Super BigBite Spectrometer: simulation and software update

Hall A collaboration meeting
Jefferson Lab, Jan 18-19, 2017

Eric Fuchey
(University of Connecticut)
On behalf of SBS collaboration / Software group
Outline

Overview of SBS

SBS Software/simulation project:
- Scope, requirements;
- organization: responsibilities and milestones;

Current status and activities:
- simulation;
- analysis framework;

Summary
Overview of SBS
See Mark Jones' presentation for more details

Super BigBite spectrometer:
One of the major new projects for Hall A @ 12 GeV (with Moller and SoLID):
Medium solid angle spectrometer with a modular detector package behind a dipole magnet.
=> Many new subsystems with large nb of channels / events sizes (wrt Hall A standards)
Earliest run start: 2019, 184 (+27 cond.) running days approved;
=> major occupation for Hall A collaboration for many years.

Physics programs:
- Form factors at high $Q^2$:
  * $G_m^n (LD_2)$, $G_E^n$ (pol. $^3$He);
  * $G_E^p$ (LH$_2$, recoil pol);
- Semi-Inclusive DIS (pol. $^3$He);
- Tagged DIS (cond. approved);
=> Major physics impact;
(Good opportunity for grad students, young postdocs to join)
=> challenging measurements: high luminosities, high detectors and DAQ rates;
SBS Software/simulation: scope and requirements

**Simulation:**
* Estimation of physics and background rates, detector occupancies;
* Experimental requirements, configuration optimization;
* Radiation dose rates + shielding designs;
* Data sizes, DAQ requirements + design of trigger logics
* Detectors performances (resolutions in position, time, energy)
* Magnetic field maps for SBS and BigBite (optics / spin transport,...)
* Realistic detector response (digitization);
=> *Production of pseudo-data to test analysis software;*

**Analysis software:**
* Detector decoders (DAQ / online analysis)
* Robust reconstruction algorithms (tracking, clustering);
* Optics / spin transport;
* Particle ID;
* Coherent event reconstruction:
  - between detectors in a single arm;
  - between multiple arms;
* Calibration scripts;
* Event displays;
* Physics analysis scripts;

**Strong requirement:**
*Online and offline analysis both need to be ready and tested, and pseudo-data sets have to be analyzed before data taking* (likely spring 2019).
=> *critical given high luminosities / high detectors and DAQ rates.*
Software/simulation project organization

* Major goal: "End-to-end" simulation: production of pseudodata + simulation of data sizes;

* Both simulation and analysis framework need to be:
  → modular (ease configuration changes);
  → accessible (ease handling for new people);
  → flexible (ease inclusion of new configurations);

* Also need:
- Well defined IO formats and standards
- Flexible database to accommodate both MC and data (SQL ?);

* Requires significant coordination between working subgroups
  → 1 dedicated software meeting every 2 weeks
    (in addition to SBS weekly meeting).
  + About to migrate to e.g. Redmine for project management

* Well defined responsibilities and milestones (next 2 slides)
Software/simulation organization: responsibilities

**General purpose software**

<table>
<thead>
<tr>
<th>Responsibility</th>
<th>Lead</th>
</tr>
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<tbody>
<tr>
<td>Analyzer development</td>
<td>O. Hansen (JLab)</td>
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<tr>
<td>Front-end decoders</td>
<td>A. Camsonne (JLab)</td>
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<tr>
<td>Event Reassembly</td>
<td>JLab DAQ group</td>
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**SBS specific**

<table>
<thead>
<tr>
<th>Responsibility</th>
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<tr>
<td>Repository maintenance</td>
<td>S. Riordan</td>
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<td>Simulation maintenance</td>
<td>UConn</td>
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<tr>
<td>MPD decoding</td>
<td>SBU, JLab, UVA, INFN</td>
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<td>GEM Tracking</td>
<td>INFN, JLab, UConn</td>
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<tr>
<td>HCal Analysis</td>
<td>G. Franklin (CMU)</td>
</tr>
<tr>
<td>ECal analysis</td>
<td>A. Puckett (UConn)</td>
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<tr>
<td>CDet analysis</td>
<td>CNU (P. Monoghan, E. Brash)</td>
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<tr>
<td>GRINCH analysis</td>
<td>T. Averett (W&amp;M)</td>
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<tr>
<td>BigBite analysis</td>
<td>S. Riordan</td>
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</tbody>
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**Experimental analysis**

