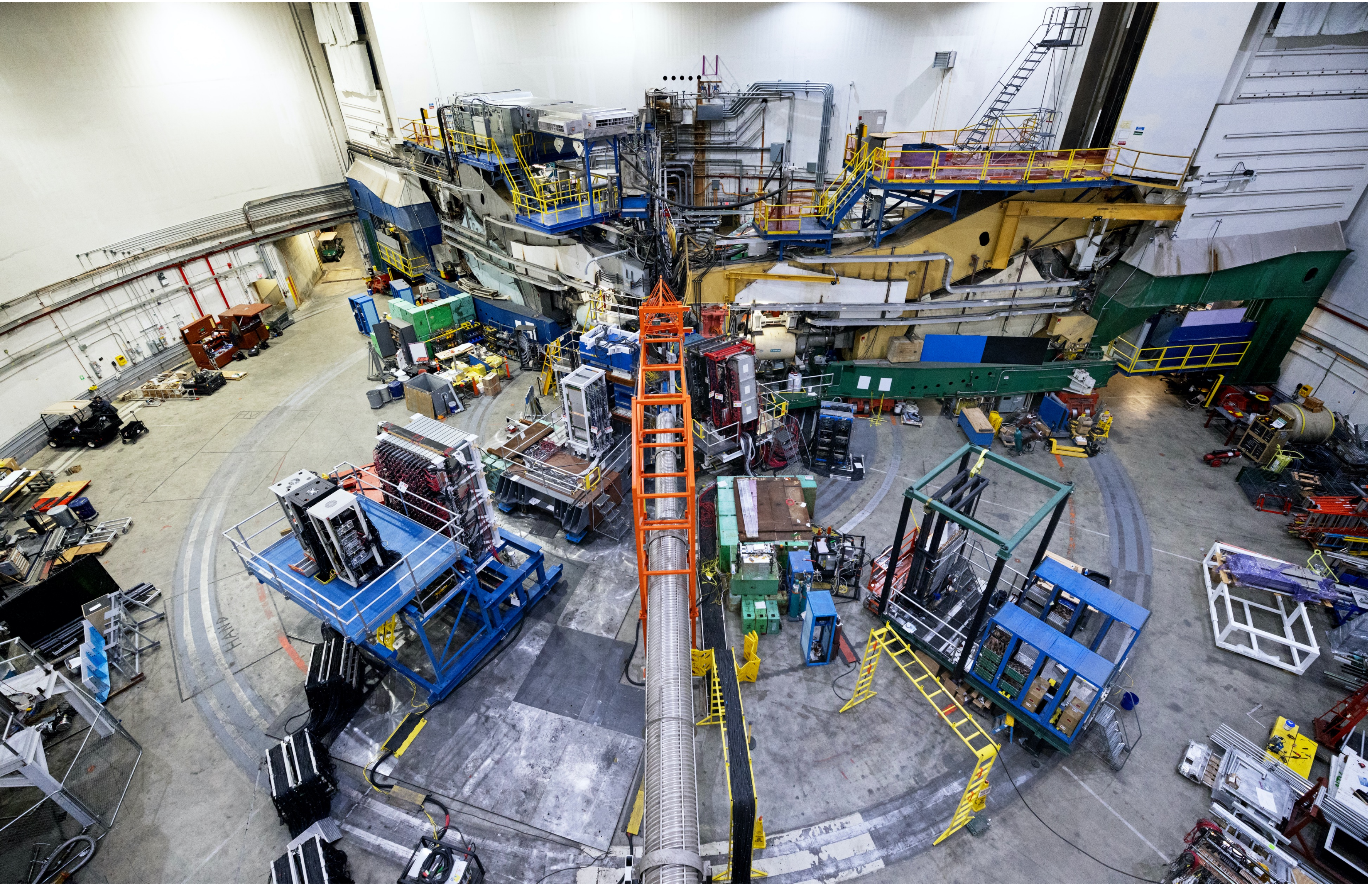
“SBS Results”

