINCH detector of BigBite – The contact person is T. Averett. The team member is Bradley Yale.

The gas Cherenkov counter considerations are:

1. The 510 PMT array
2. The HV distribution and cabling to LeCroy supply located in BigBite DAQ weldment
3. The front-end NINO cards with LV power
4. The level translators are between front-end and DAQ
5. The VME based electronics for the signal time measurement
6. The VME based ADC for PMT gain measurement.

The GEM chambers of BigBite – The contact person is N. Liyanage.

The team includes E. Cisbani and P. Souder for the INFN chambers, and K. Gnanvo and T. Averett for the UVa chambers.

The INFN GEM considerations are:

1. The three planes of three modules each.
2. The front end electronics on chambers.

The UVa GEM considerations are:

1. The U/V strip orientation in a single module of 40 cm by 150 cm
2. A large UVa chamber of four modules (each 60 cm by 50 cm)

3. The gas distribution for all GEM chambers of BigBite

4. The VME readout for all GEM chambers

The configuration of the tracker above is plan A, which could be revised by 2020 if construction of the U/V chamber has problems or delays. In such a case, plan B will be implemented with two 50 cm x 60 cm modules (standard UVa modules) to be assembled in 50 cm x 130 cm (with a 10 cm dead zone).

Electronics of BigBite – The contact person is E. Fuchey.

1. The DAQ weldment with FASTBUS, VME and DAQ computers
2. Software for readout of all detectors and on-line analysis
3. Software for Shower, GRINCH, Hodoscope, GEMs
4. Calibration of the detector package on cosmic rays
5. Calibration of the spectrometer tracking and optics
6. Coincidence event displays

BigBite spectrometer – The contact persons are Mark Jones (DAQ&analysis) and B. Wojtsekhowski (detectors & spectrometer). The team includes contact persons A. Tadepalli (for the Shower array), T. Averett (for the Gas Cherenkov counter), R. Montgomery (for the Timing hodoscope), N. Liyanage (for the GEM chambers), and E. Fuchey (for DAQ electronics).

The BigBite considerations are:

1. BigBite dipole magnet (max current is 750 A).
2. BigBite sieve slit for optics calibration, needs smaller holes, more of them.
3. The 243-block two-layer shower calorimeter.
4. Five planes of the GEM chambers.
5. The 510-channel gas Cherenkov counter.
6. A relay rack for a set of LVDS-to-ECL convertors located 80 feet from the detector.
7. Front end electronics located at the detector and two relay racks.
8. The DAQ weldment located in the main DAQ bunker.
9. The GEM electronics in the local shielded bunker.

GEn-RP detectors – The contact person is Brad Sawatzky. The team includes the following contact persons: B. Sawatzky (for Glasgow analyzer, Recoil Proton hodoscope arrays), K. Gnanvo (for the UVa GEMs), and E. Cisbani (for the INFN GEMs).

The GEn specific hardware includes the following:

1. Recoil Proton detector assemblies (2x)
   (a) Each assembly includes 1 hodoscope array, and 2 UVa GEM planes.
   (b) Each Hodoscope array has 48 PMTs (neg. HV) [96 PMTs total]
2. "Inline" SBS GEMs [2x INFN + 6x UVa GEMs]
3. Active analyzer array [32 PMTs total; pos. HV]

The SBS GEM gas distribution system is part of the same system providing gas to the BB GEMs and will be overseen by J. Segal.

Readout and supporting electronics for the SBS GEMs will be overseen and supplied by the GEM group (contact: K. Gnanvo).

Readout and supporting electronics for the hodoscopes and active analyzer array (cables, VXS crate, TDC, FADCs, and HV supply) will be provided by Brad Sawatzky.

The SBS GEM crates and the GEn-specific TDC+FADC crate (hodoscopes + active analyzer) will be incorporated into a 'GEn' CODA configuration in the usual way.

3 Run Plan

3.1 Pre-beam commissioning - integration

The contact person is B. Wojtsekhowski. The team includes the contact person subsystems. For timely realization of the run plan, every item of the experiment (presented in this document) needs to be planned, fully tested and calibrated with pulser and cosmic rays. The results of the tests need to be shown using the event displays and scaler display. The experiment will have daily meetings starting one month prior to beam start where every contact person will present an update on the status of his/her subsystem.

The production run will start with GEn-RP data taking. All GEn-RP items need to be installed prior the beam line commissioning except the passive and active analyzers. After a few days of running for GEn-RP the equipment unrelated to GMn will be removed and GMn experimental plan will be executed.

