ERR Response

E. Cisbani, K. Gnanvo, M. Kohl,
N. Liyanage, A. Puckett, and B. Sawatzky
(on behalf of the E12-17-004 Collaboration)

August 11, 2019

Text in bold-italic are the ERR Committee comments and recommendations. Collaboration response follows in plain text.

1 Comments

There is some uncertainty about the scope of existing SBS documentation and what new documentation is or is not required for GEn. The Physics DSO (Ed) & Deputy Associate Director (Patrizia) are available to help make this determination.

The Collaboration understands that new documents (OSPs, etc) will be drafted to accommodate the additional hardware that we are adding. Support/guidance from the DSO et al. will certainly be appreciated. Brad Sawatzky will be the contact person responsible for pulling this material together.

Remaining procurements include copper analyzer plate, optical fibers, HV modules, HDMI cables, and others. Although none of them appear to be challenging to obtain, it would be useful to create a comprehensive list of all remaining procurements and the plans for accomplishing them so that the spokespersons can monitor their progress.

A spreadsheet with these items has been generated and is being tracked.

It would be a good idea to formulate a high rate test with the MPD and SSP DAQ hardware to fully test these devices as close as possible to the simulated rates of the experiment.

GEM performance in the Hall A PREx configuration is being monitored. Unfortunately, due to issues with the Accelerator and other Hall systems, there has been very limited runtime with the GEMs to date. The GEM experts are involved in the PREx GEM setup and will use the data from that experience to validate simulation and shared tracking code wherever possible.

Some high-rate tests with the MPD-SSP system have been demonstrated. Testing of the full system is underway with the support of the JLab Fast Electronics group. (See also the response to Recommendation #1.)

2 Responses to Recommendations

2.1 Recommendation #1:

Outline a plan and schedule to pursue realistic simulations of high-rate tracking performance in the presence of anticipated backgrounds, and to take advantage of any opportunities to validate the simulations using real data.

The simulations of high rate tracking performance for the GEn-RP experiment involve BigBite as the electron-arm (which is common to both GMn and GEn-RP experiments), and the Super BigBite recoil polarimeter side (which is modified for the GEn-RP experiment).

2.1.1 BigBite tracking simulation for GMn and GEn-RP

The GEM tracking performance has already been evaluated under realistic full background conditions with simulated and digitized data for the BigBite (BB) side of GMn and GEn-RP experiments. A detailed report of this simulation and analysis is attached to this document; only a short summary is given here.

- The background rates expected on the BB side were determined using the detailed Geant4 simulation of the full GMn experiment setup. Under those conditions, the worst-case expected background hit rate at the BB GEM tracker is around 100 kHz/cm^2. By far the largest fraction of that rate are random single GEM layer hits resulting from photon conversion.
- Elastic events at the expected rate are generated from elastic generator. For each simulated elastic event passing the calorimeter trigger criteria, background hits in the correct proportion from the G4 simulation were mixed in, randomized in time, over the trigger window.
- This simulation result (hit position in each GEM and energy deposition into the ionization region of the GEM due to that hit) was then converted to simulated raw data files using the digitization library. This digitization process included the following factors involved in the GEM detector signal formation, signal shaping in the APV 25 chip and the ADC conversion to the digital signal:
  - ionization process to electron-ion pairs,

  - amplification and drift through the GEM detector including effects due to transverse diffusion,
  - cluster formation at the readout layer,
  - electronic pedestal noise,
  - electronics cross talk, and
  - signal time jitter.

- All above factors simulated in the digitization were calibrated against real GEM data including MIPs in JLab beam test runs, PRad experiment runs, and cosmic runs, and for background hits due to photon conversion using x-ray data from the UVa x-ray test facility.

- The digitized events were then analyzed with an improved version of the tree-search algorithm already used wire chamber tracking for 6-GeV high rate BigBite experiments. The following list of realistic cuts, already tested against real GEM data, were used to reduce background and to select acceptable x-y correlated tracks under the high rate conditions.

  - Strip hit timing cuts to use the correlation between signal hits and trigger time.
  - Matching the hit position with the allowed position window given the calorimeter hit location for the triggering event.
  - Elastic kinematic cut using the correlation between the slope and intercept of the elastic track.
  - Module ID requirement that both x and y hits of a track in a given layer come from the same module.
  - Hit amplitude correlation requirement for x and y hits of a track in a given layer.
  - Hit time correlation requirement for x and y hits of a track in a given layer.

