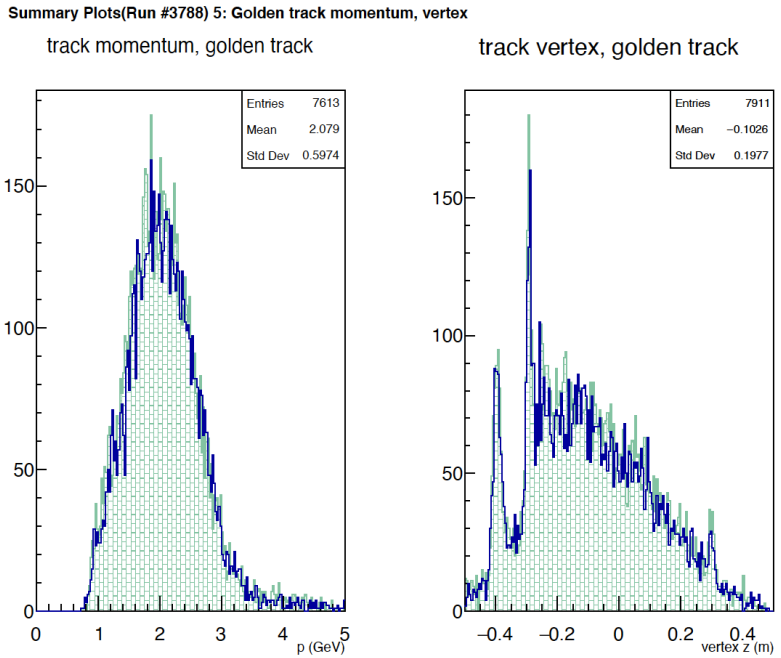
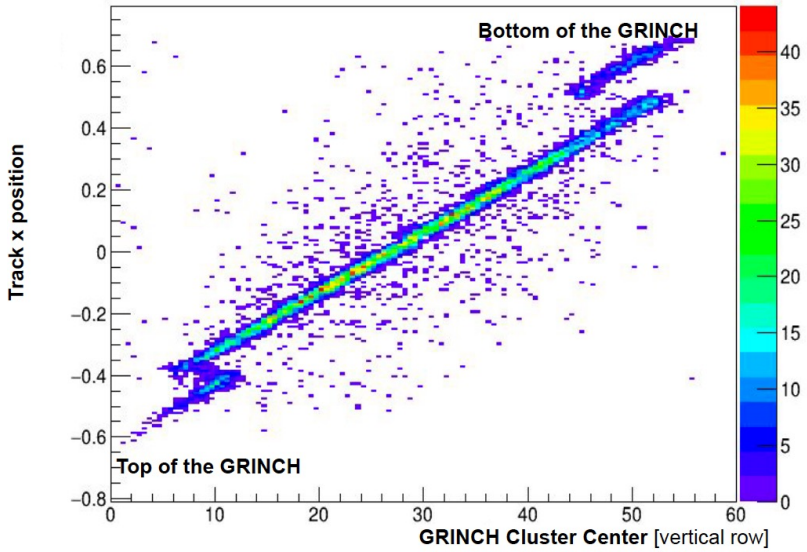
SBS Software and Analysis

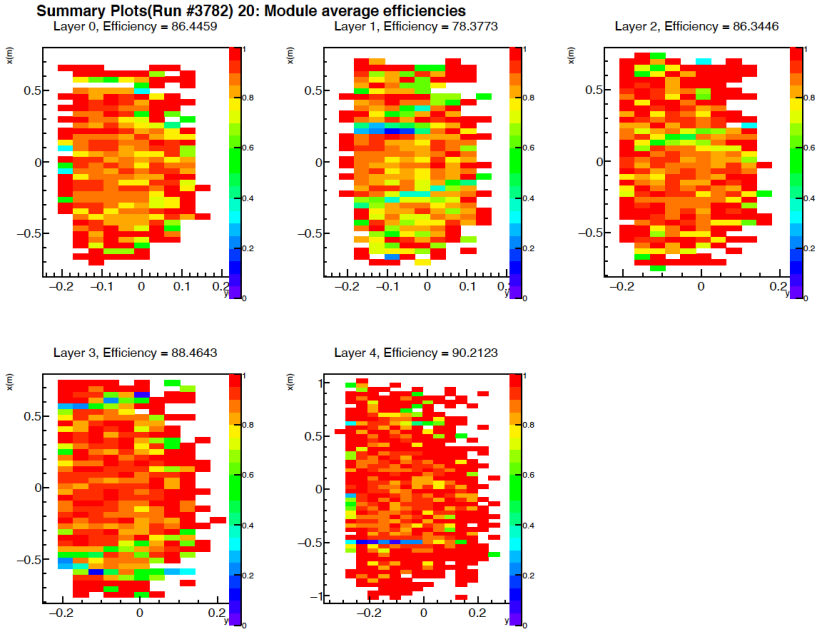
Andrew Puckett
University of Connecticut
Hall A Winter Meeting
January 27, 2023

UCONN





Negative x is “up” in this transport coordinate system.



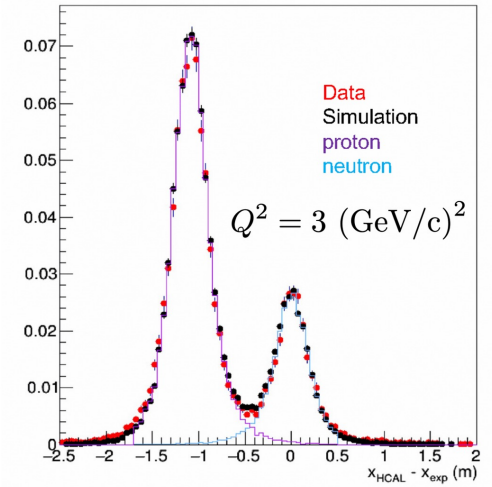
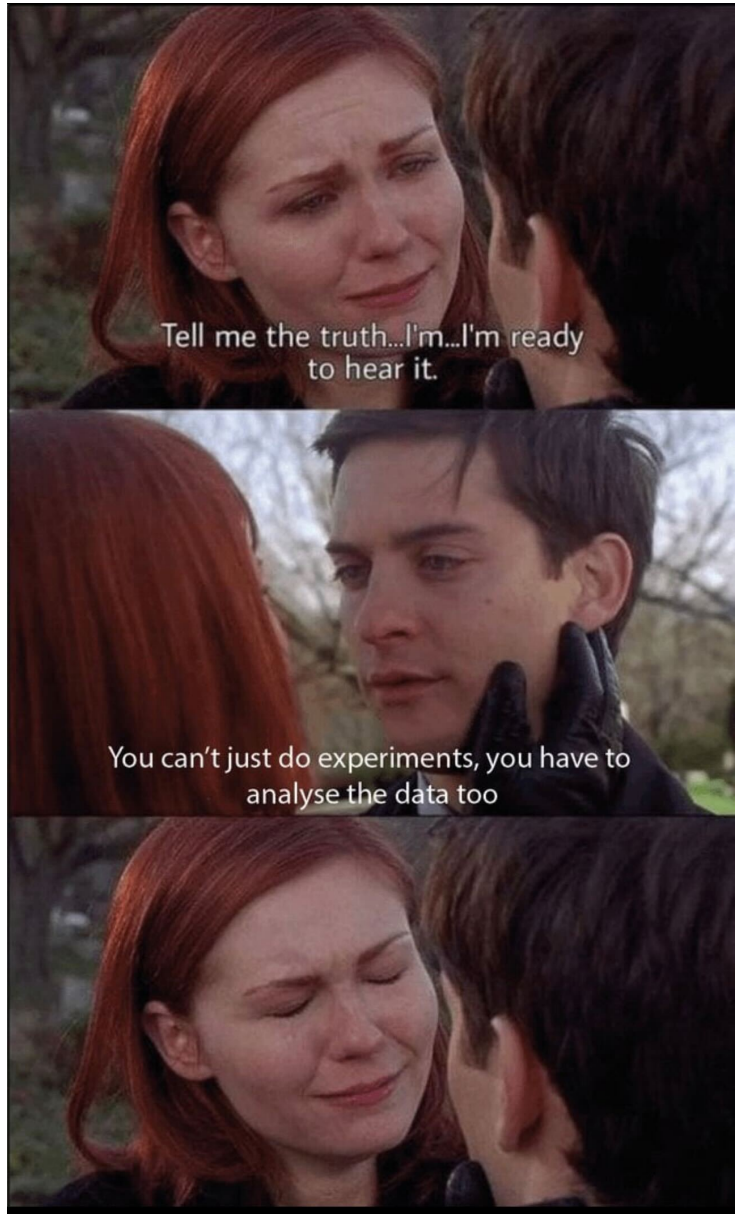


Figure 2: Difference between the vertical coordinate of the particle detected by the SBS hadron calorimeter and its predicted position from the measured electron kinematics in BigBite, assuming (quasi-) elastic scattering.



Meme-smithing by Jack Jackson

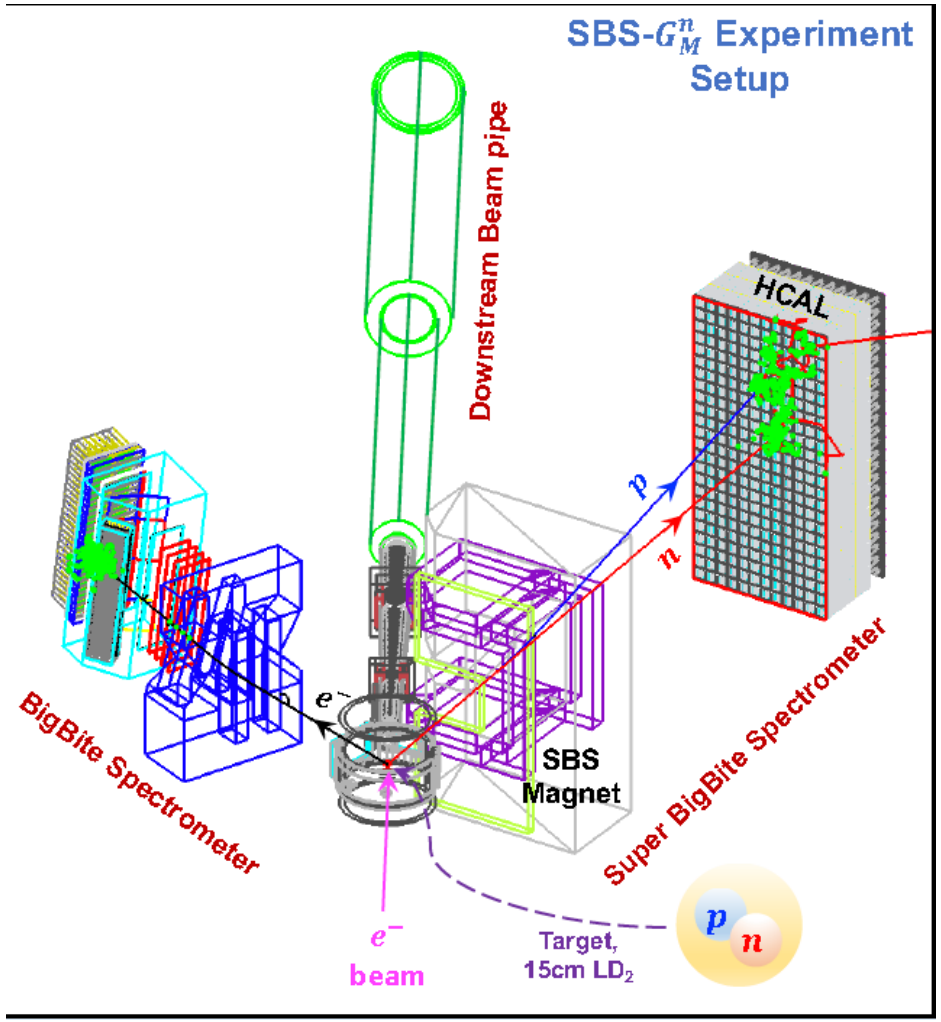
Existing SBS Software

- 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-offline**: (primary authors: S. Riordan, A. Puckett, E. Fuchey, O. Hansen, J. C. Cornejo, M. Jones, R. Montgomery, D. Hamilton, S. Jeffas, *et al.*) https://github.com/JeffersonLab/SBS-Offline Main software repository of SBS-specific libraries and source code. Includes raw data decoders that aren't yet standardized under Podd for new readout modules such as MPD w/VTP and VETROC
  - SBS-replay: (principal authors: A. Puckett, E. Fuchey, O. Hansen, S. Seeds, P. Datta, D. Hamilton, others) 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 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 GEANT4-based simulation of all of the major SBS experiments. Documentation at https://hallaweb.jlab.org/wiki/index.php/Documentation_of_g4sbs
  - **SBSGEM_standalone**: (principal author A. Puckett) 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

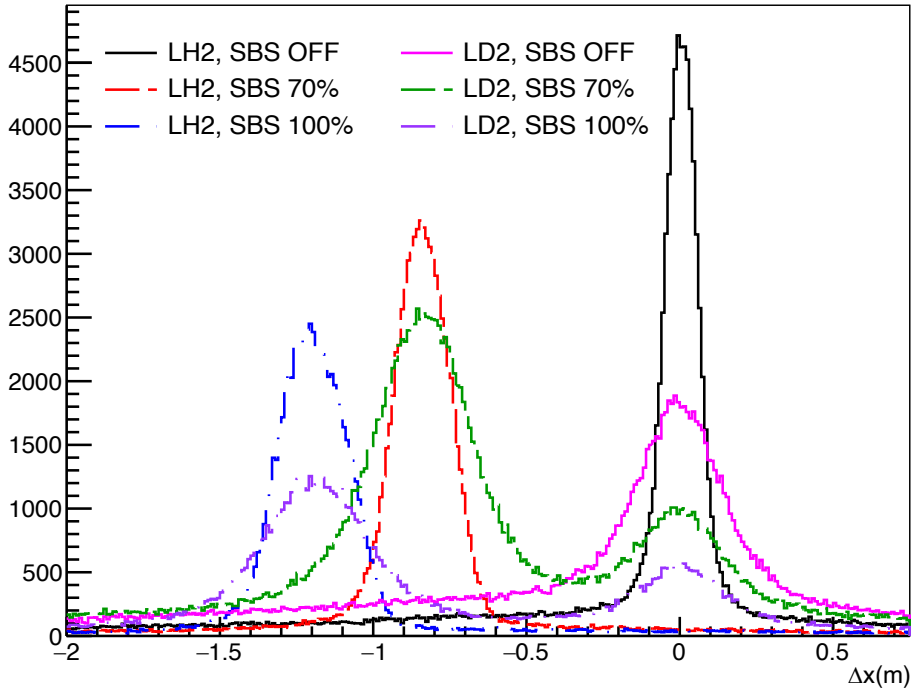
- Mailing list: https://mailman.jlab.org/mailman/listinfo/Sbs_software
- Standing weekly meeting; currently Fridays at 1:00 PM
- SBS Software Coordinator: Andrew Puckett
- SBS software/analysis wiki page: https://sbs.jlab.org/wiki/index.php/SBS_Software/GMN_analysis_meeting_agendas_and_minutes
- Dedicated 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