3.2 Time table of the run

The contact person is B. Wojtsekhowski. The table 1 below provides a summary of the time allocation detailed in specialized sections. Total time is 46.3 days (including the beam tune and reconfigurations and the GEn-RP period) without accounting for 0.5 efficiency. Total time from February 1 until May 6 is 94 days.

step #	task	Q^2 GeV^2	θ_{BB} / θ_{SBS} degrees	Beam, GeV	Time hours	Work time
1 see table 2	beam line		41.9 / 24.7	4.4	24	
2 see table 3	BigBite		41.9 / 24.7	4.4	48	
3 see table 4	HCAL at 14 m		41.9 / 24.7	4.4	48	
4a (move 14 m to 8.5 m)	HCAL		41.9 / 24.7	-	4	4
4b (install both analyzers)	GEn-RP		41.9 / 24.7	-	4	4
4c see table 5	production	4.5	41.9 / 24.7	4.4	104	
4d (removal of GEn-RP)	GEn-RP		41.9 / 24.7	-	56	24
4e see table 7	production	4.5	41.9 / 24.7	4.4	64	
5a (move tab. 7 to 6)	BB/SBS/HCAL		32.5 / 31.1	-	32	16
5b (beam tune)	beam		32.5 / 31.1	4.4	4	
5c see table 6	production	3.5	32.5 / 31.1	4.4	64	
6a (move tab. 6 to 8)	BB/SBS/HCAL		58.4 / 17.5	-	32	16
6b (beam tune)	beam		58.4 / 17.5	4.4	4	
6c see table 8	production	5.7	58.4 / 17.5	4.4	50	
7a (move tab. 8 to 9)	BB only		43.0 / 17.5	-	8	8
7b (energy change)	beam		43.0 / 17.5	6.6	8	
7c see table 9	production	8.1	43.0 / 17.5	6.6	46	
8a (energy change)	beam		43.0 / 17.5	8.8	8	
8b (move tab. 9 to 10)	BB only		34.0 / 17.5	-	8	8
8c see table 10	production	10.2	34.0 / 17.5	8.8	40	
9a (move tab. 10 to 11)	BB/SBS/HCAL		44.3 / 13.3	-	32	16
9b (beam tune)	beam		44.3 / 13.3	8.8	4	
9c see table 11	production	12.0	44.3 / 13.3	8.8	64	
10a (move tab. 11 to 12)	BB/SBS/HCAL		33.0 / 14.8	-	32	16
10b (new config)	beam line		33.0 / 14.8	-	56	24
10c (energy change)	beam		33.0 / 14.8	11	8	
10d see table 12	production	13.5	33.0 / 14.8	11	124	
11a (removal)	BigBite		HRS/ 14.8	-	56	24
11b (energy change)	beam		60. / 14.8	4.4	8	
11c see table 13	calibration	6.0	60. / 14.8	4.4	40	
12a (move tab. 13 to 14)	SBS/HCAL		34. / 25.5	-	32	16
12 see table 14	calibration	3.5	34. / 25.5	4.4	38	
Beam in Hall					798 (33.3 days)	
Re-configuration					352 (14.7 days)	176
Total					1150 (47.9 days)	

Table 1: The time table of the GMn run (and GEn-RP).

3.3 Commissioning of the beam line

The contact person is TBD. The total allocated time for this work is 24 hours in three 8 hour periods. We will do the following:

- With BigBite and all SBS magnets currents set to zero, deliver a pulsed beam to the beam dump.
- Obtain BPM information and perform HARP scans for BPM calibration.
- Test rastered beam operation and test BPM readout with CODA.
- Send a cw beam and increase the current to 50 μA.
- In the pulsed beam mode, check impact of the BigBite magnet current (710 A) on the beam position at the dump.
- In the pulsed beam mode, ramp up SBS correctors with SBS current increased up to 2.1 kA.
- Send a cw beam, increase the current to 50 μA and calibrate IC readings.
- Insert the C-hole target and perform a scan of beam position in X and Y (raster OFF) using the rate monitor (specialized small scintillator counter located near the target at 90 deg. position). Use the detector rate on a scaler with EPIC. Adjust the beam position if needed to have the beam centered in the Carbon target hole. Set the raster ON (5 mm x 5 mm), collect the data - rate vs. x/y in new SPOT++.

item		Beam	Target	Beam	Time	BB angle/dist.	SBS angle/dist.	SBS	HCAL
#		GeV		μA	hour	deg. / meter	deg. / meter	Bdl	dist. m
1		4.4	empty, C-hole	1-50	8	41.9 / 1.55	24.7 / 2.25	0	8.5
2		4.4	empty, C-hole	1-50	8	41.9 / 1.55	24.7 / 2.25	0	8.5
3		4.4	empty, C-hole	1-50	8	41.9 / 1.55	24.7 / 2.25	0	8.5

Table 2: The beam time and other parameters of the beam line commissioning. Total allocated time is of 24 hours.