Andrew Puckett
University of Connecticut

UCONN

Outline

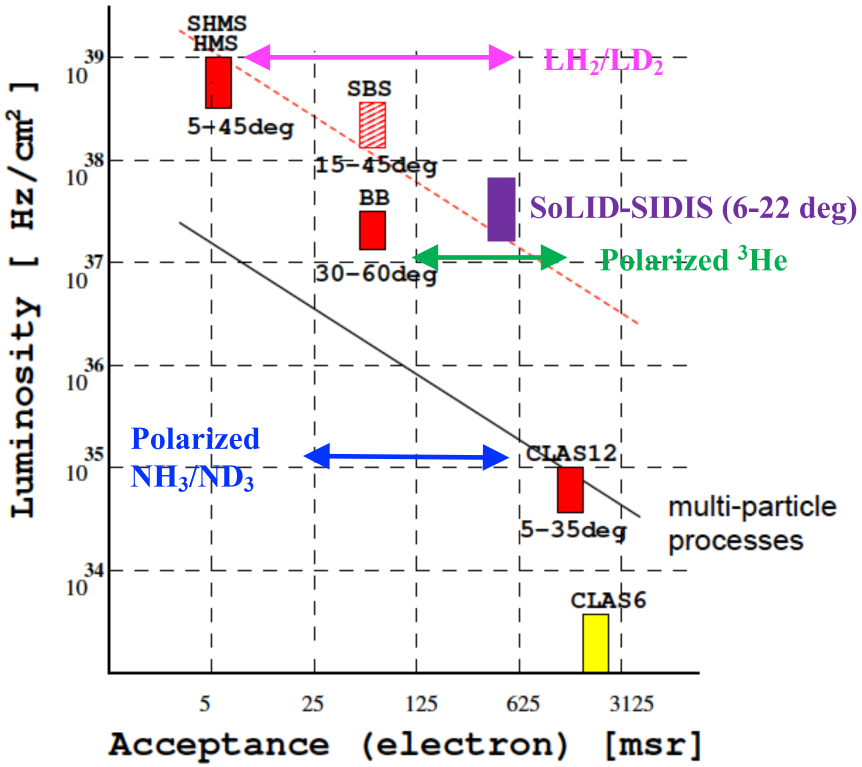


- Overview of SBS physics program
- Overview of SBS apparatus
- Status of completed experiment analyses:
  - GMN/nTPE
  - GEN (Helium-3)
  - GEN-RP/Pion-K_{LL}
- Upcoming experiments
- Summary/conclusions

Acknowledgements

- This work supported in part by DOE Office of Science, Office of Nuclear Physics, award DE-SC0021200
- SBS Collaboration
- Materials/photos/analysis in this talk provided by:
  - Arun Tadepalli, Mark Jones, Bogdan Wojtsekhowski, Robin Wines, Eric Fuchey, Gordon Cates, David Hamilton, etc.
  - GMN analysis results/plots provided by GMN/nTPE thesis students: Provakar Datta, Sebastian Seeds, Anuruddha Rathnayake, Maria Satnik, Zeke Wertz, John Boyd *et al.*
  - GEN analysis results/plots from GEN thesis students: Faraz Chahili Kate Evans, Jack Jackson, Sean Jeffas, Gary Penman, Hunter Presley, *et al.*
- Too many others to name…

JLab detector landscape



A range of 10^4 in luminosity.

A big range in solid angle:
from 5 msr (SHMS)
to about 1000 msr (CLAS12).
========================

The SBS is in the middle:
for solid angle (up to 70 msr)
and high luminosity capability.

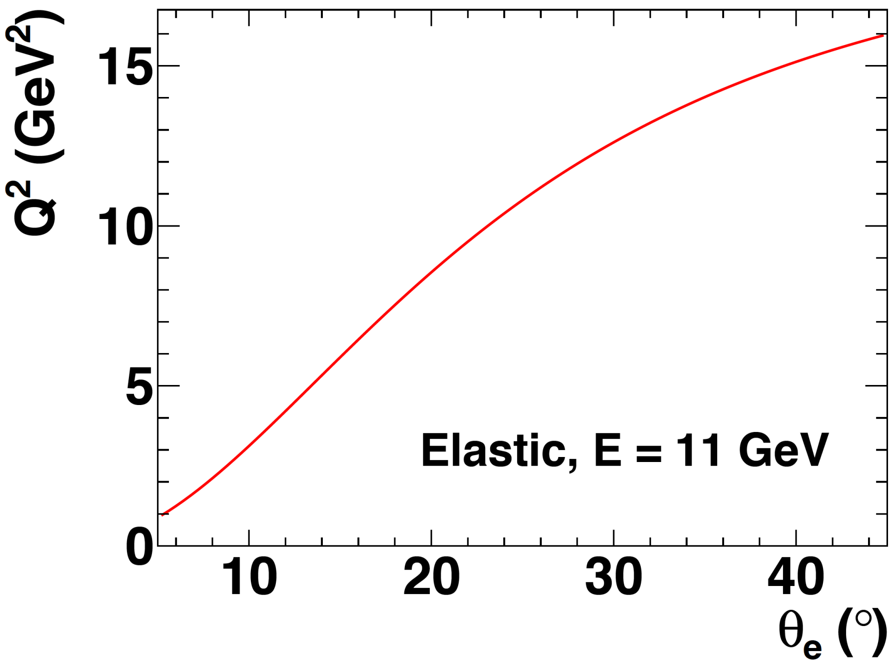
In several A-rated experiments SBS was found to be the best match to the physics.