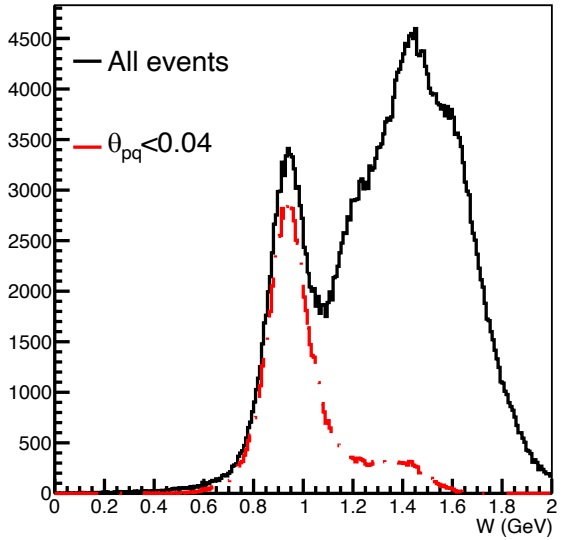


Plots from "SBS-8" kinematics:

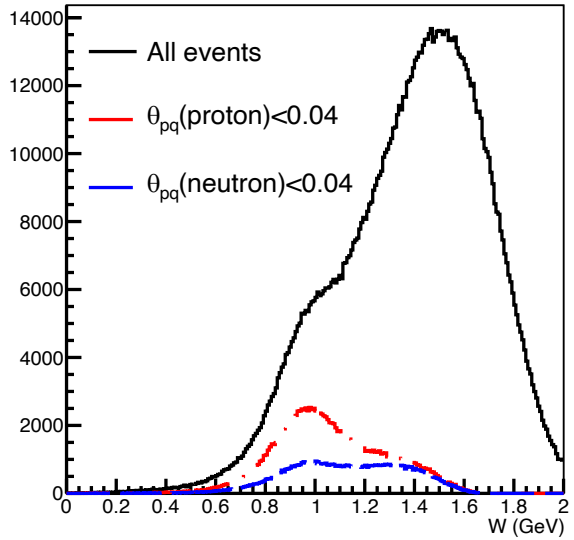
$$E = 6 \text{ GeV}$$
$$Q^2 = 4.5 \text{ GeV}^2$$



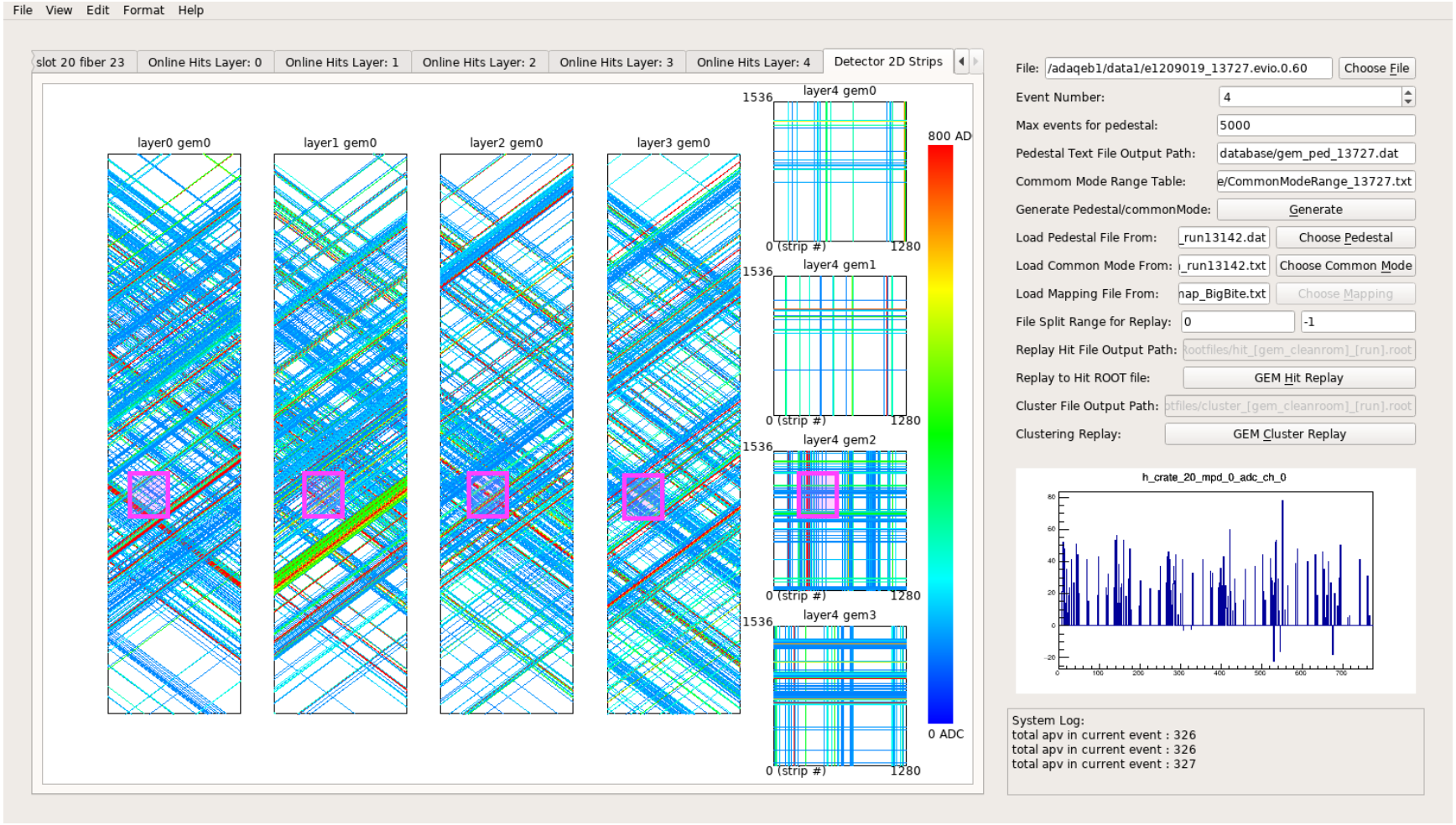
LH2



LD2



What we're up against (GMN run 13727, 12 uA LD2, $Q^2 = 4.5\ GeV^2, E = 4\ GeV$)



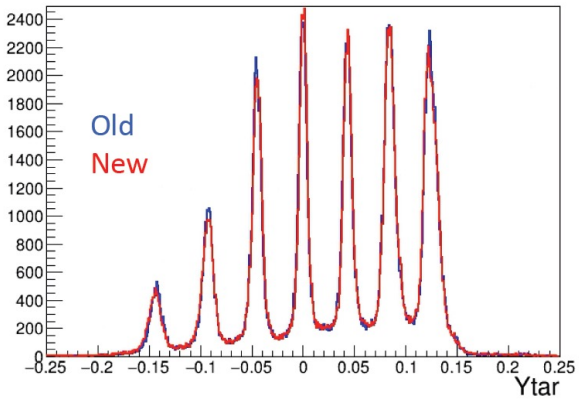
- Single event display for BigBite GEMs; all fired strips color-coded by ADC values

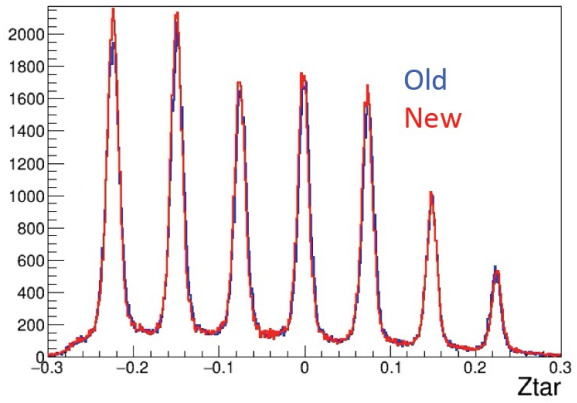
= approximate size of calorimeter-constrained track search region at each layer

GEN Optics calibration (by Holly)

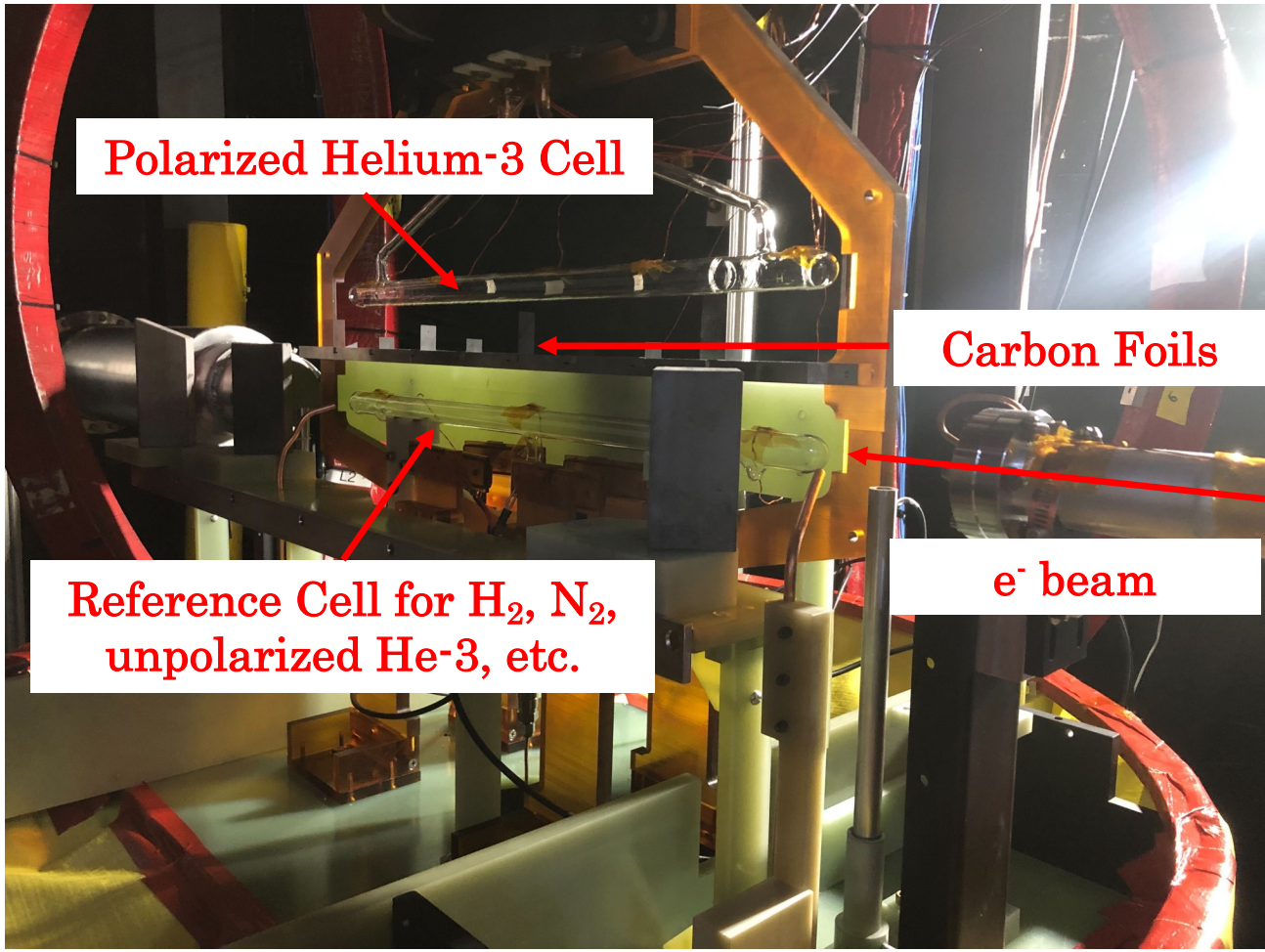
https://sbs.jlab.org/cgi-bin/DocDB/private/ShowDocument?docid=344

Comparing the old and new reconstruction.





- Lessons learned from GMN experience allow “pretty good” starting optics model for BigBite from simulation



GRINCH software

Plots and analysis credit: Maria Satnik

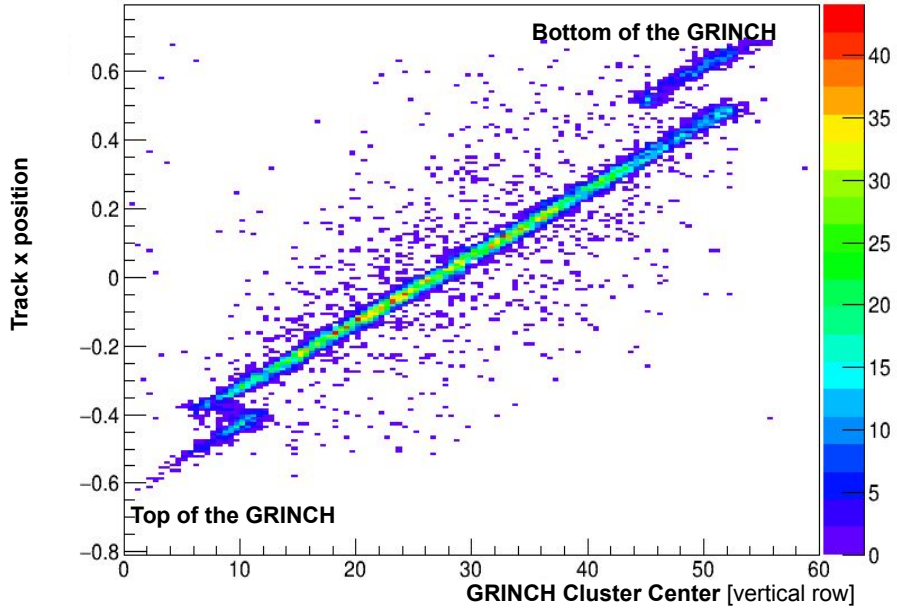
Maira is working on implementing multiple clusters into SBS offline.