3.4 Commissioning of the BigBite

The contact person is Eric Fuchey & Mark Jones. The total allocated time is of 48 hours in six intervals each of 8 hours. The following is the plan:

- Magnet position for 4.5 GeV^2 kinematics (41.9 deg, 1.55 m from the pivot).
- Beam is 4.4 GeV (two-pass) 1 μA.
- Target at a single C foil.
- BigBite magnet current set 710 A.
- HV is ON for all detectors per cosmic calibration.
- Measure the shower detector trigger rate.
- Increase beam current for 10 kHz trigger rate.
- Collected data with the Shower signals.
- Collect data with GEM information for parallel studies.
- Use event display for raw data with large shower signal.
- Replay GEM data for track search correlated to the shower cluster.
- Plot shower/pre-shower correlation, select electrons.
- Calculate momentum for selected electrons.
- Calculate shower blocks coefficients and HV corrections.
- Repeat shower study and equalize coefficients with optimum HV set.
- Collect 1M events GEM calibration.
- Find GEM efficiency and coordinate resolution for all planes vs. coordinates.
- Set the SBS magnet at 1 kA.
- Collect 1M events.
- Calculate change of BigBite Shower PMTs gain change.
- Put the target at a multi foil position.
- Collect 10M events for optics analysis.
- Insert a sieve slit, collect 20M events.

- Put the target at LH2 position.
- Collect 10M events.
- GRINCH data analysis in parallel, HV tune, data display, PID vs Shower.

The distance for BB is shown from the pivot to the front of the magnet yoke. The distance for SBS is shown from the pivot to the front of the magnet yoke.

item	Q^2	Beam	Target	Beam	Time	BB angle/dist.	SBS angle/dist.	SBS	HCAL
#	GeV^2	GeV		μA	hour	deg. / meter	deg. / meter	Bdl	dist. m
1	3.5	4.4	C	1-50	8	41.9 / 1.55	24.7 / 2.25	0	8.5
2	3.5	4.4	LH2	1-50	8	41.9 / 1.55	24.7 / 2.25	0	8.5
3	3.5	4.4	C	1-50	8	41.9 / 1.55	24.7 / 2.25	0	8.5
4	3.5	4.4	LH2	1-50	8	41.9 / 1.55	24.7 / 2.25	0	8.5
5	3.5	4.4	C-foils	1-50	8	41.9 / 1.55	24.7 / 2.25	0	8.5
6	3.5	4.4	C+sieve	1-50	8	41.9 / 1.55	24.7 / 2.25	0	8.5

Table 3: The beam time and other parameters of the BigBite commissioning run. Total 48 hours of the beam on target. Total allocated time is of 48 hours.

3.5 Commissioning of the SBS-HCAL

The total allocated time is six intervals each of 8 hours. The contact person is Scott Barcus & B. Quinn The following is a plan:

- SBS magnet current set to zero.
- BigBite sieve slit is removed.
- Target is LH2.
- HCAL at 14 m from the target.
- DAQ trigger is the BigBite shower.
- HCAL HV is ON per cosmic calibration.
- Beam current set to give 10 kHz BigBite trigger rate.
- Collect 10M events for HCAL initial study.
- Use event display to see correlated electron-proton.
- Apply angular correlation to observe and select clean elastic events.
- Calculate HCAL blocks gain coefficients, find corrections for HV.
- Repeat HCAL study with optimum HV set to the level of 5% or better.
- Set the SBS magnet at 2 kA.
- Readjust BigBite Shower HV setting using clean e-p events
- Collect 10M events for proton deflection with SBS magnet OFF and ON
- Calculate elastic proton deflection angles in a grid over SBS acceptance.
- Collect e-p events with clean BigBite trigger, look for proton re-scattering events.

