SBS Software and Analysis

Andrew Puckett
University of Connecticut
Hall A Winter Meeting
January 27, 2023
Summary Plots/Runs176806: Golden track momentum, vertex

track momentum, golden track

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Summary Plots/Runs176806: Golden track momentum, vertex

track vertex, golden track

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<tr>
<td>StdDev</td>
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Meme-smithing by Jack Jackson

Tell me the truth. I'm ready to hear it.

You can't just do experiments, you have to analyse the data too.

$Q^2 = 3 \text{ (GeV/c)}^2$

Figure 2: Difference between the vertical coordinate of the particle detected by the SBS hadron calorimeter and its predicted position from the measured electron kinematics in BigBite, assuming (quasi-) elastic scattering.
Existing SBS Software

• SBS online/offline analysis software is based on Podd, the standard C++/ROOT-based Hall A analysis framework, and uses the ROOT-based “panguin/OnlineGUI” for online monitoring plots for shift workers.

• Existing repositories:
  • **SBS-replay**: (principal authors: A. Puckett, E. Fuchey, O. Hansen, S. Seeds, P. Datta, D. Hamilton, others) [https://github.com/JeffersonLab/SBS-replay](https://github.com/JeffersonLab/SBS-replay) Repository for analyzer database files, replay scripts, analysis and calibration macros, online GUI configuration files, etc. No build system. Just a collection of files. This repo is needed to analyze GMN/nTPE data.
  • **Libsbsdig**: (principal author Eric Fuchey) [https://github.com/JeffersonLab/libsbsdig](https://github.com/JeffersonLab/libsbsdig) Main library for digitization of simulation output; translates *g4sbs* output (hit time, position, energy deposit) into simulated raw detector signals (“pseudo-data”), populates ”hit” data structures used by reconstruction (ADC, TDC, crate, slot, channel, etc); purpose is to test and develop reconstruction algorithms on simulated events using identical algorithms to those used for real data: **Crucial for high-rate tracking studies done with simulation so far**
  • **G4sbs**: (principal authors Andrew Puckett, Seamus Riordan, Eric Fuchey, many, many contributors) [https://github.com/JeffersonLab/g4sbs](https://github.com/JeffersonLab/g4sbs) GEANT4-based simulation of all of the major SBS experiments. Documentation at [https://hallaweb.jlab.org/wiki/index.php/Documentation_of_g4sbs](https://hallaweb.jlab.org/wiki/index.php/Documentation_of_g4sbs)
  • **SBSGEM_standalone**: (principal author A. Puckett) [https://github.com/ajpuckett/SBSGEM_standalone](https://github.com/ajpuckett/SBSGEM_standalone) standalone GEM reconstruction code, takes decoded raw data (after common-mode/pedestal subtraction and zero suppression), does clustering, tracking, and alignment. Still useful here and there, but mostly superseded by analyzer/SBS-offline. No longer under active development.
SBS software working group

• Mailing list: https://mailman.jlab.org/mailman/listinfo/Sbs_software

• Standing weekly meeting; currently Fridays at 1:00 PM

• SBS Software Coordinator: Andrew Puckett

• SBS software/analysis wiki page: https://sbs.jlab.org/wiki/index.php/SBS_Software/GMN_analysis_meeting_agendas_and_minutes

• Dedicated GMN/nTPE analysis meetings; currently Fridays at 9:00 AM, organized by Sheren Alsalmi

• GEN analysis effort ramping up soon...

• Upcoming GEN-RP and GEP experiments
GMN/nTPE

Plots from “SBS-8” kinematics:

\[ E = 6 \text{ GeV} \]
\[ Q^2 = 4.5 \text{ GeV}^2 \]
What we’re up against (GMN run 13727, 12 uA LD2, $Q^2 = 4.5 \text{ GeV}^2, E = 4 \text{ GeV}$)

- Single event display for BigBite GEMs; all fired strips color-coded by ADC values

= approximate size of calorimeter-constrained track search region at each layer
Lessons learned from GMN experience allow “pretty good” starting optics model for BigBite from simulation.
Maira is working on implementing multiple clusters into SBS offline.