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.

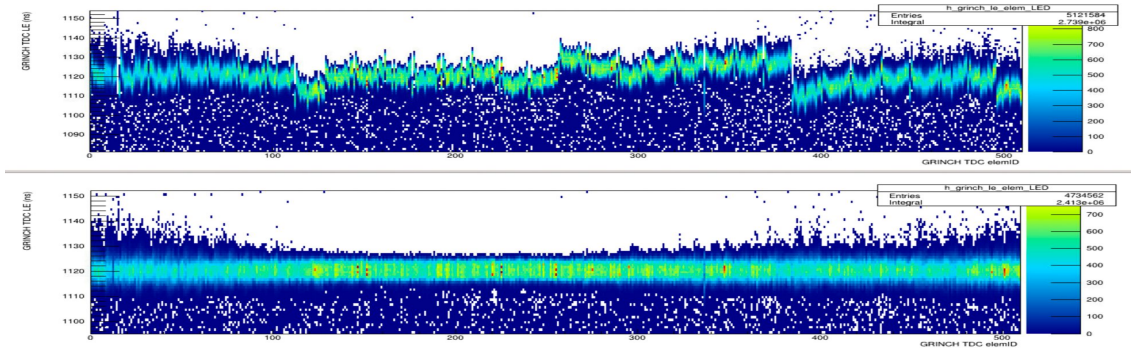
Satnik, 9 Jan 2023



Negative x is “up” in this transport coordinate system.

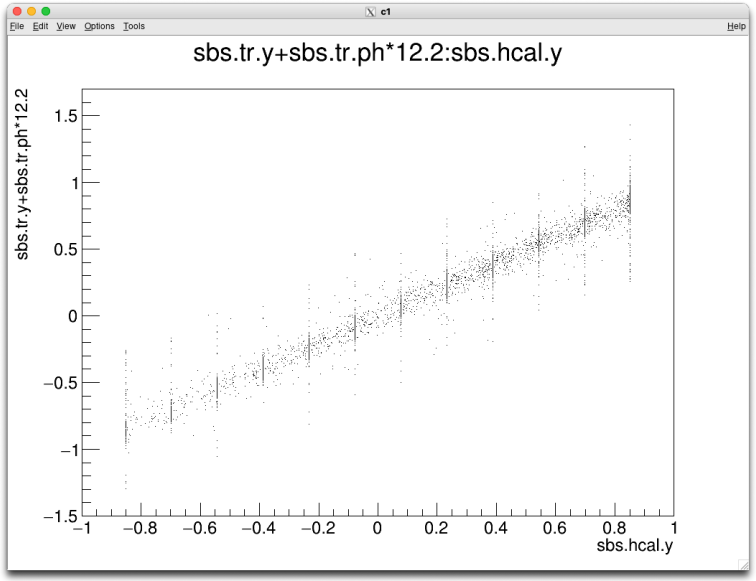
Before

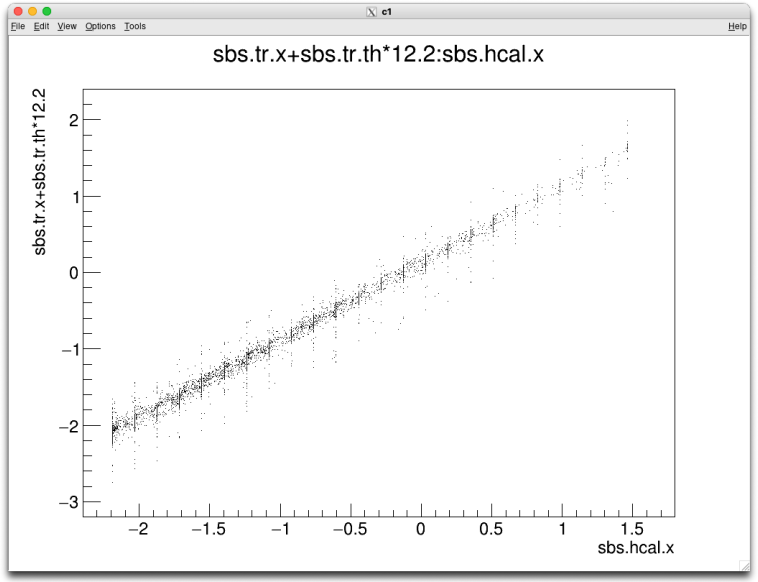
After

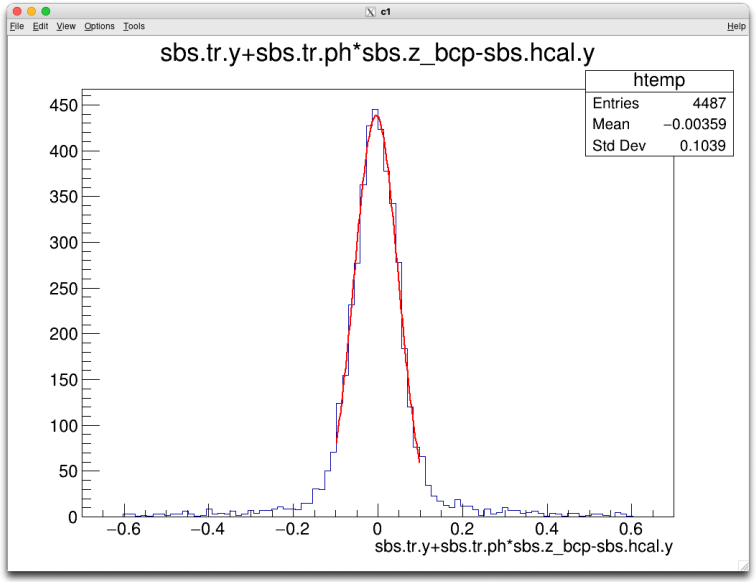


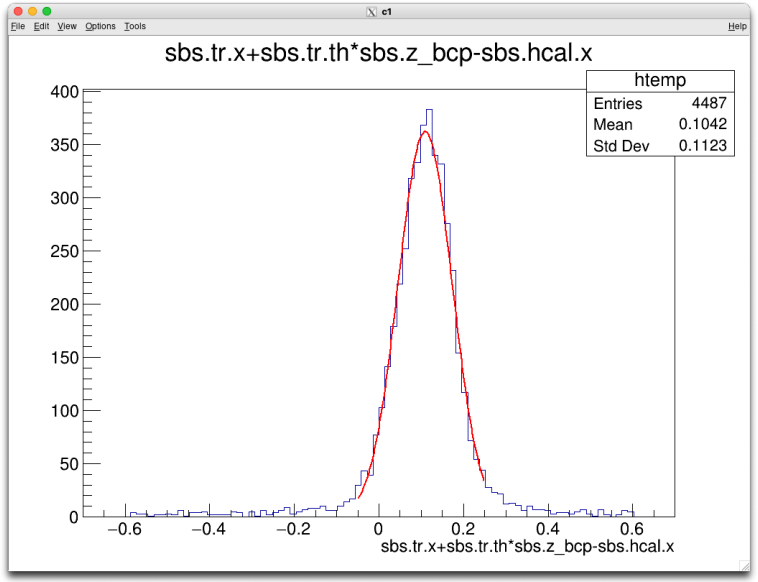
Timing correction using GRINCH LED

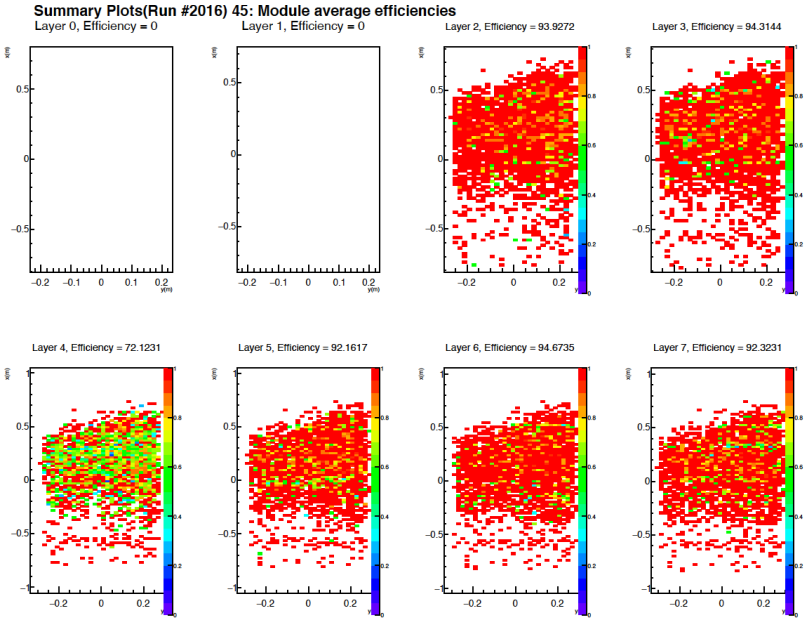
SBS GEM commissioning in GEN: https://logbooks.jlab.org/entry/4061825