item	Q^2	Beam	Target	Beam	Time	BB angle/dist.	SBS angle/dist.	SBS	HCAL
#	GeV^2	GeV		μA	hour	deg. / meter	deg. / meter	Bdl	dist. m
1	4.5	4.4	LH2	1-50	8	41.9 / 1.55	24.7 / 2.25	0	14
2	4.5	4.4	LH2	1-50	8	41.9 / 1.55	24.7 / 2.25	0	14
3	4.5	4.4	LH2	1-50	8	41.9 / 1.55	24.7 / 2.25	0	14
4	4.5	4.4	C	1-50	8	41.9 / 1.55	24.7 / 2.25	0	14
5	4.5	4.4	LH2	1-50	8	41.9 / 1.55	24.7 / 2.25	0	14
6	4.5	4.4	C	1-50	8	41.9 / 1.55	24.7 / 2.25	0	14

Table 4: The beam time and other parameters of the HCAL commissioning run. Total 48 hours of the beam on target. Total allocated time is of 48 hours.

3.6 GEn-RP production parameters for 4.5 GeV^2 kinematics

- SBS position remains at 24.7 deg and 2.25 m from the pivot.
  (No change from commissioning settings in Sect. 2.)
- Beam energy remains 4.4 GeV.
  (No change from commissioning settings in Sect. 2.)
- Beam polarization is assumed to be 80% for the production run times below.

E12-17-004 has been approved for 120 PAC hours, or a nominal 10 calendar days at the typically assumed 50% efficiency. Of those 120 PAC hours, 12 PAC hours (or a nominal 3 calendar shifts) have been allocated to overhead associated with GEn-related configuration changes. The contact person is Brad Sawatzky.

After GMn has completed their equipment commissioning (BigBite and HCAL). GEn-RP will take a shift to finish GEn-RP equipment commissioning.

1. Install the GEn specific components (**nominal 1 shift**)
    - Install shielding in the beamline dipole cutout (if this is not already inplace).
    - Install shield wall on beamline as needed.
    - Install shielding around SBS GEM crates (if not already installed).
    - Install SBS rear field clamp.
    - Install analyzer plate.
    - Install active analyzer.
2. Run GEn measurement (**108 PAC hours; 9 calendar days**)

- Beam and target configuration match those of the GMn 4.5 GeV^2 setting (Sect. 3.8.) *except* GEn requires **polarized beam**.
  - Beam is **polarized** (80% assumed).
  - Beam energy is 4.4 GeV.
  - Raster is 2mm x 2mm.
  - Target is LD2.
  - SBS at 24.7 deg and 2.25 m from the pivot.
  - HCal is 8.5 meters.
  - SBS magnet current set to +2 kA.
  - BB magnet current set to 0.71 kA.
  - Set primary DAQ trigger to [BigBite .AND. HCal-sum], others pre-scaled for 10% or total rate.
- Take runs as follows. See Table 5 for additional detail.
  - Møller measurement.
  - Positive SBS field running (standard GMn polarity)
  - Negative SBS field running (reverse GMn polarity)
  - Møller measurement (if desired).

3. De-install GEn components (**nominal 1 shift**)

- Remove field clamp (Techs, crane).
- Remove analyzer plate (Techs, crane).
- Remove Glasgow analyzer (Collaboration).
- Remove shield wall on beamline as needed.
- Remove shielding in SBS dipole gap as needed.
- Remove shielding around SBS GEM crates.
- Disconnect cables from the beamline side (left) Recoil Proton detector assembly (Collaboration).
- Remove beamline side (left) Recoil Proton detector from SBS stand (Techs, crane).
- The right-side RP detector can remain, or be craned off as desired.

Item	Q^2	Beam	Target	Beam	Time	BB ang/dist	SBS ang/dist	SBS BdL	HCAL
#	$(\mathrm{GeV/c})^2$	GeV/c		μA	hour	deg./meter	deg./meter	T·m	dist. m
M1	*Møller Meas.*	4.4	–	< 5	8				
1	4.5	4.4	LD2	30	22	41.9/1.55	24.7/2.25	+1.71	8.5
2	4.5	4.4	–	–	2	Verify beam tune after polarity flip			
3	4.5	4.4	LD2	30	22	41.9/1.55	24.7/2.25	−1.71	8.5
4	4.5	4.4	–	–	1	Polarity flip to positive			
5	4.5	4.4	LD2	30	22	41.9/1.55	24.7/2.25	+1.71	8.5
4	4.5	4.4	–	–	1	Polarity flip to negative			
6	4.5	4.4	LD2	30	22	41.9/1.55	24.7/2.25	−1.71	8.5
M2	*Møller Meas.*	4.4	–	< 5	8	*Optional / As needed.*			

Table 5: The beam time and other parameters of the GEn-RP 4.5 GeV^2 run (Sect. 3.6). Total 108 hours of beam on target (out of 120 PAC hours). 8 of the remaining 12 PAC hours (nominal 2 calendar shifts) are used for backing-in and backing-out of the GEn configuration. One additional calendar shift is used for overhead during production running. Note that (existing) E12-09-019 BB optics and SBS momentum calibrations for the 4.5 GeV^2 kinematic setting will be used and will not be remeasured.