The results from this analysis for BigBite side tracking efficiency and vertex reconstruction accuracy under the expected background conditions of GMn and GEp-RP experiments are presented in more detail in the attached report.

The improved track finding algorithms based on this simulated analysis have been incorporated into the Hall A analyzer.

The BigBite GEM simulation code and the analysis software repositories can be found in the following github repositories:

- Offline software repository[1]
- SBS simulations[2]

[1] https://github.com/JeffersonLab/SBS-Offline
[2] https://github.com/JeffersonLab/g4sbs

- SBS simulation digitization library (*libsbsdig*)[3]
- GEM digitization library[4] (to be merged with SBS simulation digitization library *libsbsdig*).

2.1.2 Plan for tracking with recoil polarimeter GEMs

The polarimeter is designed to measure neutron polarization in three ways. It can also be used to measure proton polarization.

1. The requirements for the neutron analyzing process include:

   a) Charge exchange (CE) with (passive) Copper analyzer:

   - No tracks reconstructed in the GEMs upstream of the analyzer plate within the vicinity of the expected neutron track (effective veto)
   - forward proton track for CE in GEMs downstream of the Copper analyzer
   - no tracks in side PR GEMs

   b) PR with second (active) analyzer and large-angle proton detection:

   - no tracks in GEMs upstream of the analyzer plate (effective veto)
   - hit in active analyzer providing a proton vertex
   - large-angle proton detected with in side GEMs and hodoscope array.

   c) PR with second (active) analyzer and forward neutron detection:

   - no hits in GEMs before the analyzer (effective veto)
   - hit in active analyzer providing vertex for forward neutron track
   - forward neutron hit in HCAL

2. For all three neutron analyzing processes *a*-*c*, two simulation packages have been developed in parallel and independent of each other:

   1) Glasgow (David Hamilton and John Annand)

   2) Northern Michigan (Will Tireman)

   Framework 1 has been used to simulate the signal process and figure of merit under realistic running conditions, for quasielastic electron-deuteron scattering with polarization. The package is using Ladygin analyzing powers for PR, and Dubna experimental results for CE. It uses a QE event generator for the main physics events including spin tracking and customized G4 physics processes to simulate spin-dependent nucleon scattering in the analyzers. The SBS tracking team (Andrew Puckett and Eric Fuchey) are now engaged in analyzing hits, clusters, and tracks of GEM detectors.

[3] https://github.com/JeffersonLab/libsbsdig
[4] https://github.com/JeffersonLab/libsolgem

Framework 2 was rooted in an independently developed code base used to study a scintillator-based neutron polarimeter for the (unrelated) *C-GEN* measurement planned for Hall C. Its focus has been on evaluating background rates and shielding requirements, while also providing a consistency check for the other Hall A focused simulations (Framework 1, and the GMn SBS/BB simulation).

Simulated results from both Framework 1 and Framework 2 are in good agreement. Rates from the above GEn simulations have also been cross checked with with the GMn SBS/BB simulation where applicable, and have shown consistent results.

2.2 Recommendation #2:

Update simulation geometries to the latest CAD model of the final installation and include fringe magnetic fields.

Simulation detector, beamline, and shielding geometries have been checked against CAD models from the JLab engineering group. Rates and FoM estimates have been updated and are generally consistent with those presented during the ERR. Where they differ (for example, where we have improved some shielding) background rates have reduced.

A TOSCA simulation of the SBS fringe field has been computed and is being added to the simulations as well.

2.3 Recommendation #3:

Obtain a written agreement with the E12-09-019 which includes a high-level schedule showing how installation and deinstallation of all experiment hardware interleave with the run plans of the two experiments.

Please find the written agreement attached.

2.4 Review question #4:

Provide an evaluation of the expected INFN GEM performance or present a plan for using alternate detectors

Four of the INFN GEM chambers are under cosmic test since September 2018. Details on the present INFN GEM performance and ongoing development plans are covered in the response to Recommendation #5. Backup plans are discussed below.