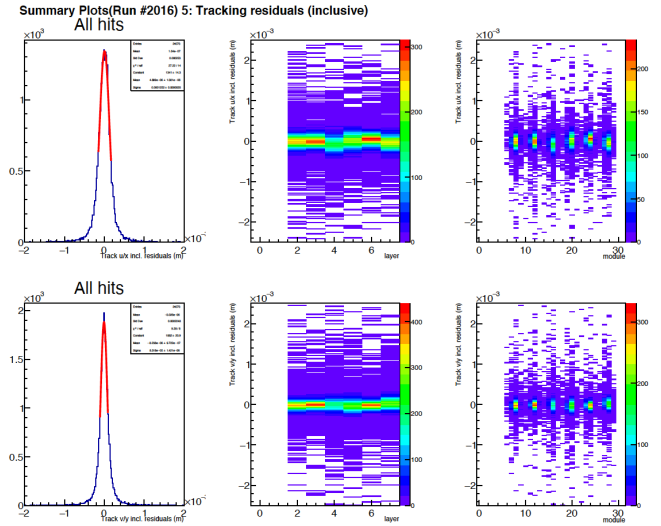




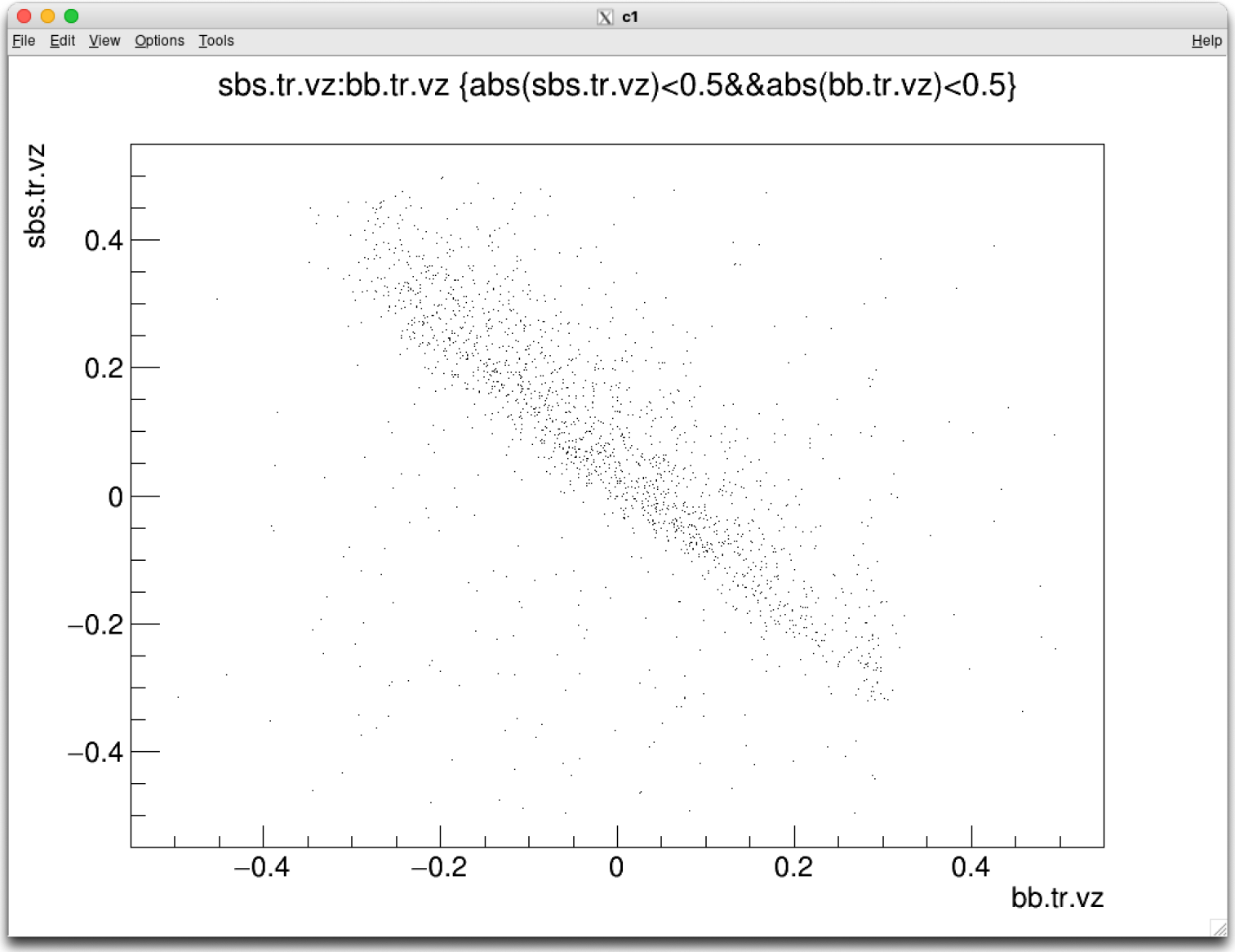






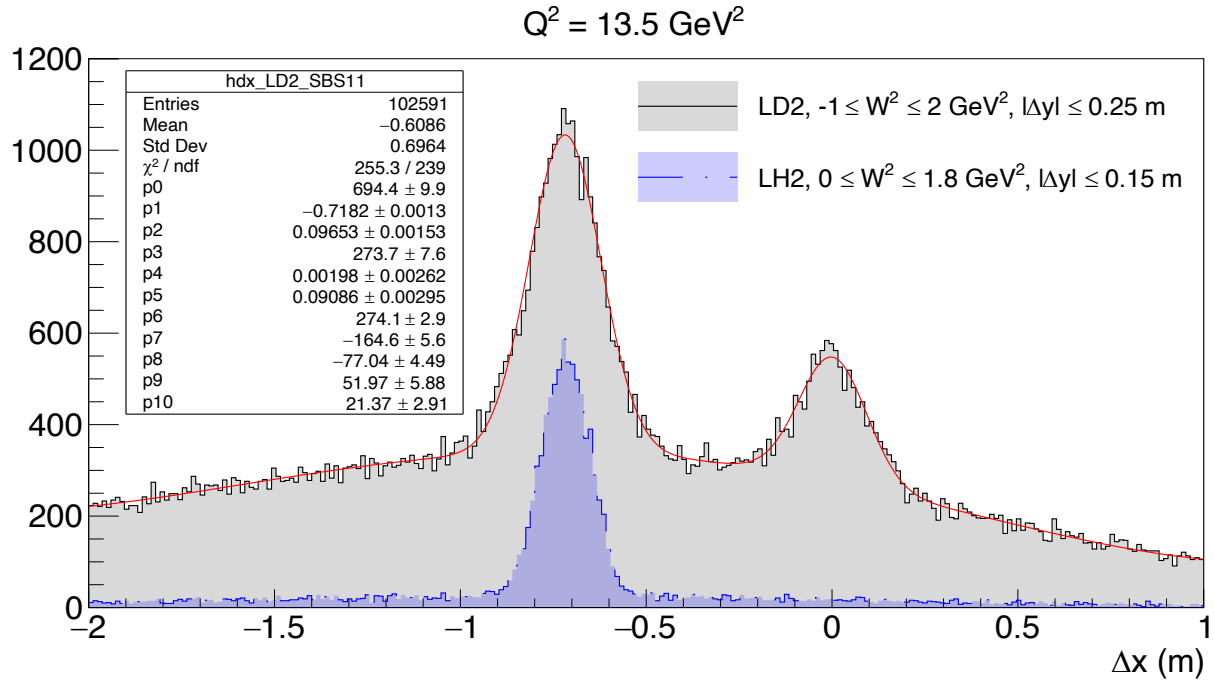


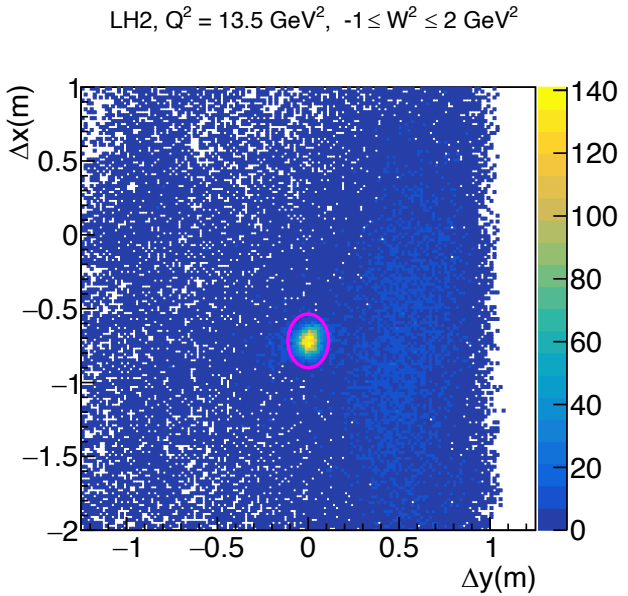
SBS-BigBite vertex correlation: https://logbooks.jlab.org/entry/4061825

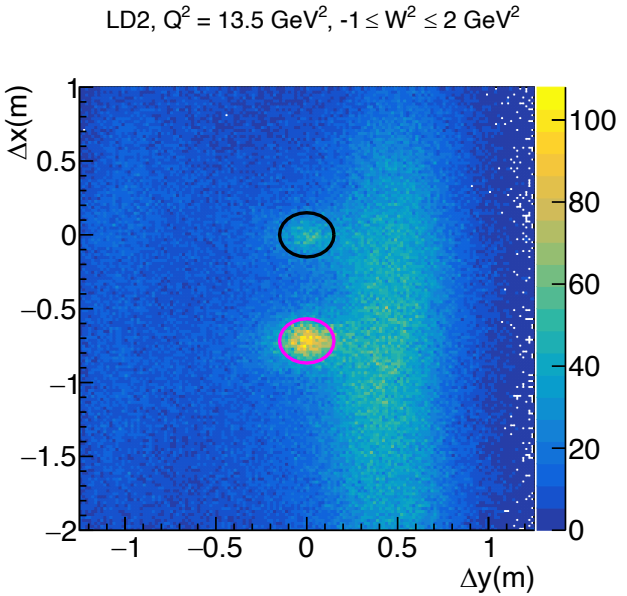


- Used simulation optics models for SBS+BigBite (no calibration)
- Run 2016 (H2 reference cell)
- I screwed up SBS coordinate system so SBS vertex z has wrong sign (among other issues)
- No alignment of SBS GEMs wrt Hall coordinate system (position is based on educated guess from survey)
- Lots of H(e,e'p)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

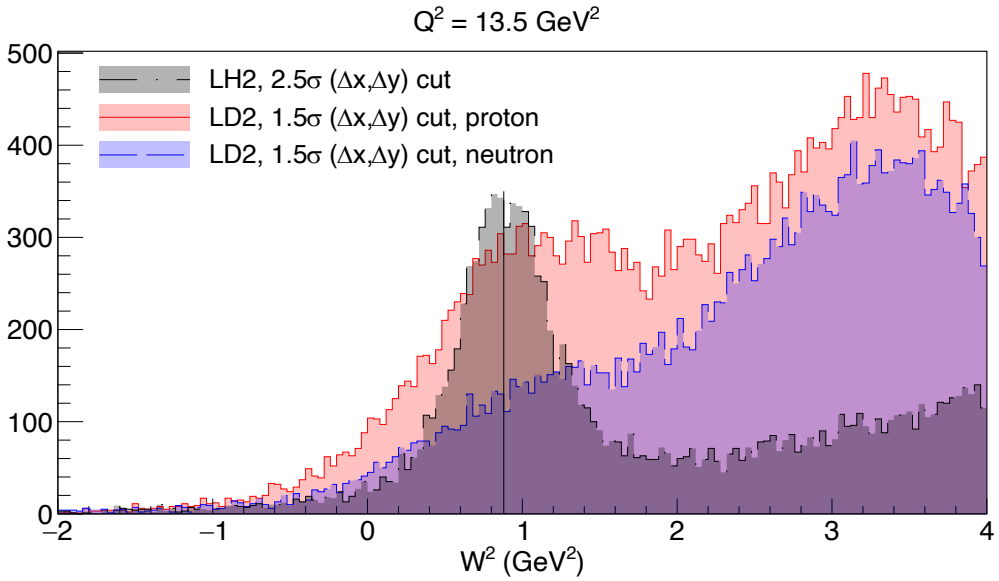
Quasi-Elastic Event Selection, $Q^2 = 13.5$ GeV^2





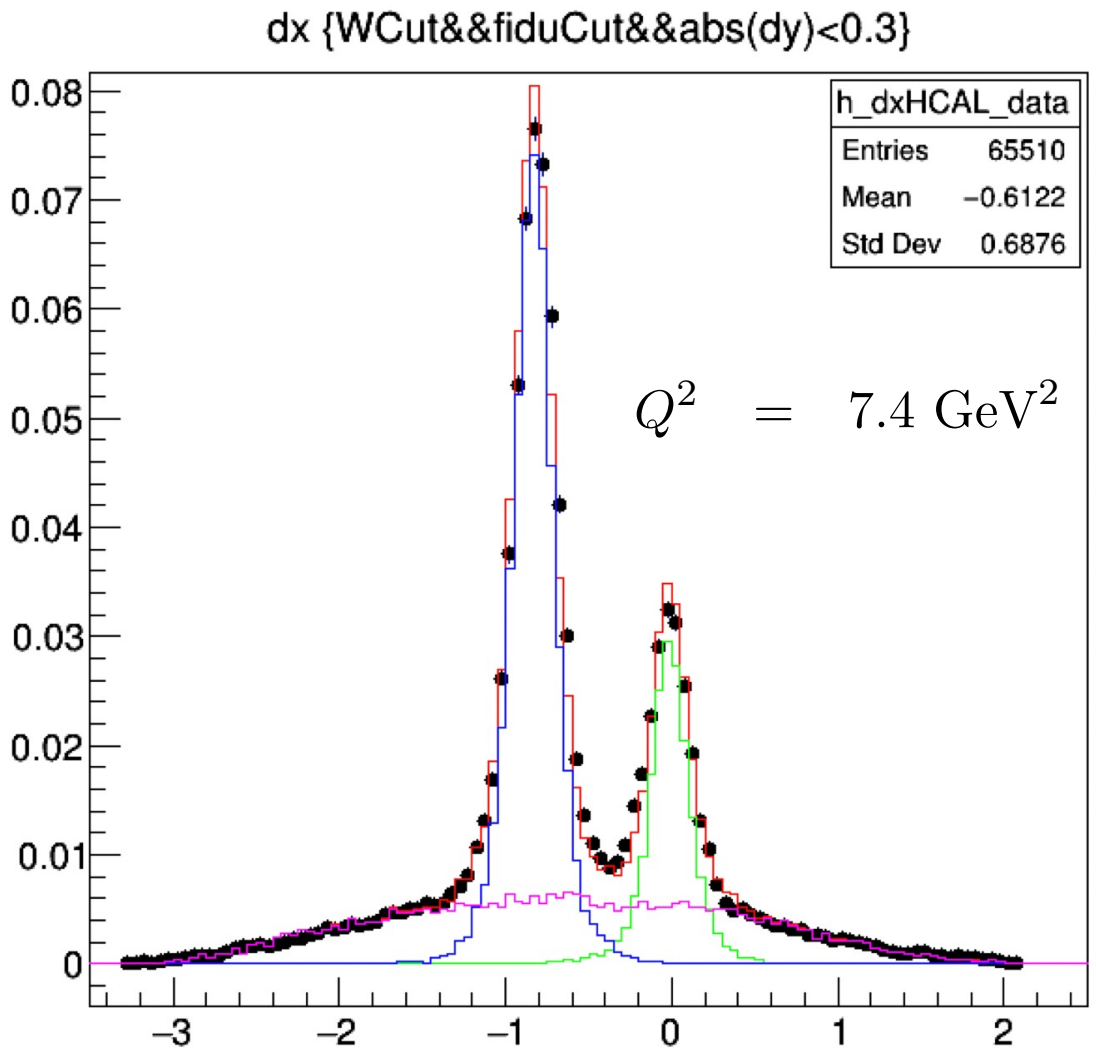


- Above, right: $(\Delta x, \Delta y)$ distribution for LH2 and LD2
- Above, left: Δx distributions for LH2, LD2
- Bottom, right: W^2 distributions for LH2, LD2 with proton, neutron cuts

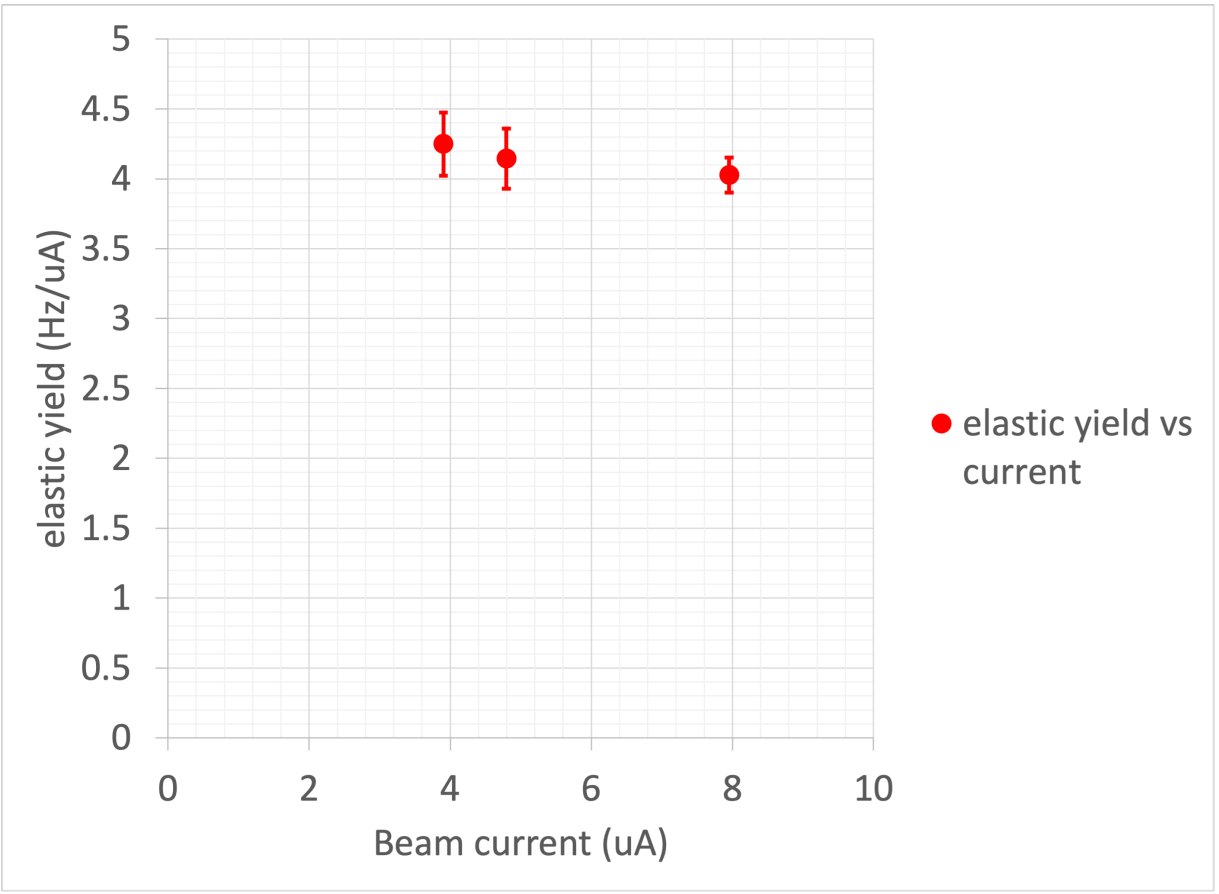


GMN/nTPE/GEN analysis achievements

- 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



Expected LH2 elastic yield for SBS-8 ~= 3,700 elastics/mC (or 3.7 Hz/uA)

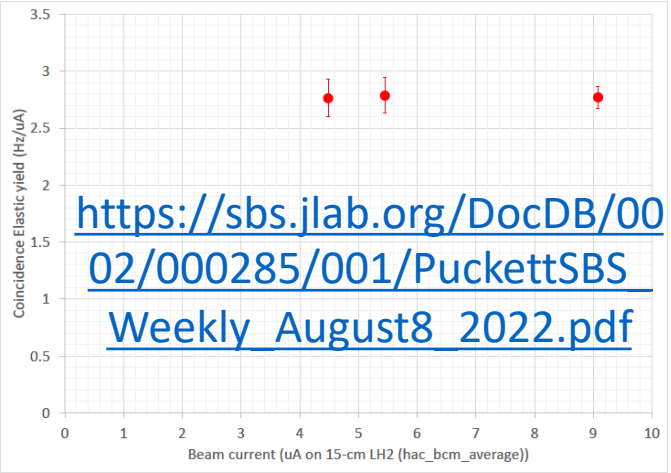
Lognumber 3974973. Submitted by puckett on Fri, 01/21/2022 - 12:52.