3.7 GMn production parameters for 3.5 GeV^2 kinematics

The total allocated time is of 64 hours. The contact person is Brian Quinn.

The following is a plan:

- Beam energy is 4.4 GeV.
- Have SBS at 31.1 deg and 2.00 m from the pivot.
- Set the SBS magnet current at 2 kA.
- Have BigBite at 32.5 deg and 1.8 m from the pivot.
- Set the BigBite magnet current at 0.71 kA.
- The target is LD2.
- HCal at 7.2 meters.
- Get beam current according to the table 6.
- Set raster size 2mm x 2mm.
- Set DAQ trigger from the BigBite, others pre-scaled for 10% or total rate
- Take the data according to the table 6.

item	Q^2	Beam	Target	Beam	Time	BB angle/dist.	SBS angle/dist.	SBS	HCAL
#	GeV^2	GeV		μA	hour	deg. / meter	deg. / meter	Bdl	dist. m
1	3.5	4.4	LD2	30	12	32.5 / 1.80	31.1 / 2.00	1.71	7.2
2	3.5	4.4	dummy	30	2	32.5 / 1.80	31.1 / 2.00	1.71	7.2
3	3.5	4.4	LD2	15	12	32.5 / 1.80	31.1 / 2.00	1.71	7.2
4	3.5	4.4	dummy	15	2	32.5 / 1.80	31.1 / 2.00	1.71	7.2
5	3.5	4.4	LD2	6	6	32.5 / 1.80	31.1 / 2.00	1.71	7.2
6	3.5	4.4	dummy	6	1	32.5 / 1.80	31.1 / 2.00	1.71	7.2
7	3.5	4.4	LH2	60	3	32.5 / 1.80	31.1 / 2.00	1.71	7.2
8	3.5	4.4	LH2	30	3	32.5 / 1.80	31.1 / 2.00	1.71	7.2
9	3.5	4.4	LH2	12	9	32.5 / 1.80	31.1 / 2.00	1.71	7.2
10	3.5	4.4	LH2	60	6	32.5 / 1.80	31.1 / 2.00	0	7.2
11	3.5	4.4	dummy	60	2	32.5/1.80	31.1/2.00	1.71	7.2

Table 6: The beam time and other parameters of the 3.5 GeV^2 run. Total 58 hours of the beam on target. Total allocated time is of 64 hours.

3.8 GMn production parameters for 4.5 GeV^2 kinematics

The total allocated time is of 64 hours. The contact person is Brian Quinn.

The following is a plan:

- Beam energy is 4.4 GeV.
- Have SBS at 24.7 deg and 2.25 m from the pivot.
- Set the SBS magnet current at 2 kA.
- Retune SBS beam line correctors.
- Have BigBite at 41.9 deg and 1.55 m from the pivot.
- Set the BigBite magnet current at 0.71 kA.
- The target is LD2.
- HCal at 8.5 meters.
- Get beam current according to the table 7.
- Set raster size 2mm x 2mm.

- Set DAQ trigger from the BigBite, others pre-scaled for 10% or total rate
- Take the data according to the table 7.

item #	Q^2 GeV^2	Beam GeV	Target	Beam μA	Time hour	BB angle/dist. deg. / meter	SBS angle/dist. deg. / meter	SBS Bdl	HCAL dist. m
1	4.5	4.4	LD2	30	12	41.9/1.55	24.7/2.25	1.71	8.5
2	4.5	4.4	dummy	30	2	41.9/1.55	24.7/2.25	1.71	8.5
3	4.5	4.4	LD2	15	12	41.9/1.55	24.7/2.25	1.71	8.5
4	4.5	4.4	dummy	15	2	41.9/1.55	24.7/2.25	1.71	8.5
5	4.5	4.4	LD2	6	6	41.9/1.55	24.7/2.25	1.71	8.5
6	4.5	4.4	dummy	6	1	41.9/1.55	24.7/2.25	1.71	8.5
7	4.5	4.4	LH2	60	3	41.9/1.55	24.7/2.25	1.71	8.5
8	4.5	4.4	LH2	30	6	41.9/1.55	24.7/2.25	1.71	8.5
9	4.5	4.4	LH2	12	9	41.9/1.55	24.7/2.25	1.71	8.5
10	4.5	4.4	LH2	60	6	41.9/1.55	24.7/2.25	0	8.5
11	4.5	4.4	dummy	60	2	41.9/1.55	24.7/2.25	1.71	8.5

Table 7: The beam time and other parameters of the GMn 4.5 GeV^2 run. Total 61 hours of the beam on target. Total allocated time is of 64 hours.