GEM allows a spectrometer with open geometry (->large acceptance) at high L.

11/16/15 Super Bigbite Spectrometer Review slide 9

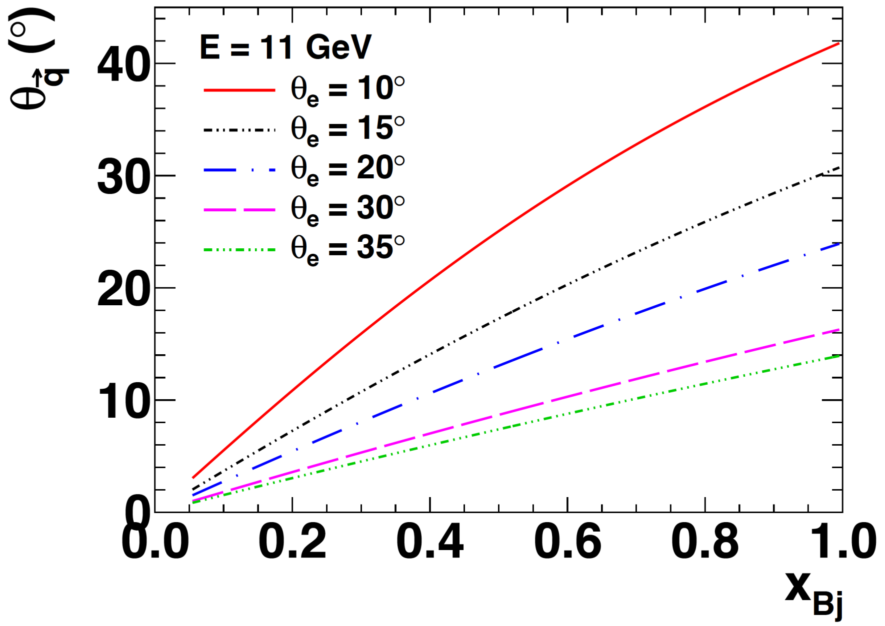
- Complementary equipment/capabilities of Halls A, B, C allow optimal matching of (Luminosity x Acceptance) of the detectors to the luminosity capabilities of the targets, including state-of-the-art polarized target technology.

Toward high-Q^2: Fixed-target Electron Scattering Kinematics @11 GeV



- Measurements of high-Q^2 elastic FFs, SIDIS, DVCS, etc involve two-arm coincidence N(e,e'X) (electroproduction) reactions, where X =
  - N' (elastic or quasi-elastic)
  - h (SIDIS or DVMP)
  - γ (DVCS) (nucleon reconstructed via missing mass technique)
- Virtual photon angle decreases as "inelasticity" and Q^2 increase:

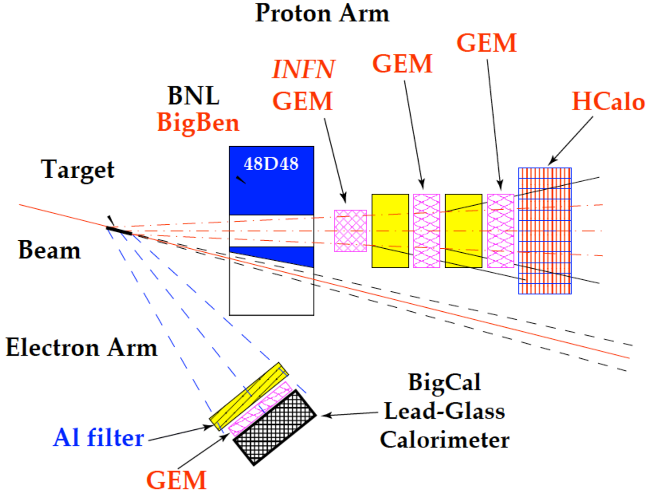
$$Q^2 = 2M\nu x_{Bj}$$

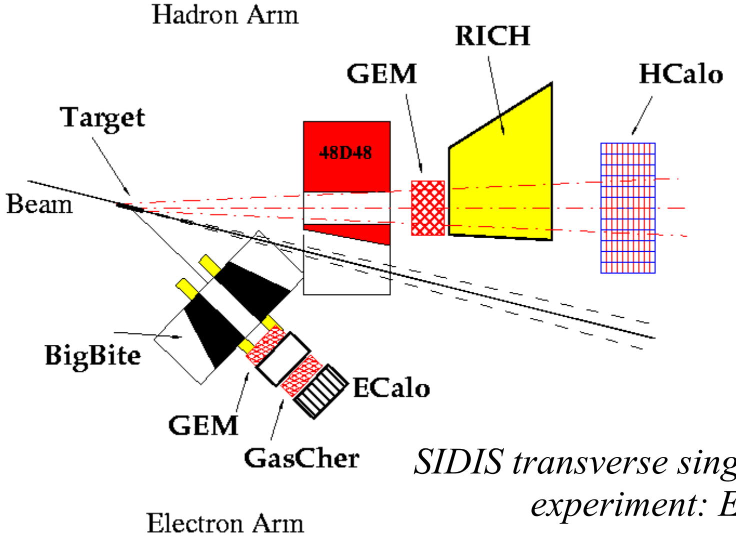


- Final-state particles associated with the struck parton in a hard lepton-nucleus collision are found predominantly near the direction of the momentum transfer **q**
- ***Partonic interpretation of electron scattering data is accessible at large Q^2 → particles of interest are located at forward angles and high momentum***

The Super BigBite Spectrometer in Hall A

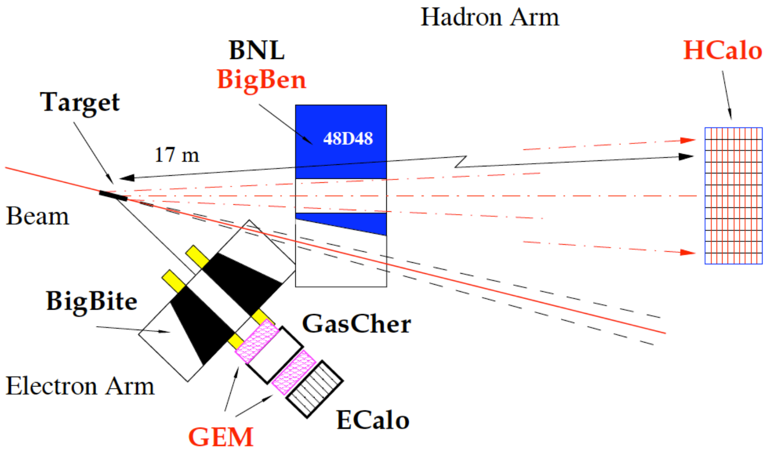
Proton form factors ratio, GEp(5) (E12-07-109)





SIDIS transverse single-spin asymmetry experiment: E12-09-018

Neutron form factors, E12–09–016 and E12–09–019



- What is SBS? → A 2.5 T*m dipole magnet with vertical bend, a cut in the yoke for passage of the beam pipe to reach forward scattering angles, and a flexible/modular configuration of detectors.
- Designed to operate at luminosities up to 10^{39} cm^{-2} s^{-1} with large momentum bite, moderate solid angle
- Time-tested "Detectors behind a dipole magnet", two-arm coincidence approach—historically most productive in fixed-target expts.
- Study large-momentum transfer exclusive and semi-inclusive reactions in electron-nucleus scattering
- ***Large solid-angle + high luminosity @ forward angles = most interesting physics!***

Overview of SBS Program—Actual and Potential

Fully Approved:

- E12-07-109 (GEP): 45 PAC days, A- rate, "High Impact"—status: **Scheduled 2025**
  - PR12-24-010 (GEP+): 2 PAC days, A- rate
- E12-09-019 (GMN): 25 PAC days, B+ rate ✓
  - nTPE (E12-20-010): 2 PAC days, A- rate ✓
- E12-09-016 (GEN): 50 PAC days, A- rate ✓
- E12-09-018 (SIDIS): 64 PAC days, A- rate
- E12-17-004 (GEN-RP): 5 PAC days, A- rate ✓
- E12-20-008 (K_{LL} in $\vec{\gamma} n \rightarrow \pi^- \vec{p}$): 2 PAC days, B+ rate ✓
- ✓ = completed