Logbooks: HALOG

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

▸ Comment Form

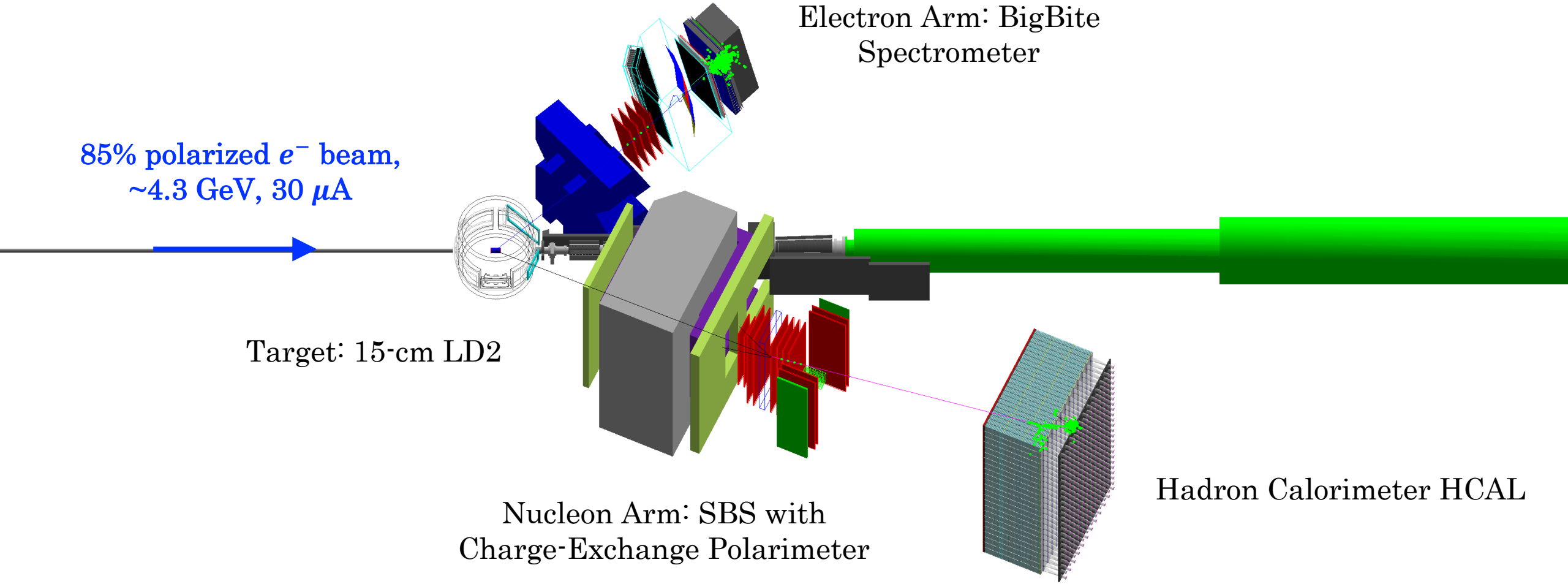
Elastic yield vs. beam current, SBS-8



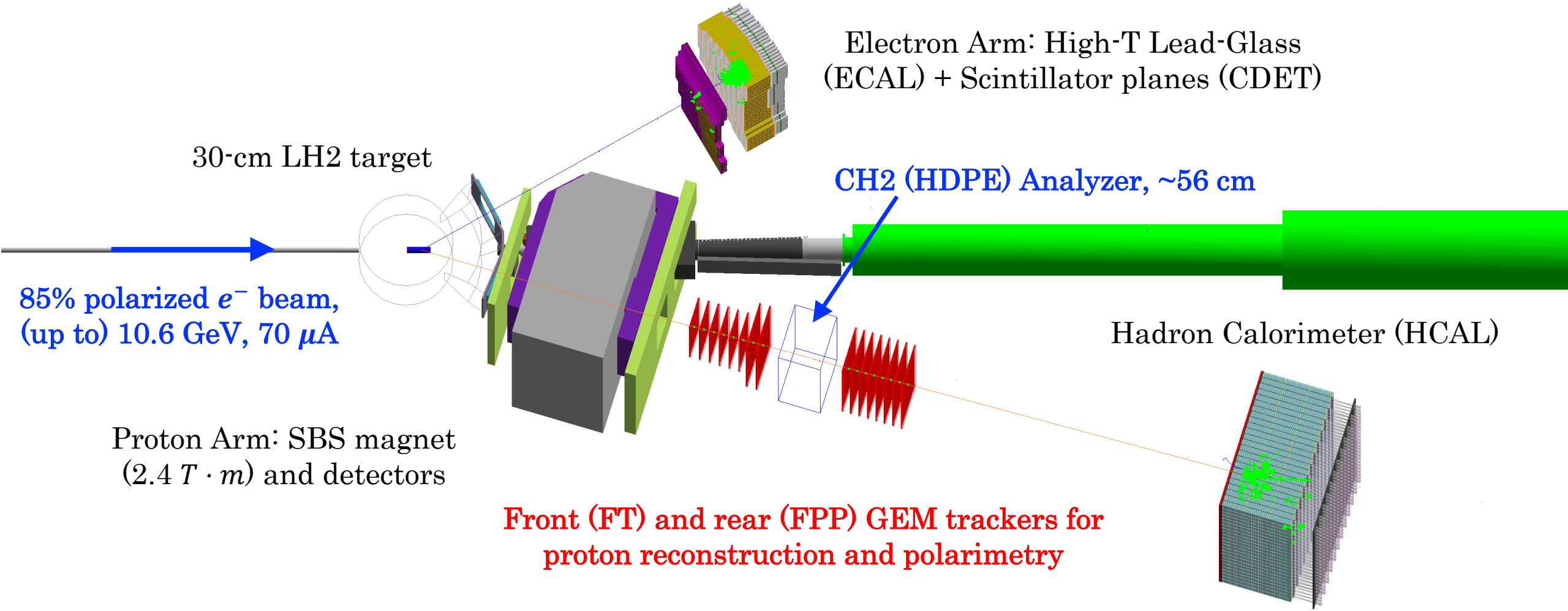
https://sbs.jlab.org/DocDB/0002/000285/001/PuckettSBS_Weekly_August8_2022.pdf

- 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?

- 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

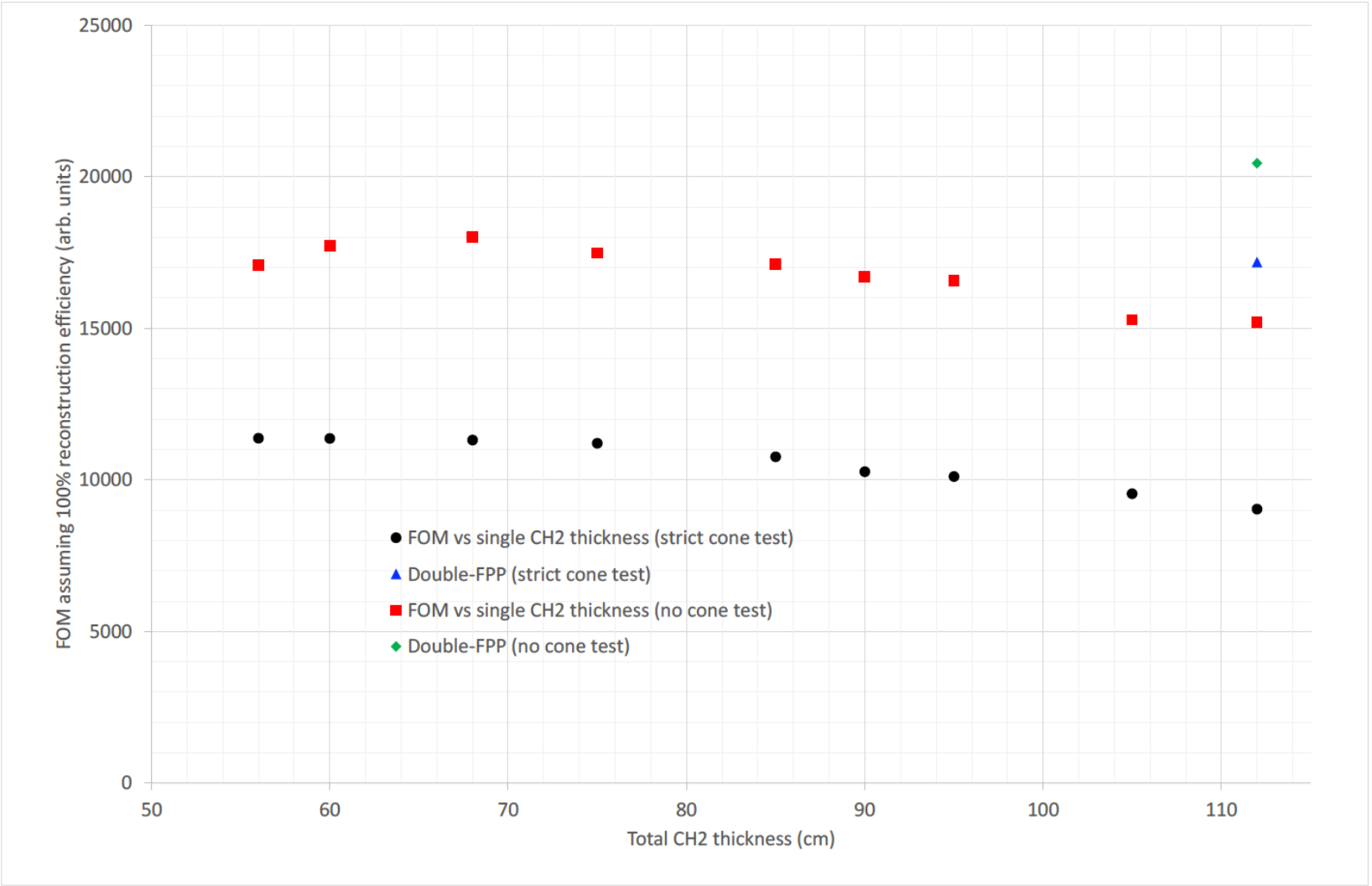


- GEN-RP (Summer 2023): Need software for charge-exchange and proton recoil polarimeter detectors. Otherwise re-use GMN/GEN software infrastructure



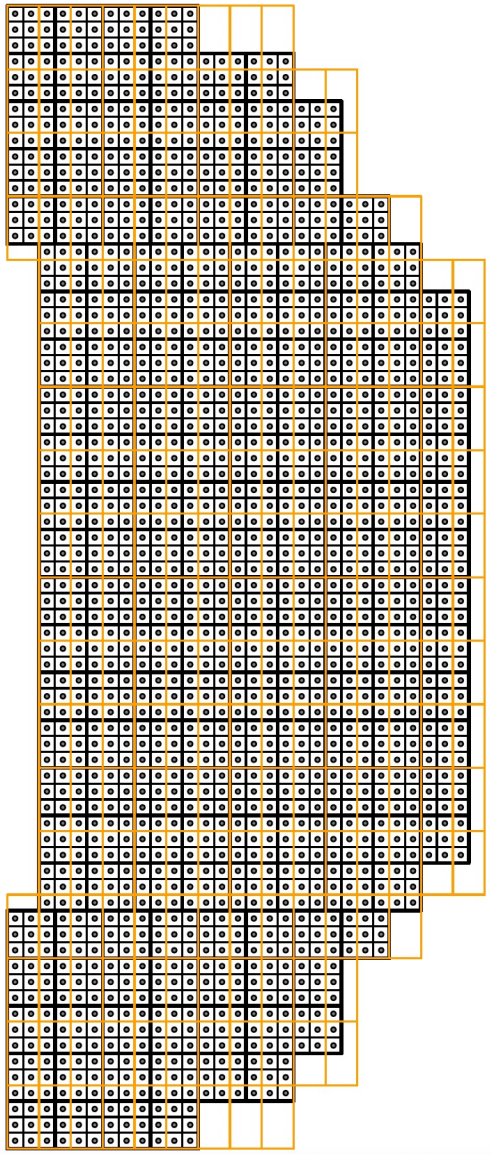
- GEP (2024): all production software and calibration tools for GEP electron arm needs writin' (re-use existing "SBSGenericDetector" and "SBSCalorimeter" base classes)
- Define region-of-interest for front tracker reconstruction
- Some recoil polarimetry code can be re-used from GEN-RP

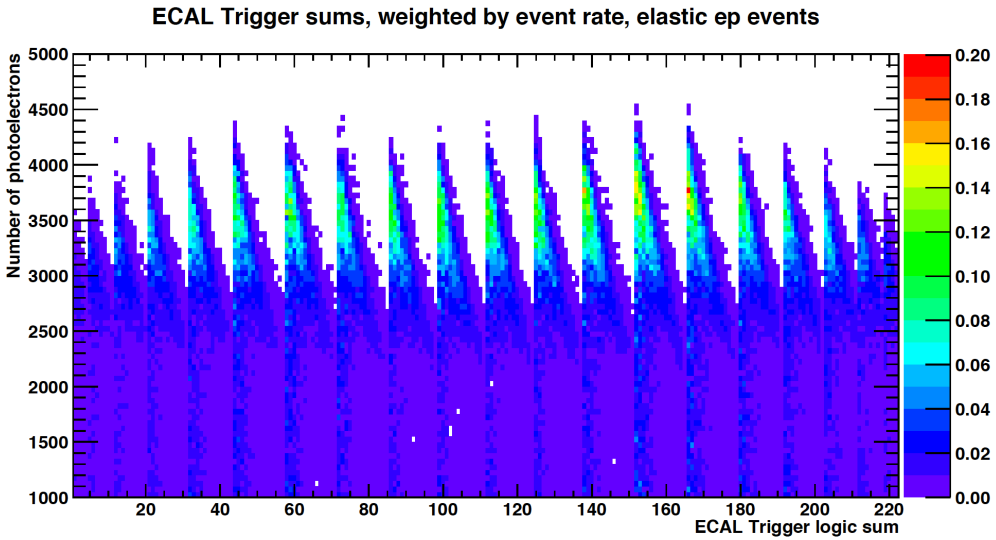
GEP Software Considerations—FPP redesign