There are two fall back plans in place, depending on future progress and performance of the INFN chambers. We understand that the BigBite electron stack requires the two best, fully functioning INFN chambers to accomplish the tracking goals on the electron side. In the upcoming GEn experiment, the primary function of the chambers upstream of the Cu analyzer plate is to serve as a charged particle veto. Even GEM layers with inefficient regions could serve in that role provided the veto efficiency of the 4 GEM upstream stack (INFN + INFN + UVa + UVa) remains high. We believe even the "worst case" performance of the existing INFN chambers (ie. "as is" with no improvement, despite the planned repairs) would be sufficient for this purpose.

The deep fallback would be to shuffle one or more GEM layers from the recoil proton detector assemblies, or from the 4 layer GEM stack downstream of the copper analyzer into the INFN positions upstream of the analyzer plate. In the most invasive case, this would still leave a single X+Y GEM layer in each recoil-proton side detector to augment the proton track identification between the (segmented) Glasgow analyzer and the hodoscope arrays. Obviously neither choice would be ideal, however we believe they are viable options.

As noted in the attached GEM report, the INFN group continues to work on their systems and expect to get positive results in the next 6-12 months.

2.5 Recommendation #5:

Provide updated reports and expected performance evaluations for both UVa and INFN GEM detectors based on the most recent test results. Present a plan that assures the availability of detectors having suitable performance for the experiment.

2.5.1 Performance goals and expectations for INFN & UVa GEMs

The performance evaluation of the INFN and UVa GEM tracker layers will be done using the cosmic test setups of the two trackers assembled in the test lab and EEL building clean rooms respectively as well as with the recent data being collected with UVa GEM modules for the PREx experiment. Each cosmic stand consists of four or more fully equipped tracker layers, a MPD based GEM readout assembled using the hardware to be used in the experiments and layers of scintillators counters providing the trigger signal. A robust GEM tracking software code with detector alignment algorithm and track fit error corrections is in an advanced stage of development and will be used to analyze the data.

2.5.2 Status of the GEM commissioning

- **INFN GEMs in Cosmic Setup in Testlab:**
  The integration of four INFN GEM layers and their installation in the cosmic setup in the Testlab at JLab was completed in July 2018. The cosmic stand has already been used to collect data during the course of 2018 and 2019. Preliminary analysis of this data and performance results are summarized here[5]. More details on the performance results, the status

[5] https://pandora.infn.it/public/cb4312

and commissioning plans were presented[6] recently at the GMn Readiness Review section of the SBS Summer Collaboration Meeting 2019.

- **UVa GEMs in Cosmic Stand in EEL:**
  As for the UVa setup in the EEL building, the full assembly of the cosmic setup is still in progress. The assembly of three layers and installation on the cosmic stand have been complete and the fourth layer, currently been assembled is expected to be installed by the end of this month (August 2019). The status of UVa GEM layers integration and commissioning plans were presented[7] recently at the GEn-RP Readiness Review section of the SBS Summer Collaboration Meeting 2019. Cosmic data with the four layers is expected to start by next early month (09/2019). Performance results and characterization of the GEMs following the plan below should be available by October 2019. The assembly of UVa layers will continue with four or five layers being evaluated on the cosmic setup at a given time.

2.5.3 Plans for the performance evaluation of the GEM layers

Our plan to fully commission of both INFN and UVa GEM layers can be divided along three axes: 1. Basic characterization of the GEM module with the cosmic data, 2. Advanced track efficiency analysis and coarse position resolution studies with the cosmic data and 3. Refined track efficiency and spatial resolution analysis of six UVa GEM modules with PREx data.

1. **Basic characterization of GEM modules with cosmic data:**
   The GEM commissioning teams (INFN, UVa and HU groups) who are in charge of the assembly and integration of the layers into the cosmic stands will also be in charge of the cosmic data collection and will provide the initial performance evaluation of results of the GEM modules integrated in the layers. A set of benchmark plots to provide a full characterization and performance evaluation of individual GEM modules and listed below will be delivered for each GEM module:

   - pedestal noise (in RMS ADC units) distribution in x and y
   - Cluster charges distribution (in ADC units) at nominal gain
   - Signal-to-Noise ratio at nominal gain
   - Average ADC (gain uniformity) distribution in x and y
   - GEM module efficiency as a function of high voltage.
   - Relative gain curves as a function of high voltage.
   - 1D hit and cluster positions distribution in x and y
   - ADC correlation and ratio plots between x and y

[6] https://www.jlab.org/indico/event/336/contribution/17/material/slides/0.pdf
[7] https://www.jlab.org/indico/event/336/contribution/30/material/slides/1.pdf

- Cluster size (defined as average number of strip with hit per event).
- signal time to trigger time correlations.