3.9 GMn production parameters for 5.7 GeV^2 kinematics

The total allocated time is of 50 hours. The contact person is Brian Quinn.

The following is a plan:

- Beam energy is 4.4 GeV.
- Have SBS at 17.5 deg and 2.25 m from the pivot.
- Set the SBS magnet current at 2 kA.
- Retune SBS beam line correctors.
- Have BigBite at 58.4 deg and 1.55 m from the pivot.
- Set the BigBite magnet current at 0.71 kA.
- The target is LD2.
- HCal at 11 meters.
- Get beam current according to the table 8.
- Set raster size 2mm x 2mm.
- Set DAQ trigger from the BigBite, others pre-scaled for 10% or total rate
- Take the data according to the table 8.

item	Q^2	Beam	Target	Beam	Time	BB angle/dist.	SBS angle/dist.	SBS	HCAL
#	GeV^2	GeV		μA	hour	deg. / meter	deg. / meter	Bdl	dist. m
1	5.7	4.4	LD2	30	18	58.4/1.55	17.5/2.25	1.71	11
2	5.7	4.4	dummy	30	2	58.4/1.55	17.5/2.25	1.71	11
3	5.7	4.4	LD2	15	12	58.4/1.55	17.5/2.25	1.71	11
4	5.7	4.4	dummy	15	2	58.4/1.55	17.5/2.25	1.71	11
5	5.7	4.4	LH2	60	4	58.4/1.55	17.5/2.25	1.71	11
6	5.7	4.4	LH2	30	2	58.4/1.55	17.5/2.25	1.71	11
7	5.7	4.4	LH2	60	6	58.4/1.55	17.5/2.25	0	11
8	5.7	4.4	dummy	60	2	58.4/1.55	17.5/2.25	1.71	11

Table 8: The beam time and other parameters of the 5.7 GeV^2 run. Total 48 hours of the beam on target. Total allocated time is of 50 hours.

3.10 GMn production parameters for 8.1 GeV^2 kinematics

The total allocated time is of 46 hours. The contact person is Brian Quinn.

The following is a plan:

- Beam energy is 6.6 GeV.
- Have SBS at 17.5 deg and 2.25 m from the pivot.
- Set the SBS magnet current at 1.9 kA.
- Have BigBite at 43.0 deg and 1.55 m from the pivot.
- Set the BigBite magnet current at 0.71 kA.
- The target is LD2.
- HCal at 11 meters.
- Get beam current according to the table 9.
- Set raster size 2mm x 2mm.
- Set DAQ trigger from the BigBite, others pre-scaled for 10% or total rate
- Take the data according to the table 9.

item	Q^2	Beam	Target	Beam	Time	BB angle/dist.	SBS angle/dist.	SBS	HCAL
#	GeV^2	GeV		μA	hour	deg. / meter	deg. / meter	Bdl	dist. m
1	8.1	6.6	LD2	30	18	43.0/1.55	17.5/2.25	1.65	11
2	8.1	6.6	dummy	30	2	43.0/1.55	17.5/2.25	1.65	11
3	8.1	6.6	LD2	15	12	43.0/1.55	17.5/2.25	1.65	11
4	8.1	6.6	dummy	15	2	43.0/1.55	17.5/2.25	1.65	11
3	8.1	6.6	LH2	60	4	43.0/1.55	17.5/2.25	1.65	11
4	8.1	6.6	LH2	30	2	43.0/1.55	17.5/2.25	1.65	11
5	8.1	6.6	LH2	60	2	43.0/1.55	17.5/2.25	0	11

Table 9: The beam time and other parameters of the 8.1 GeV^2 run.Total 42 hours of the beam on target. Total allocated time is of 46 hours.

3.11 GMn production parameters for 10.2 GeV^2 kinematics

The total allocated time is of 40 hours. The contact person is Brian Quinn.