<table>
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<th>Experiment</th>
<th>Lead</th>
<th>Notes</th>
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<tr>
<td>GMn</td>
<td>B. Quinn (CMU)</td>
<td>Bigbite, HCal</td>
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<tr>
<td>GEn</td>
<td>S. Riordan (SBU)</td>
<td>Bigbite, HCal, 3He target</td>
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<td>GEp</td>
<td>E. Cisbani (INFN)</td>
<td>ECal, CDet, SBS w/ FT, FPPs GEM trackers</td>
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<tr>
<td>SIDIS</td>
<td>A. Puckett (UConn)</td>
<td>Bigbite, SBS w/ GEM trackers and RICH</td>
</tr>
<tr>
<td>TDIS</td>
<td>D. Dutta (SBU)</td>
<td>SBS e – w/ GEM trackers and RICH, LAC, RTPC</td>
</tr>
</tbody>
</table>
Software/simulation organization: Milestones

Slide from S. Riordan presentation @ last 12 GeV software review (Nov, 10-11, 2016):

Future SBS Software Milestones

- Nov 2016 - Software Review
- Jan 2017 - Start Digitized Simulation Output
- Apr 2017 - Decoders for all DAQ modules written
- Jul 2017 - Each detector system in analyzer, experiment configurations, basic reconstruction algorithms
  - Can fully analyze raw data at this point
- Dec 2017 - Simulation Interfaced to analysis, Have detector event displays, calibration scripts
- Jan 2018 - Start simulated analysis for detector reconstruction
- Jun 2018 - Begin simulated experimental analysis for core form factor experiments
- Jan 2019 - Ready for beam for form factor, start simulated experimental analysis for SIDIS and TDIS
- Spring 2019 likely earliest start of neutron experiments
- Spring 2020 likely earliest start for GEp

=> Milestones agreed by SBS collaboration to be achievable.
=> Software review final report under production; reviewers satisfied with content related to SBS.
Simulation: current status and activities (1)

SBS Simulation (g4sbs): based on Geant4 (compiled against root to allow output root file).

git repository: https://github.com/JeffersonLab/g4sbs.git (NB: access to git repo granted by O. Hansen)

* Simulation well documented and organized: Complete documentation of g4sbs commands:
  https://hallaweb.jlab.org/wiki/index.php/Documentation_of_g4sbs
  + example scripts in git repo + more flexible and intuitive output root tree structures implemented.
* Mostly complete g4sbs geometry:
  - complete beamline, scattering chamber, lead shielding, for most experiments.
  - needs scattering chamber, polarized target installation, etc for $^3$He experiments (GEn, SIDIS);
  - also needs inclusion of Sieve slits (optics, spin transport).
* Full detectors response for GEMs, Cherenkovs detectors, ECals, HCal, and CDet (optical photons).
* Digitization of detectors (ADC/TDC response) needed;
  - Started for GEMs;
  - To be done for other detectors:

![An elastic ep event in g4sbs illustrating full detector response $G_E^p$, $Q^2 = 12 \text{ GeV}^2$ configuration](image-url)
Simulation: current status and activities (2)

* **Complete range of generators:** Elastic, DIS, N resonance production, single $\pi$ production (Wiser), SIDIS, Pythia (useful for estimating high energy detector rates w/ minimum bias).
  → update of detector occupancies and DAQ trigger rates (underway).

* Detailed magnetic field maps available:
  - full global magnetic field map calculated with TOSCA available for GEp @ 12 GeV$^2$;
  - also needed for other experiments/configurations (but we have satisfactory approximations).

* spin transport calculation under development;
* GEM electronics radiation level calculation and shielding design underway => should come soon;

Simulation additional needs for production of realistic pseudodata:
* Prevertex external bremsstrahlung and multiple scattering;
* **Realistic "event mixing"** (coherent combination of events from different generators):
  => non-trivial.
* optional inclusion of channel failures and miscalibrations desirable.