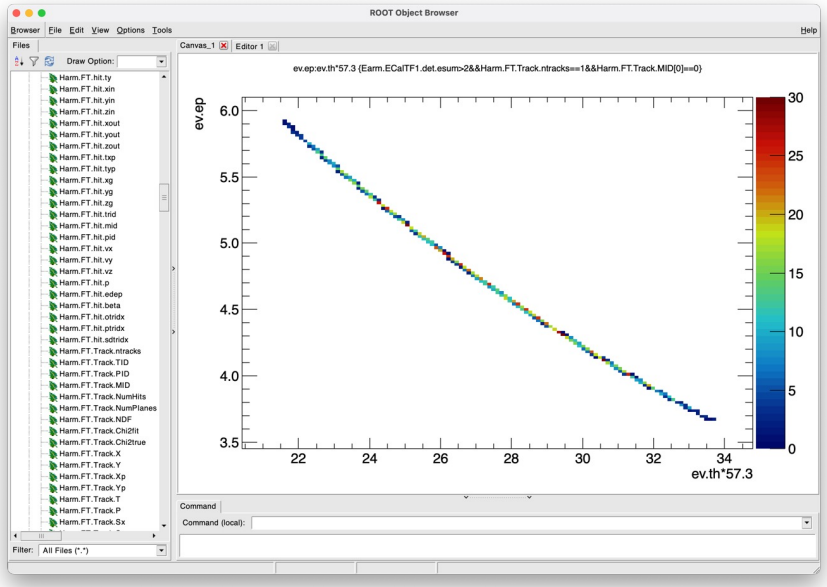


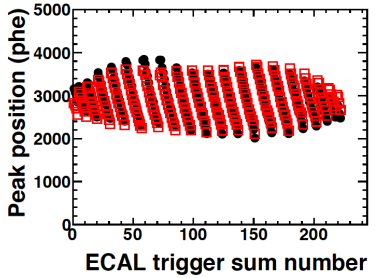
- *G4sbs* shows that double-FPP FOM is only ~20% higher than single-FPP FOM (due to HCAL in trigger, proton rescattering/absorption in 2nd analyzer), assuming 100% reconstruction efficiency
- Given GEP background rates and GEM performance, better to go with single-FPP and add redundancy to front and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

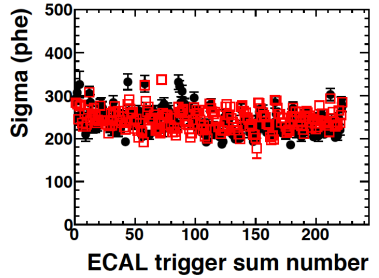
GEP software considerations—Trigger

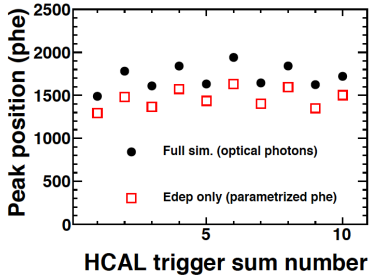


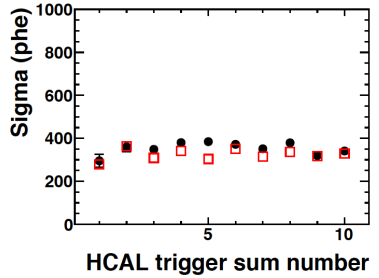






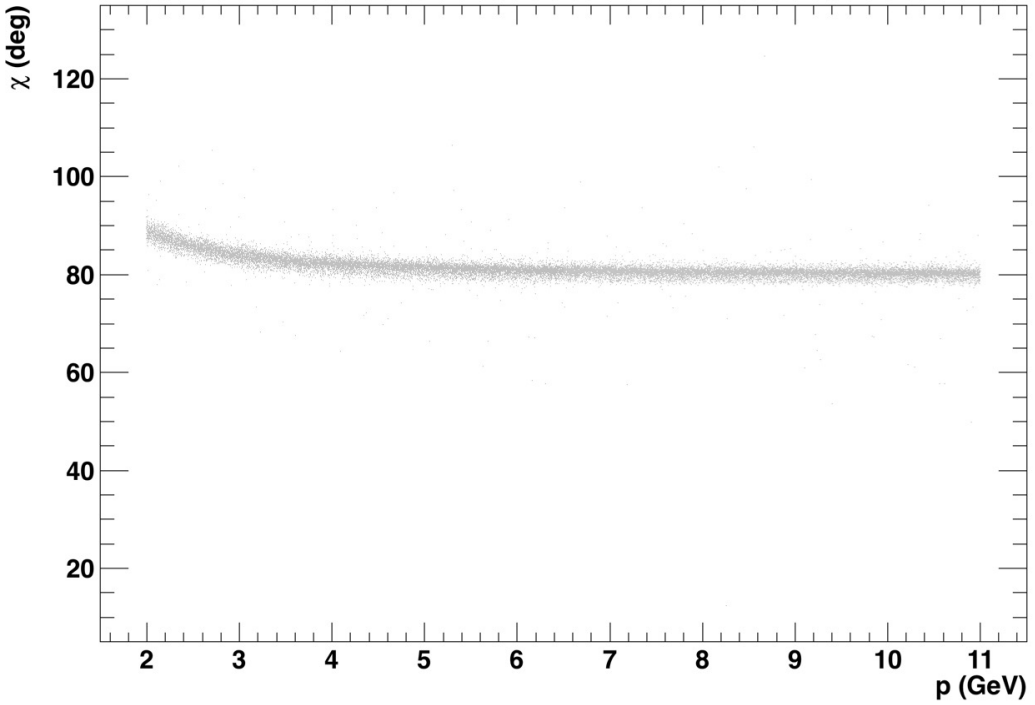


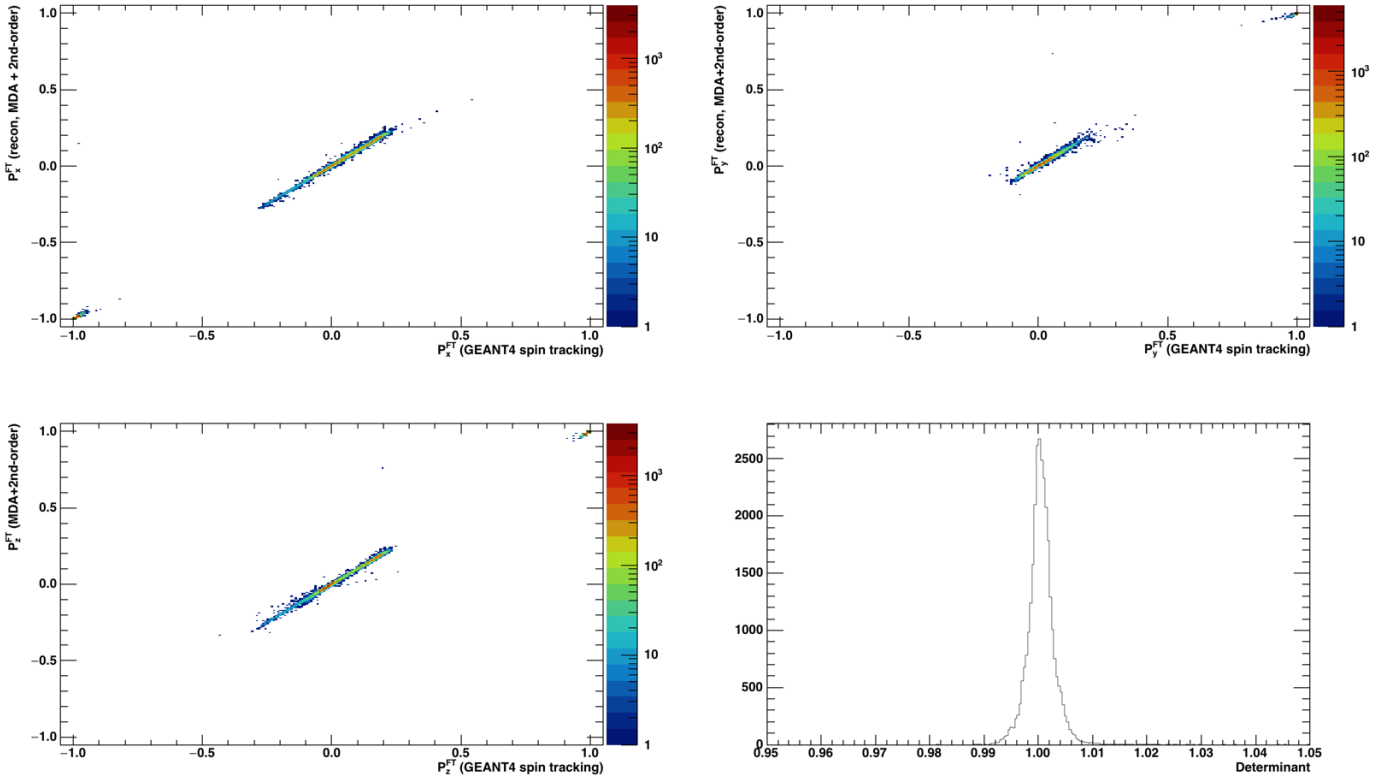




- Elastically scattered electron energy varies from $3.7\ GeV \leq E' \leq 6\ GeV$ within the acceptance
- Need software machinery to gain-match PMTs such that elastic electron signals are constant at the input to trigger summing electronics
- Trigger logic robust with overlap, threshold ~85% of elastic signal
- Still need coincidence with HCAL to achieve manageable DAQ rate

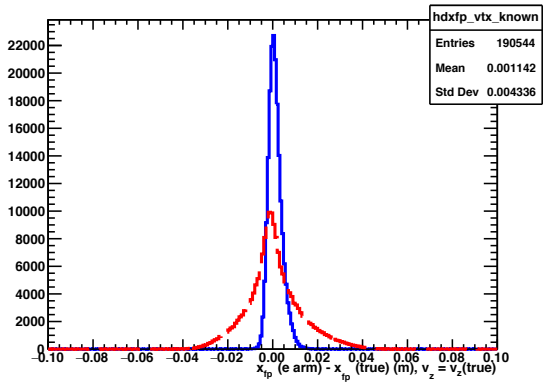
GEP Software Considerations—Spin Transport

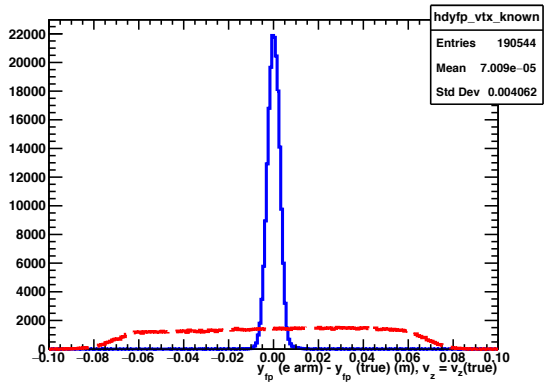


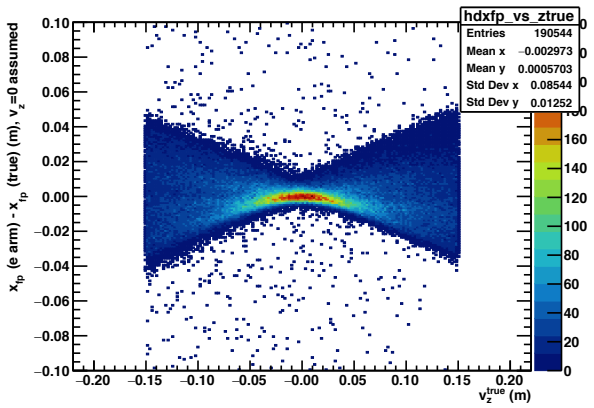


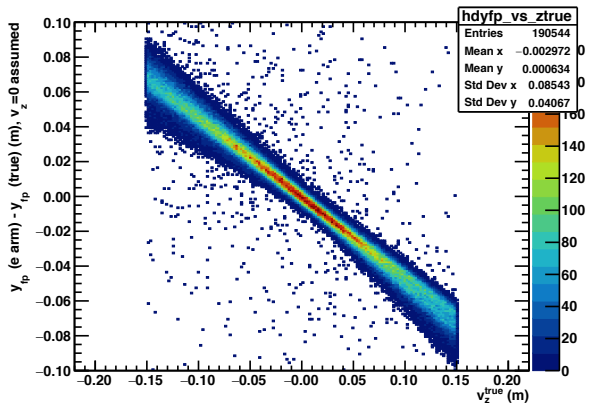
- Precession angle $\chi = \gamma \kappa_p \theta_{bend}$ is roughly constant within the acceptance, since $\gamma \propto p_p$ and $\theta_{bend} \propto \frac{1}{p_p}$
- GEANT4 spin tracking through TOSCA-generated SBS field map
- Fit low-order polynomial expansions of spin rotation matrix elements, compare to GEANT4 spin tracking, calculate determinant of fitted rotation matrix → better would be to implement unitarity constraint w/e.g. Lagrange multipliers?