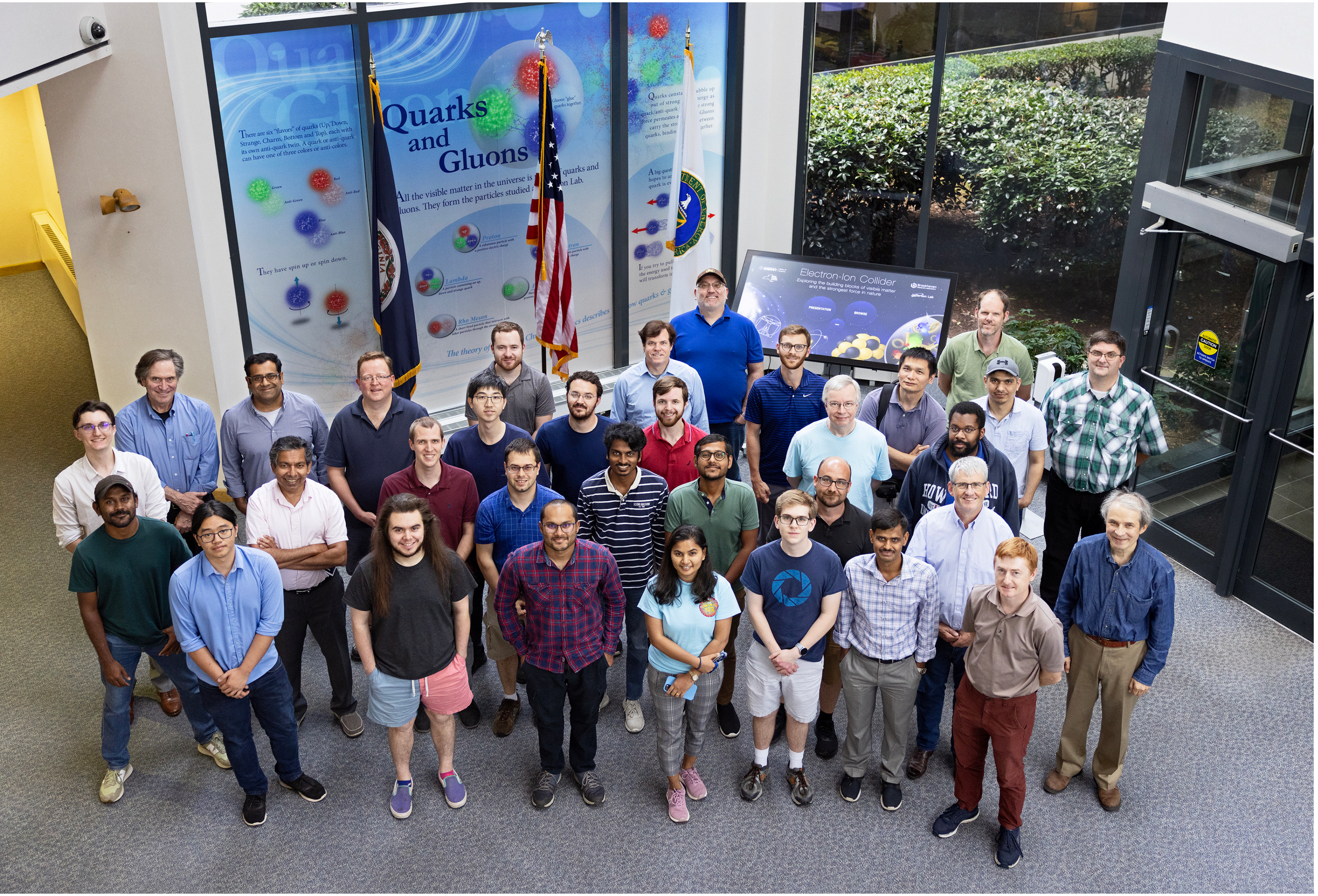
Conditionally Approved:

- C12-15-006 (TDIS): 27 PAC days, A- rate; "C1" approval status
  - "Run-group" add-on of kaon structure measurement also C1 approved

Potential future physics using SBS:

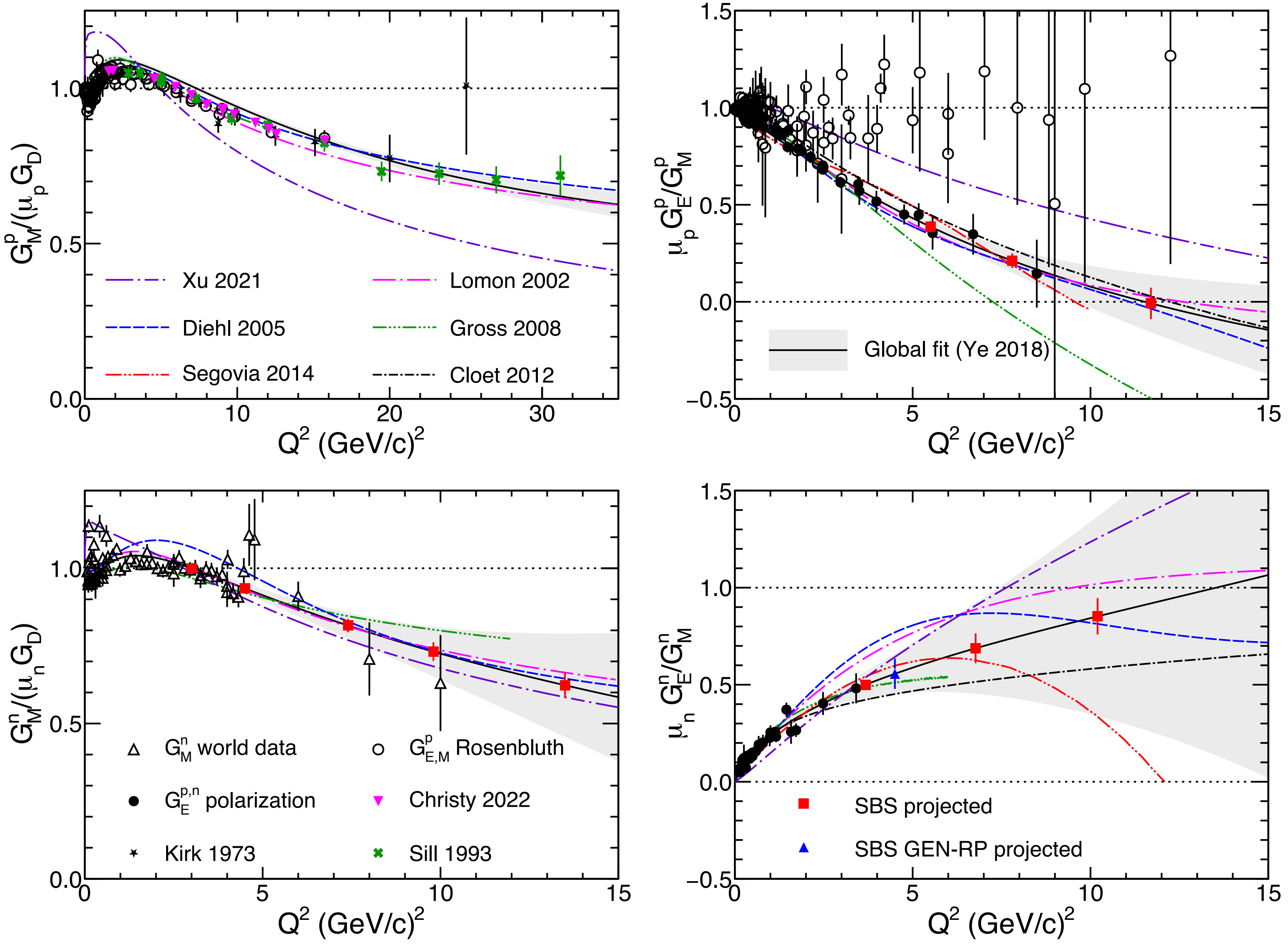
- See Bogdan's talk here
- A_1^n: formerly an approved BigBite experiment (2006), withdrawn at jeopardy (2019) due to imminent Hall C run, new proposal with BB+SBS likely (pending Hall C results)
- J/ψ photoproduction polarization observables/LHCb pentaquark physics: LOI submitted 2017… need observation of pentaquark in photoproduction at JLab energy…
- e^+p elastic scattering polarization transfer—part of science program for positron beam at CEBAF in LOI, now published in special issue of EPJ A 57, 188 (2021): https://doi.org/10.1140/epja/s10050-021-00509-5
- More DIS/SIDIS/TMD physics:
  - Longitudinally polarized SIDIS on ^{3}He and spin-flavor decomposition (deferred PR12-14-008)
  - Transversely polarized DIS/SIDIS on proton: g_2^p, Collins, Sivers, etc.
- Polarization observables and xsec in exclusive ϕ production
- Strange FFs at high Q^2 (not really an "SBS" proposal *per se*, but re-using some SBS components)
- Higher-Q^2 EMFFs/higher-x physics w/future CEBAF energy upgrade?

The SBS Collaboration (Photo from July 2023 Collab. Meeting at JLab)



- Approximately 100 members from 20+ institutions, including, but not limited to:
  - UConn
  - UVA
  - W&M
  - JLab
  - Glasgow U
  - Hampton U
  - U. Mass Amherst
  - CNU
  - Carnegie Mellon
  - Northern Michigan U
  - INFN Rome
  - Virginia Tech
  - LBNL
  - Syracuse
  - Ohio U
  - Others…
- NOTE: this photo only shows ~1/4th of our active members!

The SBS high-Q^2 Form Factor Program in Hall A



- Figure from "50 Years of QCD" (EPJ C 83, 1125 (2023)): https://inspirehep.net/literature/2617065
- GMN/nTPE (E12-09-019/E12-20-010) using "ratio" method on deuterium: **Completed Oct. 2021-Feb. 2022**
- GEN Helium-3: **Completed Oct. 2022-Oct. 2023)**
- GEN-RP: **Completed April-May, 2024**
- GEP: Projected run 2025
- Except for G_M^n, all SBS form factor measurements are based on polarization observables.
  - Small elastic cross sections and asymmetries require as large as possible FOM (= Luminosity × Polarization^2 × Acceptance)

Statistics requirements: asymmetries vs. cross section measurements

Cross sections:

$$\sigma \propto N$$

$$\Longrightarrow \frac{\Delta\sigma}{\sigma} = \frac{1}{\sqrt{N}}$$

To measure a cross section with a relative statistical precision of 1%, you need 10,000 events.