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![Graphs showing FT rates, FPP1 rates, FPP2 rates](image)

A. Puckett, July 2016

$G_E^p, Q^2 = 12\text{GeV}^2$

FT rates

$G_E^p, Q^2 = 12\text{GeV}^2$

FPP1 rates

$G_E^p, Q^2 = 12\text{GeV}^2$

FPP2 rates
Analysis framework: based on Hall A Analyzer (http://hallaweb.jlab.org/podd/)
git repository: https://github.com/JeffersonLab/SBS-offline.git
(NB: access to git repo granted by O. Hansen)

* we have a working whitepaper:
https://hallaweb.jlab.org/12GeV/SuperBigBite/documents/sbs_soft_whitepaper.pdf

* SBS-offline repository provides a basic structure to plug in the different analysis components;

* Decoders need to be written and included into the repository:
  - MPD decoder (GEMs) already exists;
  - still missing decoders for GRINCH, RICH, ECal, HCal, CDet + HCal FADC class;

* GEM tracking in progress (next slide);
**Analysis activities: GEM tracking**

**GEM tracking requirements:**
- Straight tracks (tracking in field free region);
- use of magnet optics;
- Use of calo cluster position to assist track fit;

**Most constraining:** SBS GEp FT+FPP GEMs: 

*very high rate* \( \geq 500 \text{ kHz/cm}^2 \);

→ Requires kinematic correlations with e⁻ arm to assist track fit;

**Significant amount of work already made, in common with SoLID:**

* Significant work under realistic tracking conditions has already done with *Hall A TreeSearch*
* So far, tracking under realistic conditions have been made only for FT (highest occupancy).

**2011 GEp tracking study by Vahe Mamyam (CMU)**

*Front tracker GEM strip occupancy*

*Track reconstruction accuracy*

*Realistic digitization of GEM & electronics response*

*Simplifying assumptions made (see next)*

> 90% tracking efficiency

5% ghost track probability

\( \approx 40 \mu \text{m} \) track position resolution

* Needs to be redone with the latest simulation, and integrated into the SBS package:*
  → inclusion of the lastest version of the digitization code developed in SoLID, including more realistic avalanche model, cross talk, pedestal noise (courtesy from W. Xiong, Duke).
  → right now, focus on interfacing with TreeSearch and analyzer.

* Additional neural networks algorithms being developed by INFN collaborators.*
Summary

* Efforts on SBS software development are steadily ramping up;

* Clear road map: Milestones and responsibilities well defined.
  → approved by SBS collaboration;

* There is still long way to go: *Everyone is welcome to join!*

* Simulation is in good shape, and produces useful results;
  → continuous improvement will keep going;

* Current focus on GEM tracking, raw data decoders;

* Nov. 2016 Software review (final report under production).
  - reviewers satisfied with content related to SBS.
Thank you for your attention!
Simulation activities

Other recent progress:

![g4sbs model of C16 with segmented blocks.](image)

- **ECAL in GEp high Q², I = 75 μA**
- **C16 in Hall A Test, I = 20 μA**
- **C16/GEp block avg dose rate ratio**

**Slope = (548.1 +/- 0.734) phe/GeV**

**GEp ECal block signal without radiation damage**

**Slope = (527.9 +/- 0.7512) phe/GeV**

**GEp ECal block signal with radiation damage => <4 % signal drop**

Jan. 19 2017
Simulation activities

**g4sbs with Pythia application:**

*Update of detector occupancies and DAQ trigger rates for SIDIS*

(50 μA on 60 cm $^3$He)

Integrated rates, 1.0 GeV threshold: 3.216e+05 Hz

Integrated rates, 2.5 GeV threshold: 4.950e+06 Hz

**BB ECal rates (g4sbs+pythia):**

1.0 GeV Thr => ~320 kHz

Proposal: 200 kHz @ 40 μA,

(250 kHz @ 50μA)

estimated with Wiser code.

**Thr : 1.0 GeV**

**HCal rates (g4sbs+pythia):**

2.0 GeV Thr => ~ 6.7 MHz

(2.5 GeV Thr => ~ 5.0 MHz)

Proposal: 3 MHz @ 40 μA,

(3.75 MHz @ 50μA)

estimated with Wiser code.

**Thr : 2.0 GeV**

**Inclusion of GRINCH in BB trigger:**

* divide BB Ecal in (overlapping) 2x2 block logic units

* associated with 9x5 Grinch PMT group (10ns, 3 p.e. cut):

  Occupancy <1 % → 3 % (30ns)

* 1.0 GeV threshold on ECal logic units:

  Individual rate: 6.3 kHz

* GRINCH-ECal AND: 0.19 kHz;

* OR of all modules : 8.0 kHz (uncorr.);

* Correlated GRINCH-ECal background rates: 37 kHz;

* Uncorrelated+Correlated: 38 kHz;

* AND with HCal singles (6.7 MHz):

=> SIDIS trigger rates : 7.6 kHz

DAQ rate decrease by factor 6