90% - 97% electron detection efficiency during GEn and 80% - 90% during GMn.

Clear correlation between track position and GRINCH cluster position.

Timing correction script created and implemented.

Satnik, 9 Jan 2023
SBS GEM commissioning in GEN: [https://logbooks.jlab.org/entry/4061825](https://logbooks.jlab.org/entry/4061825)
SBS-BigBite vertex correlation: [https://logbooks.jlab.org/entry/4061825](https://logbooks.jlab.org/entry/4061825)

- Used simulation optics models for SBS+BigBite (no calibration)
- Run 2016 (H2 reference cell)
- I screwed up SBS coordinate system so SBS vertex z has wrong sign (among other issues)
- No alignment of SBS GEMs wrt Hall coordinate system (position is based on educated guess from survey)
- Lots of H(e,e’p) data with SBS GEMs available for analysis!
- Will be used to commission/calibrate SBS GEMs and optics!
Quasi-Elastic Event Selection, $Q^2 = 13.5$ GeV$^2$

- Above, right: $(\Delta x, \Delta y)$ distribution for LH2 and LD2
- Above, left: $\Delta x$ distributions for LH2, LD2
- Bottom, right: $W^2$ distributions for LH2, LD2 with proton, neutron cuts
GMN/nTPE/GEN analysis achievements

- First-pass calibrations and first full “cooking” pass over entire 2-PB GMN/nTPE dataset, with entirely new detectors, finished in less than one year (could have been finished faster but we were somewhat overly cautious in planning to "crunch" 2 PB)

- Machinery for data/MC comparison established

- Preliminary “raw” $d(e, e'p), d(e, e'n)$ yields and baseline stat. uncertainties estimated

- Technical feasibility of SBS program demonstrated
First test of GEM performance with clustering based on deconvoluted ADC samples

- Apparent large increase in overall reconstruction efficiency compared to the version of this plot that I showed in August for the same three runs → too good to be true?

Expected LH2 elastic yield for SBS-8 ≈ 3,700 elastics/mC (or 3.7 Hz/uA)
Lognumber 3974973. Submitted by puckett on Fri, 01/21/2022 - 12:52.
Logbooks: HALOG

This is from g4sbs, with Born cross section, no radiative corrections (also no Aluminum plate on the scattering chamber).

- Comment Form

Elastic yield vs. beam current, SBS-8

- Using SBS-8 LH2 runs 13450 (4 uA), 13451 (5 uA) and 13485 (8 uA) to test tracking improvements
- For SBS-8, with current state of reconstruction software, there is no evidence for a reduction in tracking efficiency over the range of beam currents used on LH2 during the experiment
• GEN-RP (Summer 2023): Need software for charge-exchange and proton recoil polarimeter detectors. Otherwise re-use GMN/GEN software infrastructure.
Electron Arm: High-T Lead-Glass (ECAL) + Scintillator planes (CDET)

30-cm LH2 target

CH2 (HDPE) Analyzer, ~56 cm

Proton Arm: SBS magnet (2.4 T·m) and detectors

85% polarized $e^-$ beam, (up to) 10.6 GeV, 70 $\mu$A

Hadron Calorimeter (HCAL)

Front (FT) and rear (FPP) GEM trackers for proton reconstruction and polarimetry

- **GEP (2024):** all production software and calibration tools for GEP electron arm needs writin’ (re-use existing “SBSGenericDetector” and “SBSCalorimeter” base classes)
- Define region-of-interest for front tracker reconstruction
- Some recoil polarimetry code can be re-used from GEN-RP
GEP Software Considerations—FPP redesign

- *G4sbs* shows that double-FPP FOM is only ~20% higher than single-FPP FOM (due to HCAL in trigger, proton rescattering/absorption in 2nd analyzer), assuming 100% reconstruction efficiency.
- Given GEP background rates and GEM performance, better to go with single-FPP and add redundancy to front and back trackers (8 GEM layers each).
GEP software considerations—Trigger