Asymmetries:

$$\Delta A = \sqrt{\frac{1-A^2}{N}}$$

$$\frac{\Delta A}{A} = \sqrt{\frac{1-A^2}{NA^2}}$$

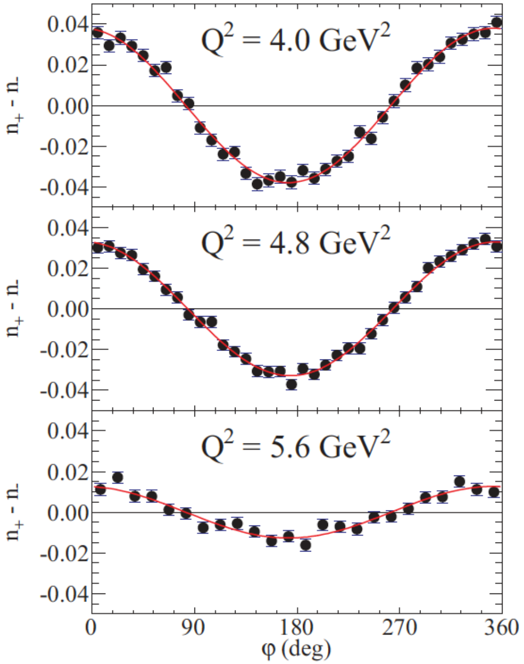


FIG. 6. (Color online) Focal-plane helicity-difference asymmetry $n_+ - n_- \equiv (N_{\text{bins}}/2)[N^+(\varphi)/N_0^+ - N^-(\varphi)/N_0^-]$, where N_{bins} is the number of φ bins and $N^\pm(\varphi)$, $N_0^\pm$ are defined as in Eq. (4), for the three highest Q^2 points from GEp-II. Curves are fits to the data. See text for details.

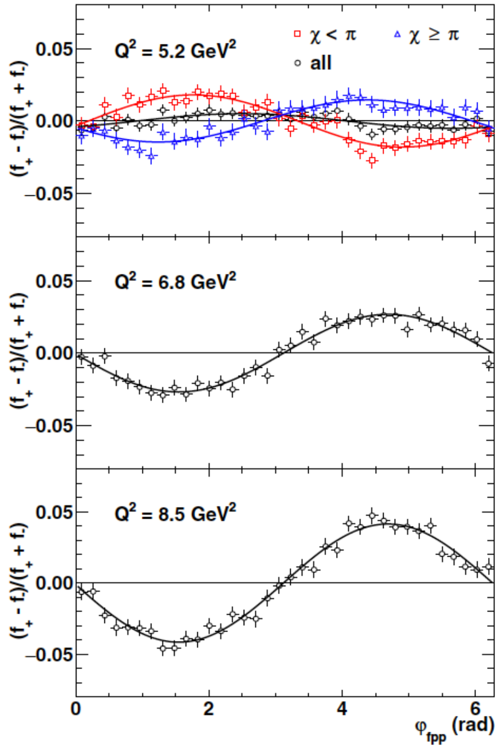
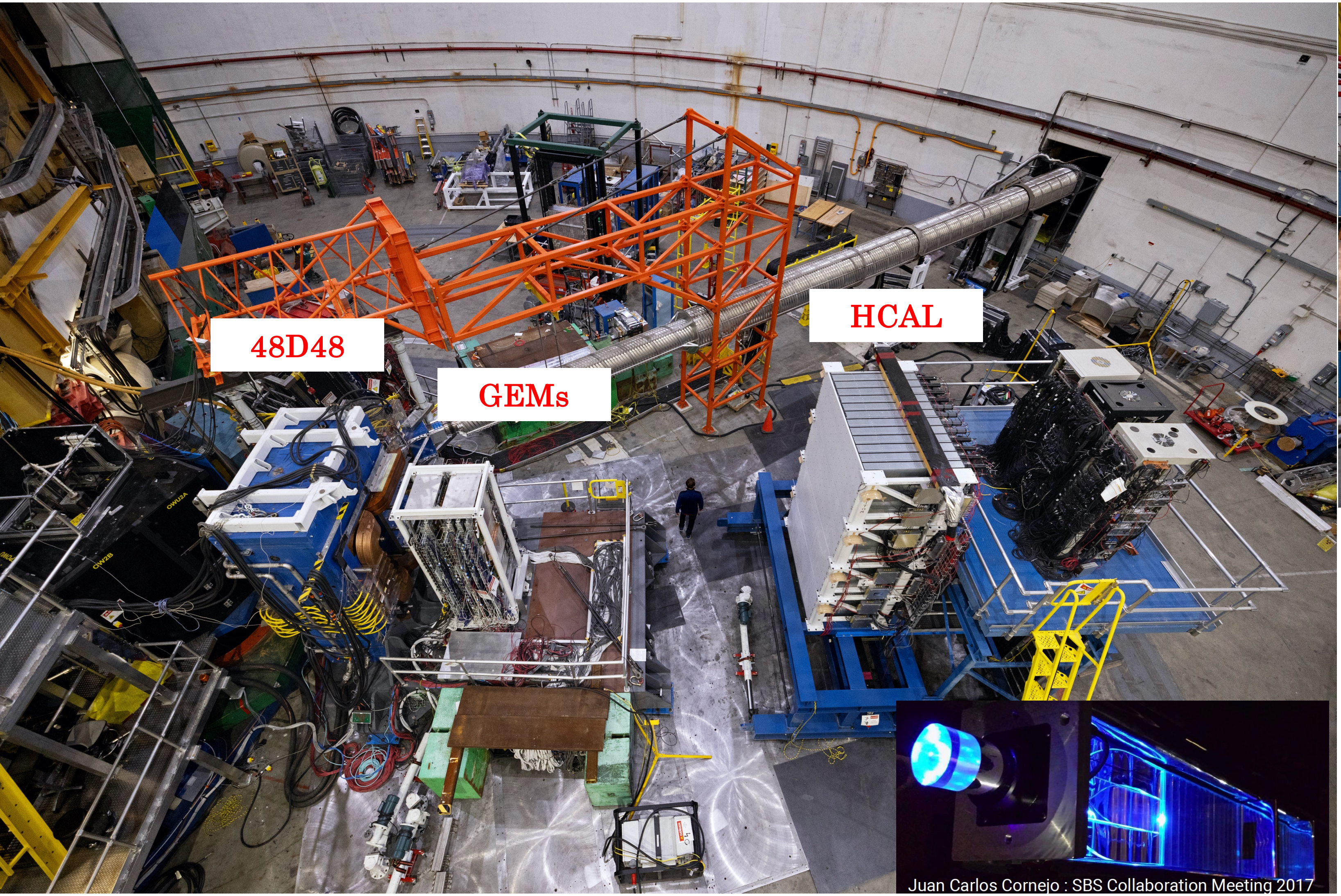