2. **Track efficiency and position resolution with cosmic data:**
The cosmic tracking data from both setups will be analyzed by Andrew Puckett's group using a version of the GEM tracking code developed for GMn and GEn-RP experiments with the tree search algorithm. A fine alignment of the layers and modules will be performed as part of this analysis. This work is already in progress for the INFN test stand cosmic data. This tracking analysis will be used to extract both GEM layer efficiency and resolution.

    - **The GEM Layer Efficiency:** will be extracted for a given layer, as a function of 2D position, by projecting x and y tracks determined using the other 3 layers on to that layer and determining if there is a valid hit within ± 5 mm of the projection point for each of the two directions. The x and y tracks used for efficiency calculation are selected using clean track conditions (minimum strip number, trigger time correlation and maximum track chi-squared cuts). Furthermore, only the valid 3-D track combinations with correlated x and y track pairs (as identified by x-y amplitude correlations) will be used for the efficiency determination. The use of the tracks, obtained from three layers under clean track requirements, for the efficiency determination of the fourth layer, removes the trigger bias from that determination.
    - **The GEM position resolution** for a given direction of a given layer is determined from the residual between the the projected track position and the actual hit position for that direction.

3. **Track efficiency and position resolution with PREx data:**
Currently, two stacks of 3 UVa GEM modules are installed in the detector huts of the two HRSs in Hall A for the PREx experiment. Combined with smaller GEMs from Idaho state University, these GEM stacks are used for PREx tracking in the counting mode. A version of the tree search based GEM tracking algorithm is used for this PREx data. This setup, where clean tracks going into the GEMs are determined simultaneously with the HRS VDCs with high accuracy, provides an ideal opportunity for determining the tracking efficiency of the SBS GEMs and of the the tracking algorithm. As part of the linearity tests for PREx, we expect to take GEM data as a function of luminosity. These data will be used to evaluate the tracking efficiency as well as tracking accuracy (both in position and angle) for GEMs as a function of the track rate. The tracking efficiency study will be done together with basic characterization of the 6 individual GEM modules in PREx experiment. The UVa GEM group will provide for these GEM modules, the same set of plots defined for the characterization of the GEM modules and layers in cosmic setups. The

results are expected to be reported in a couple of months at the next winter 2019 SBS Collaboration meeting.

The cosmics tracking software repositories will be located here[8].

2.5.4 Timeline of the performance evaluation of the GEM layers

1. **INFN GEMs:**
   The initial phase of characterization of the four INFN GEM modules destined for BigBite spectrometer for the GMn Experiment is expected to be completed by the end of August / early September 2019 before the chambers are installed in their BigBite support frame. A second phase of commissioning will then begin and continue until the spectrometer is ready to move to Hall A around March 2020. More details can be found in the BigBite Integration Plan here[9]. The assembly of INFN GEM layers in the SBS arm for for GEn-RP will start in September 2019 with the fifth INFN layer. The cosmic stand in Testlab will once again be used for the basic characterization of the new layer. Assembly of the sixth layer will follow, contingent on the availability of enough INFN GEM modules.

2. **UVa GEMs:**
   We plan to start taking cosmic data with the UVa GEM layers in the EEL cosmic setup by the end of August 2019. At that point we expect to have the fourth UVa layer installed in the cosmic stand, and will be in a full data taking mode for about three to four weeks before the integration of the UVa layer in the BigBite frame planned for mid September. The analysis of this first round of cosmic data and the preliminary performances results from the basic characterization of the GEM modules, as well as the track efficiency analysis, will be produced by October 2019. At that time the space in the cosmic test stand left by the UVa layer moved into BigBite will be filled with a new layer and another round of a month-long cosmic data taking and data analysis will be performed. We will repeat this cycle of month-long data taking and analysis as tested GEM layers are moved from the cosmic stand to be installed in the different GEn-RP frames and new layers are moved into the stand following the GEM installation schedule for GEn-RP presented in this document[10].

[8] https://github.com/JeffersonLab/SBS-Offline
[9] https://www.jlab.org/indico/event/336/contribution/17/material/slides/0.pdf
[10] https://www.jlab.org/indico/event/336/contribution/30/material/slides/1.pdf