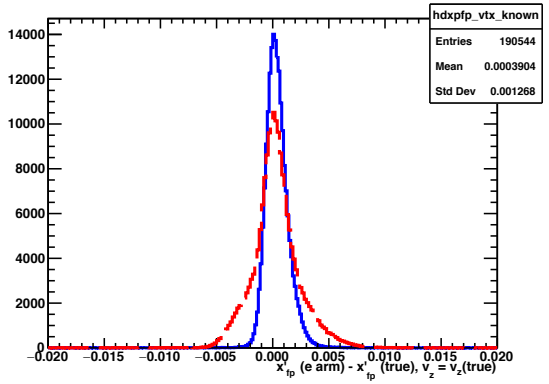
GEP Software Considerations—Electron Arm Reconstruction and FT search region calculation

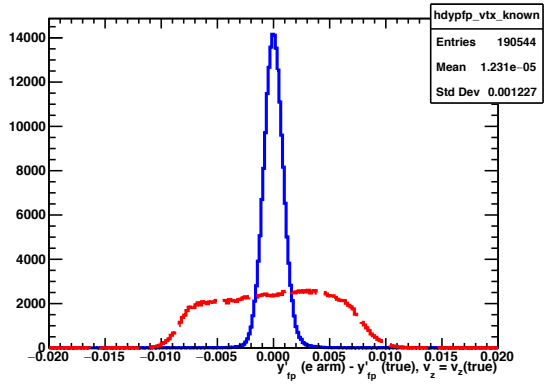


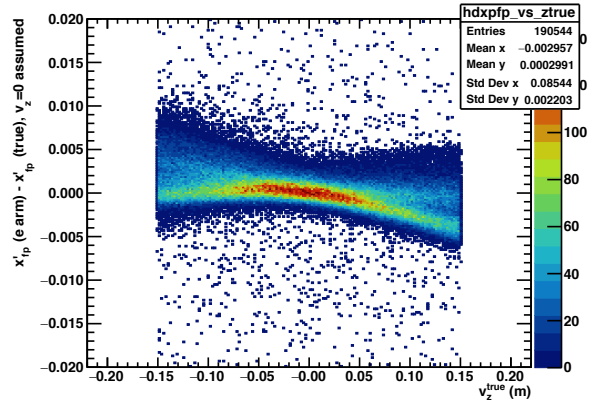


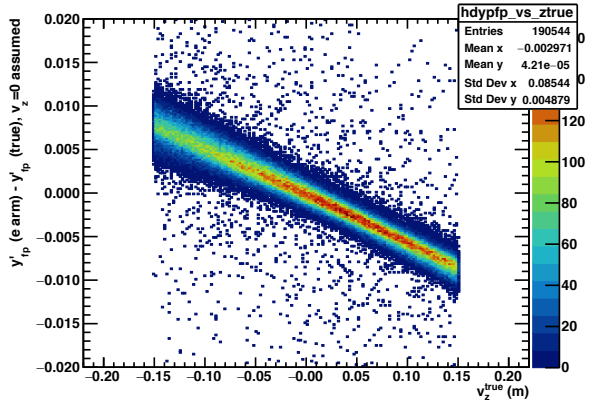










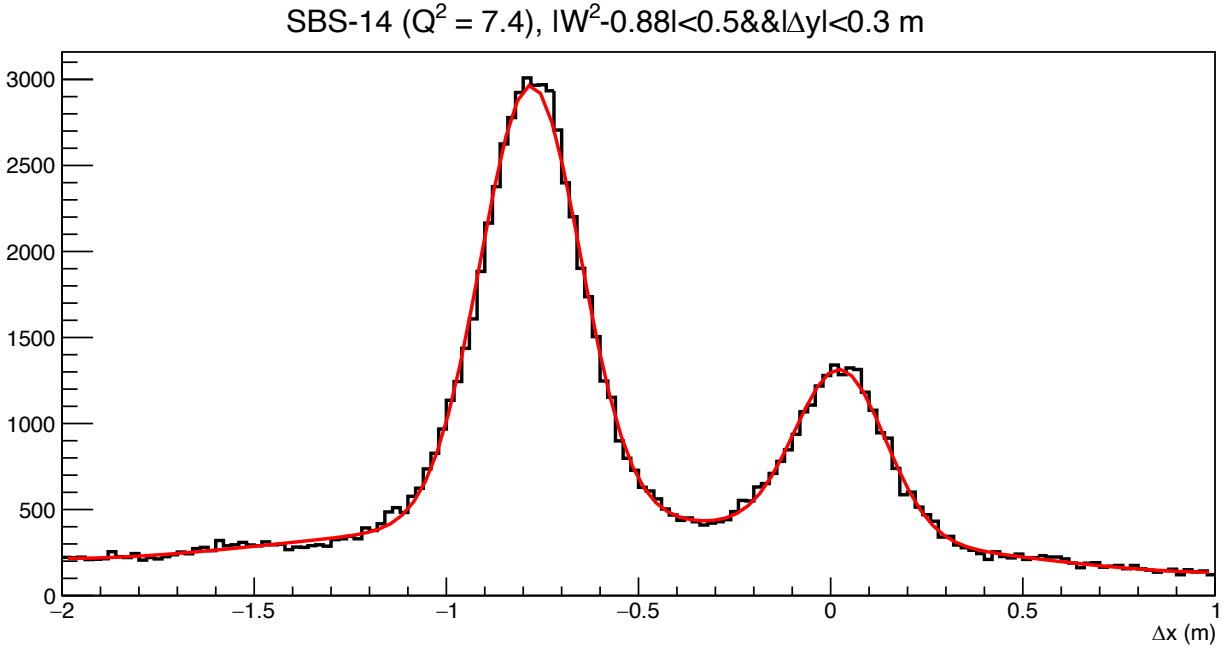


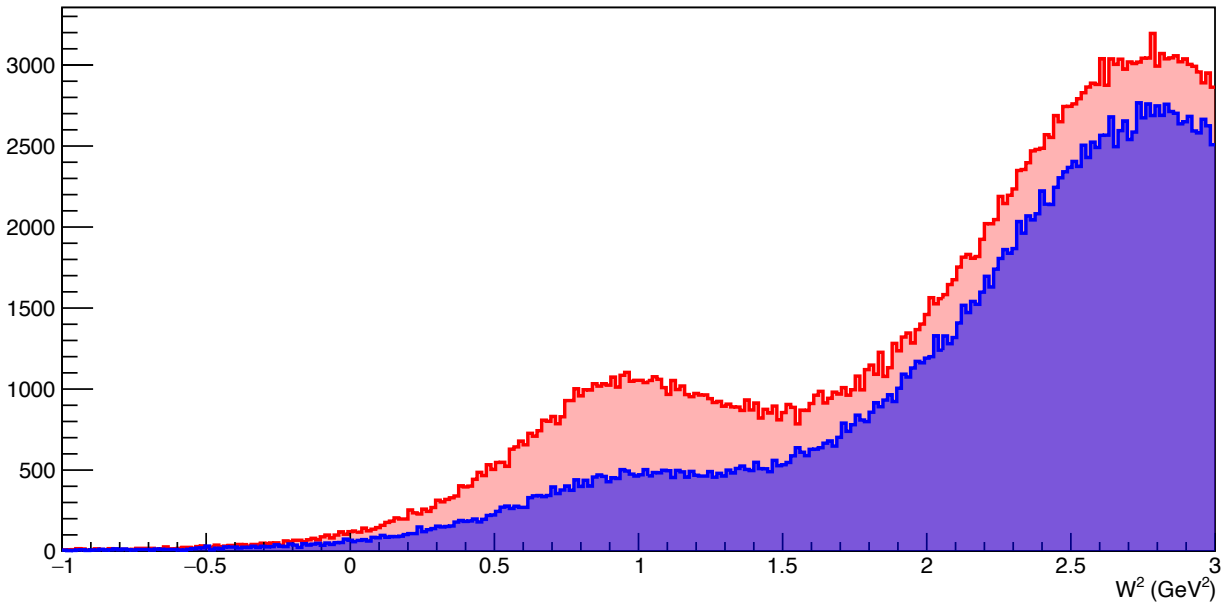
- Challenge: ECAL + CDET give precise coordinate/azimuthal angle determination but no vertex information!
- If you *know* the vertex location, the *ep* → *ep* kinematics are determined very precisely by ECAL+CDET
- GEP tracking strategy: scan assumed vertex along target length, calculate expected FT 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