The following is a plan:

- Beam energy is 8.8 GeV.
- Have SBS at 17.5 deg and 2.25 m from the pivot.
- Set the SBS magnet current at 1.9 kA.
- Retune SBS beam line correctors.
- Have BigBite at 34.0 deg and 1.75 m from the pivot.
- Set the BigBite magnet current at 0.71 kA.
- The target is LD2.
- HCal at 11 meters.
- Get beam current according to the table 10.
- Set raster size 2mm x 2mm.
- Set DAQ trigger from the BigBite, others pre-scaled for 10% or total rate
- Take the data according to the table 10.

item #	Q^2 GeV^2	Beam GeV	Target	Beam μA	Time hour	BB angle/dist. deg. / meter	SBS angle/dist. deg. / meter	SBS Bdl	HCAL dist. m
1	10.2	8.8	LD2	30	24	34.0/1.75	17.5/2.25	1.6	11
2	10.2	8.8	dummy	30	4	34.0/1.75	17.5/2.25	1.6	11
3	10.2	8.8	LH2	60	4	34.0/1.75	17.5/2.25	1.6	11
4	10.2	8.8	LH2	30	2	34.0/1.75	17.5/2.25	1.6	11
5	10.2	8.8	LH2	60	2	34.0/1.75	17.5/2.25	0	11

Table 10: The beam time and other parameters of the 10.2 GeV^2 run. Total 36 hours of the beam on target. Total allocated time is of 40 hours.

3.12 GMn production parameters for 12 GeV^2 kinematics

The total allocated time is of 64 hours. The contact person is Brian Quinn.

The following is a plan:

- Beam energy is 8.8 GeV.
- Have SBS at 13.3 deg and 2.25 m from the pivot.
- Set the SBS magnet current at 1.9 kA.
- Have BigBite at 44.2 deg and 1.55 m from the pivot.
- Set the BigBite magnet current at 0.71 kA.
- The target is LD2.
- HCal at 14 meters.
- Get beam current according to the table 11.
- Set raster size 2mm x 2mm.
- Set DAQ trigger from the BigBite, others pre-scaled for 10% or total rate
- Take the data according to the table 11.

item	Q^2	Beam	Target	Beam	Time	BB angle/dist.	SBS angle/dist.	SBS	HCAL
#	GeV^2	GeV		μA	hour	deg. / meter	deg. / meter	Bdl	dist. m
1	12.0	8.8	LD2	30	48	44.2/1.55	13.3/2.25	1.5	14
2	12.0	8.8	dummy	30	4	44.2/1.55	13.3/2.25	1.5	14
3	12.0	8.8	LH2	60	4	44.2/1.55	13.3/2.25	1.5	14
4	12.0	8.8	LH2	30	2	44.2/1.55	13.3/2.25	1.5	14
5	12.0	8.8	LH2	60	3	44.2/1.55	13.3/2.25	0	14

Table 11: The beam time and other parameters of the 12 GeV^2 run. Total 61 hours of the beam on target. Total allocated time is of 64 hours.

3.13 GMn production parameters for 13.5 GeV^2 kinematics

The total allocated time is of 124 hours. The contact person is Brian Quinn.

The following is a plan:

- Beam energy is 11 GeV.
- Have SBS at 14.8 deg and 3.10 m from the pivot.
- Set the SBS magnet current at 1.9 kA.
- Retune SBS beam line correctors.
- Have BigBite at 33.0 deg and 1.55 m from the pivot.
- Set the BigBite magnet current at 0.71 kA.
- The target is LD2.
- HCal at 17 meters.
- Get beam current according to the table 12.
- Set raster size 2mm x 2mm.
- Set DAQ trigger from the BigBite, others pre-scaled for 10% or total rate
- Take the data according to the table 12.

item	Q^2	Beam	Target	Beam	Time	BB angle/dist.	SBS angle/dist.	SBS	HCAL
#	GeV^2	GeV		μA	hour	deg. / meter	deg. / meter	Bdl	dist. m
1	13.5	11	LD2	30	100	33.0/1.55	14.8/3.10	0.97	17
2	13.5	11	dummy	30	8	33.0/1.55	14.8/3.10	0.97	17
3	13.5	11	LH2	60	5	33.0/1.55	14.8/3.10	0.97	17
4	13.5	11	LH2	30	2	33.0/1.55	14.8/3.10	0.97	17
5	13.5	11	LH2	60	6	33.0/1.55	14.8/3.10	0	17

Table 12: The beam time and other parameters of the 13.5 GeV^2 run. Total 121 hours of the beam on target. Total allocated time is of 124 hours.

3.14 HCAL calibration for GMn production parameters for 6.0 GeV^2

The total allocated time is of 40 hours. The contact person is Brian Quinn.