- Elastically scattered electron energy varies from $3.7 \text{ GeV} \leq E' \leq 6 \text{ GeV}$ within the acceptance
- Need software machinery to gain-match PMTs such that elastic electron signals are constant at the input to trigger summing electronics
- Trigger logic robust with overlap, threshold ~85% of elastic signal
- Still need coincidence with HCAL to achieve manageable DAQ rate
• Precession angle $\chi = \gamma K_p \theta_{bend}$ is roughly constant within the acceptance, since $\gamma \propto p_p$ and $\theta_{bend} \propto \frac{1}{p_p}$

• GEANT4 spin tracking through TOSCA-generated SBS field map

• Fit low-order polynomial expansions of spin rotation matrix elements, compare to GEANT4 spin tracking, calculate determinant of fitted rotation matrix $\rightarrow$ better would be to implement unitarity constraint w/e.g. Lagrange multipliers?
GEP Software Considerations—Electron Arm Reconstruction and FT search region calculation

- Challenge: ECAL + CDET give precise coordinate/azimuthal angle determination but no vertex information!
- If you know the vertex location, the $ep \rightarrow ep$ kinematics are determined very precisely by ECAL+CDET
- GEP tracking strategy: scan assumed vertex along target length, calculate expected FT track using forward optics model, look for tracks in small search region (~few cm$^2$ for each $z$-vertex bin)
- Reconstruct any found tracks back to target, check consistency of vertex with assumption
Summary and Conclusions

• 1st-pass cooking of GMN/nTPE (2 PB) finished. Major analysis effort involving 8 PhD thesis students!
• GEN analysis will ramp up in a major way soon (March/April)—lots of shared software tools between GEN/GMN
• GEN-RP summer 2023; by the end of the summer we will have 3 major SBS analyses going
• GEP summer-fall 2024; in less than two years we will have four major SBS analyses ongoing—but hopefully GMN/nTPE will be close to finished by then
• Significant development work ongoing for GEN-RP/GEP—GEP ERR late March/April?
• DOE proposal submitted with JLab/UConn/UVA/ODU/Hampton consortium to apply AI/ML methods to improve GEM tracking speed and reconstruction performance with the goal of fast, reliable online data reduction.
• Main GEP tracking development is independent of the success of this proposal
Backups
SBS-14 \( (Q^2 = 7.4) \), \( lW^2 - 0.88l < 0.5 \)\&\&\( lyl < 0.3 \) m

- \( SBS-14 \ (Q^2 = 7.4 \text{ GeV}^2) \):
  - "deltax" (top left), "dx vs dy" (top right), \( W^2 \) (bottom left):
  - Proton cut (\( \theta_{pq} < 0.025 \) under proton hypothesis)
  - Neutron cut (\( \theta_{pq} < 0.025 \) under neutron hypothesis)
SBS-7 ($Q^2 = 10$), $W^2$-$0.88l<0.5$, $l_{y}<0.3$ m

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- SBS-7 ($Q^2 = 10$ GeV$^2$): "deltax” (top left), “dx vs dy” (top right), $W^2$ (bottom left):
  - Proton cut ($\theta_{pq} < 0.02$ under proton hypothesis)
  - Neutron cut ($\theta_{pq} < 0.02$ under neutron hypothesis)
• Same as previous slide, for SBS-11 (Q^2 = 13.5)
• Proton cut (thetapq < 0.015 under proton hypothesis)
• Neutron cut (thetapq < 0.015 under neutron hypothesis)
BigBite Spectrometer in Monte Carlo (w/GEN-II target)

- Preshower+Shower Calorimeter and timing hodoscope
- GEM-based tracking: 5 layers
- Target iron shield box and Helmholtz coils with apertures (implemented by D. Flay)
- Gas Ring Imaging Cherenkov (GRINCH)
- BigBite dipole magnet