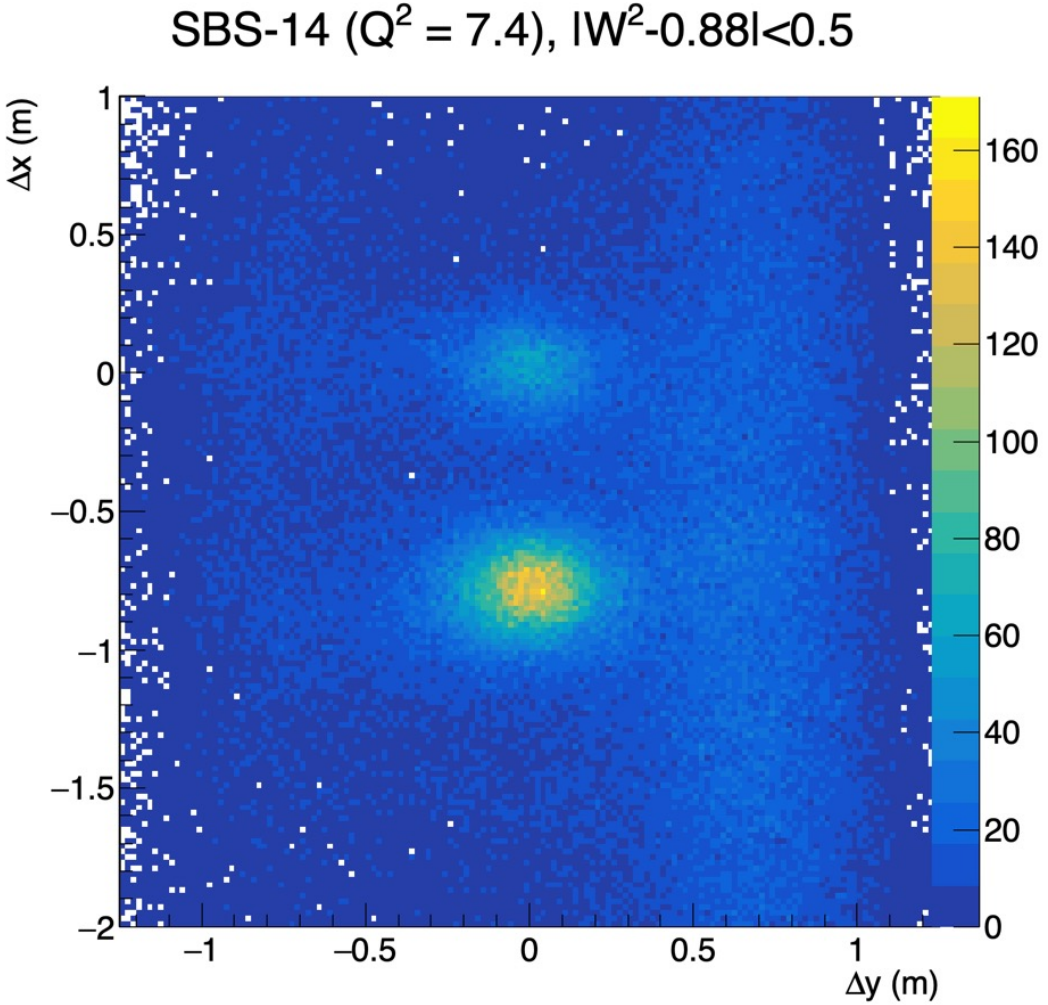
Summary and Conclusions

- 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

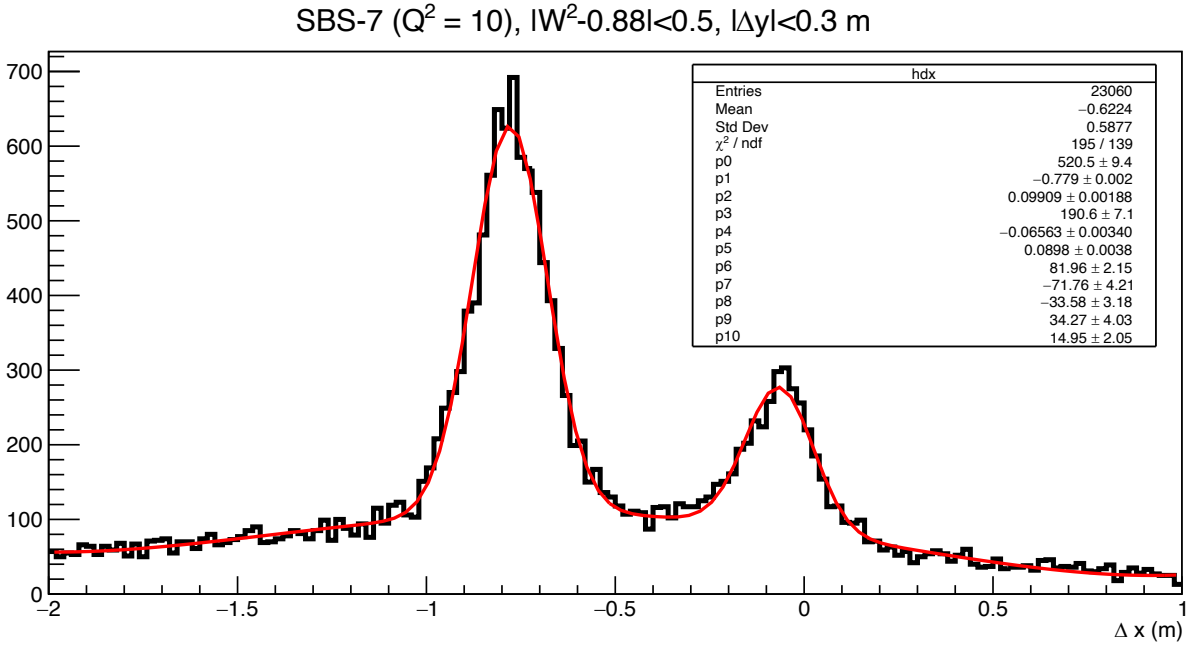
Backups

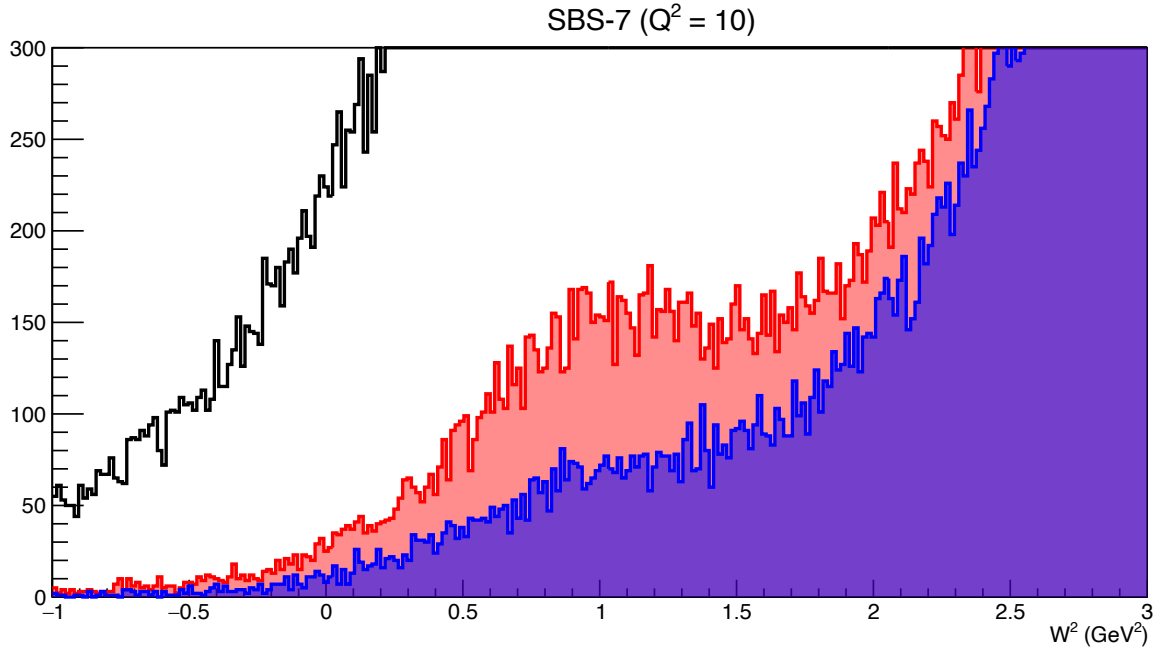


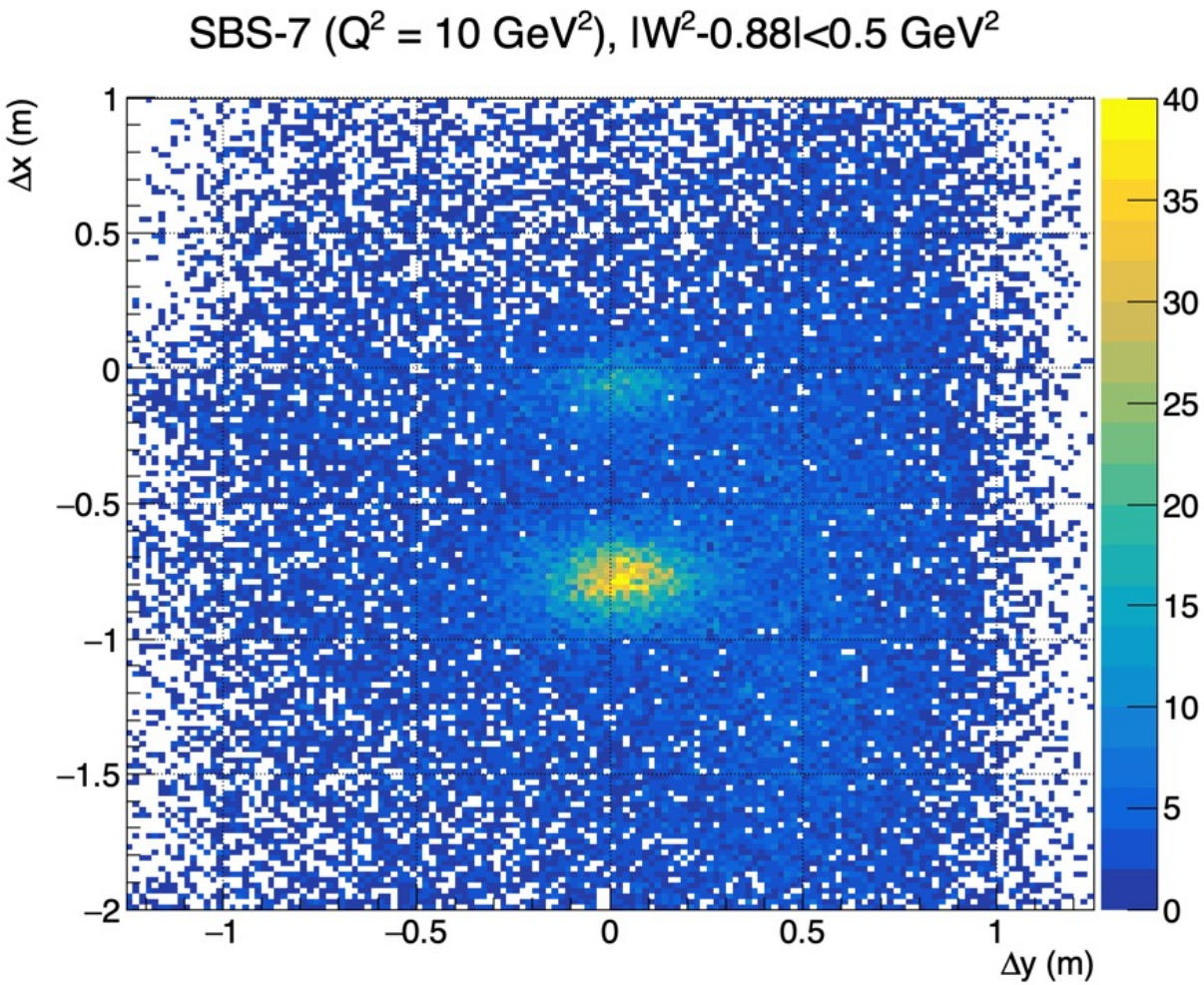




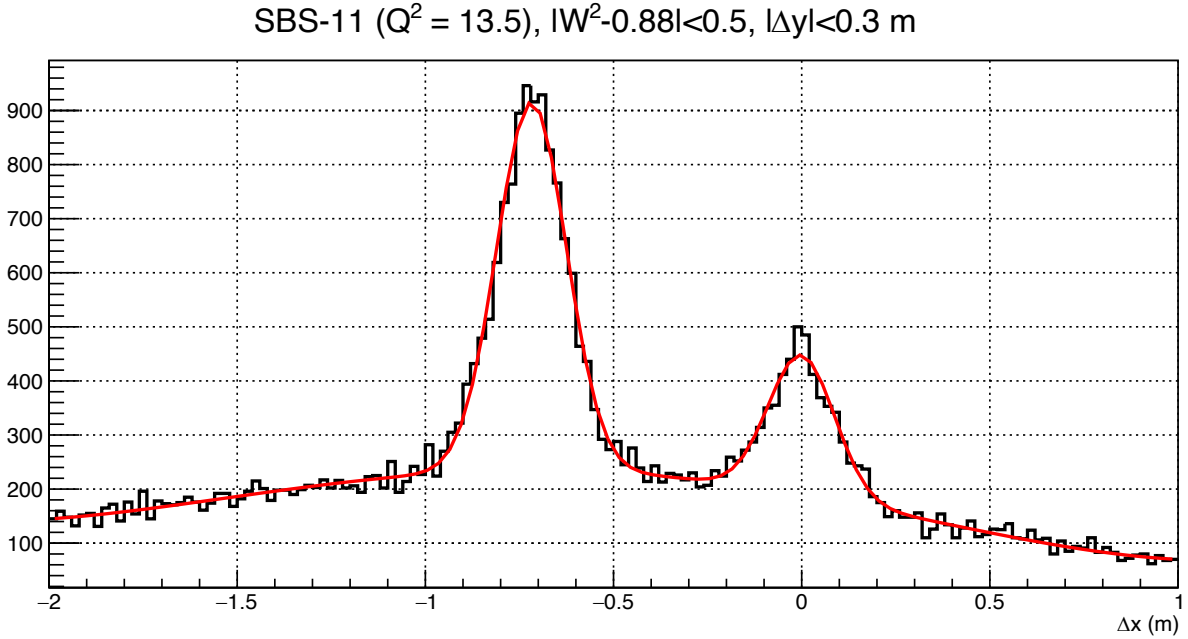
- SBS-14 (Q^2 = 7.4 GeV^2): ”deltax” (top left), “dx vs dy” (top right), W^2 (bottom left):
- **Proton cut (thetapq < 0.025 under proton hypothesis)**
- **Neutron cut (thetapq < 0.025 under neutron hypothesis)**

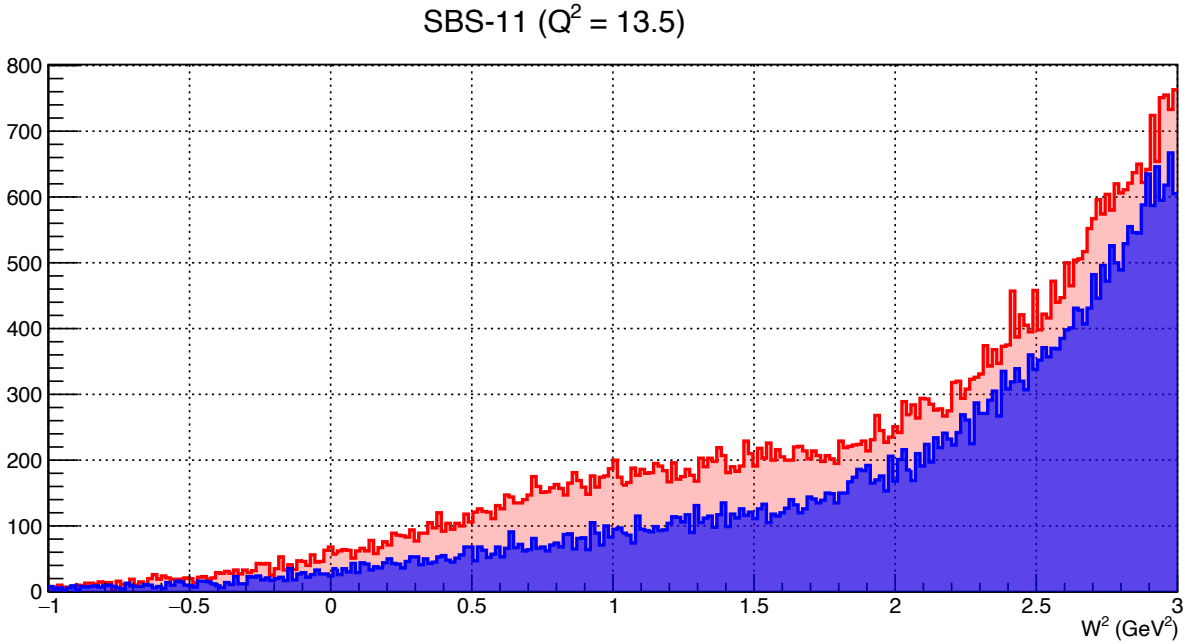


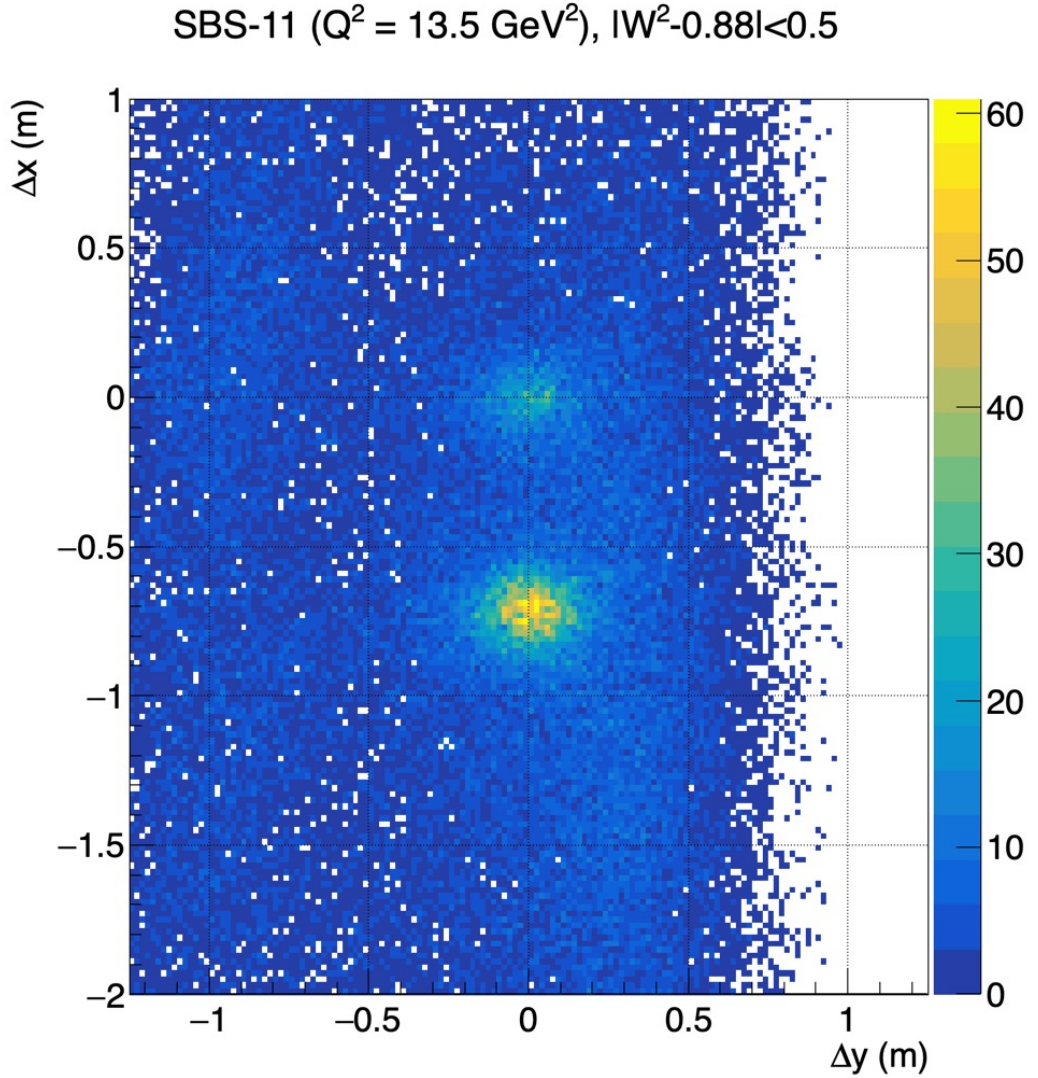




- SBS-7 (Q^2 = 10 GeV^2): ”deltax” (top left), “dx vs dy” (top right), W^2 (bottom left):
- **Proton cut (thetapq < 0.02 under proton hypothesis)**
- **Neutron cut (thetapq < 0.02 under neutron hypothesis)**







- 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)