The following is a plan:

- Beam energy is 4.4 GeV.
- Set the SBS magnet current at 2.0 kA.
- Have LHRS at 61.1 deg., 64.3 deg., 67.5 deg., and 70.7 deg.
- Set the LHRS momentum at 1.2 GeV/c.
- The targets are LH2, LH2+radiator, dummy, dummy+radiator
- HCal at 17 meters.
- Get beam current according to the table 13.
- Set raster size 2mm x 2mm.
- Set DAQ trigger from LHRS S2m&S0, others pre-scaled for 10% or total rate
- Take the data according to the table 13.

item	Q^2	Beam	Target	Beam	Time	LHRS angle	SBS angle/dist.	SBS	HCAL
#	GeV^2	GeV	6%X0	μA	hour	deg.	deg. / meter	Bdl	dist. m
1a	6.1	4.4	LH2+6%	30	6	61.1	14.8/3.10	1.71	17
1b	6.1	4.4	LH2	60	1	61.1	14.8/3.10	1.71	17
1c	6.1	4.4	dummy+6%	20	1	61.1	14.8/3.10	1.71	17
1d	6.1	4.4	dummy	20	1	61.1	14.8/3.10	1.71	17
2a	6.1	4.4	LH2+6%	30	6	64.3	14.8/3.10	1.71	17
2b	6.1	4.4	LH2	60	1	64.3	14.8/3.10	1.71	17
2c	6.1	4.4	dummy+6%	20	1	64.3	14.8/3.10	1.71	17
2d	6.1	4.4	dummy	20	1	64.3	14.8/3.10	1.71	17
3a	6.1	4.4	LH2+6%	30	6	67.5	14.8/3.10	1.71	17
3b	6.1	4.4	LH2	60	1	67.7	14.8/3.10	1.71	17
3c	6.1	4.4	dummy+6%	20	1	67.7	14.8/3.10	1.71	17
3d	6.1	4.4	dummy	20	1	67.7	14.8/3.10	1.71	17
4a	6.1	4.4	LH2+6%	30	6	70.7	14.8/3.10	1.71	17
4b	6.1	4.4	LH2	60	1	70.7	14.8/3.10	1.71	17
4c	6.1	4.4	dummy+6%	20	1	70.7	14.8/3.10	1.71	17
4d	6.1	4.4	dummy	20	1	70.7	14.8/3.10	1.71	17

Table 13: The beam time and other parameters of the 6.0 GeV^2 calibration run. Total 36 hours of the beam on target. Total allocated time is of 40 hours.

3.15 HCAL calibration for GMn production parameters for 3.5 GeV^2

The total allocated time is of 38 hours. The contact person is Brian Quinn.

The following is a plan:

- Beam energy is 4.4 GeV.
- Have SBS at 31.1 deg and 3.10 m from the pivot.
- Set the SBS magnet current at 2.0 kA.
- Retune SBS beam line correctors.
- Have LHRS at 30.9 deg and 34.1 deg.
- Set the LHRS momentum at 2.54 GeV/c.
- The targets are LH2, LH2+radiator, dummy, dummy+radiator

- HCal at 17 meters.
- Get beam current according to the table 14.
- Set raster size 2mm x 2mm.
- Set DAQ trigger from LHRS S2m&S0, others pre-scaled for 10% or total rate
- Take the data according to the table 14.

item	Q^2	Beam	Target	Beam	Time	LHRS angle	SBS angle/dist.	SBS	HCAL
#	GeV^2	GeV	6%X0	μA	hour	deg.	deg. / meter	Bdl	dist. m
1a	4.4	4.4	LH2+6%	30	12	34.1	25.5/3.10	1.71	17
1b	4.4	4.4	LH2	60	3	34.1	25.5/3.10	1.71	17
1c	4.4	4.4	dummy+6%	20	1	34.1	25.5/3.10	1.71	17
1d	4.4	4.4	dummy	20	1	34.1	25.5/3.10	1.71	17
2a	4.4	4.4	LH2+6%	30	12	30.9	25.5/3.10	1.71	17
2b	4.4	4.4	LH2	60	3	30.9	25.5/3.10	1.71	17
2c	4.4	4.4	dummy+6%	20	1	30.9	25.5/3.10	1.71	17
2d	4.4	4.4	dummy	20	1	30.9	25.5/3.10	1.71	17

Table 14: The beam time and other parameters of the 3.5 GeV^2 calibration run. Total 34 hours of the beam on target. Total allocated time is of 38 hours.