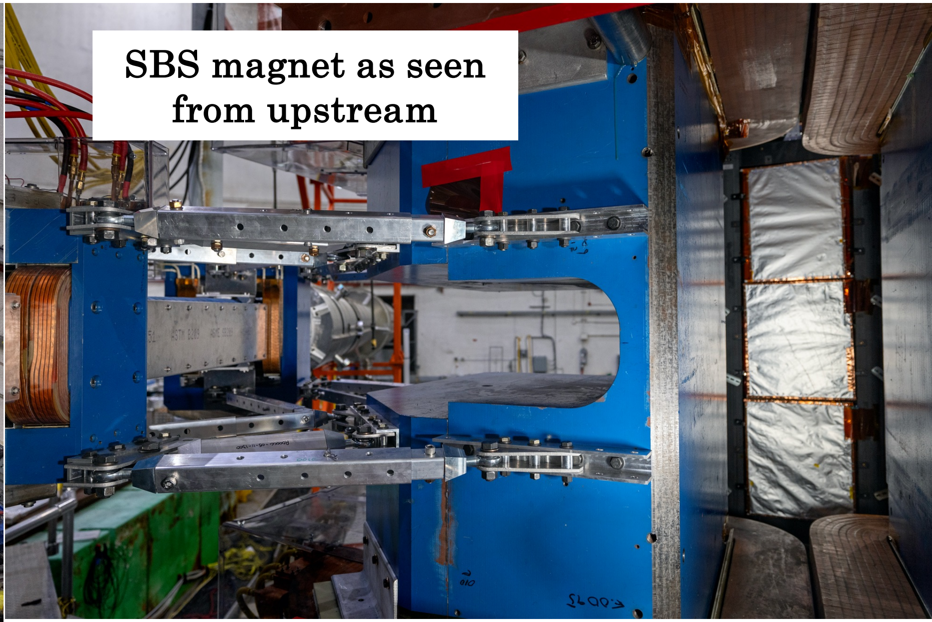
FIG. 10. Focal plane helicity difference/sum ratio asymmetry $(f_+ - f_-)/(f_+ + f_-)$, defined as in Eq. (20), for the GEp-III kinematics, for FPP1 and FPP2 data combined, for single-track events selected according to the criteria discussed in Sec. III B 2. Asymmetry fit results are shown in Table V. The asymmetry at $Q^2 = 5.2$ GeV^2 is also shown separately for events with precession angles $\chi < \pi$ and $\chi \geqslant \pi$, illustrating the expected sign change of the sin(φ) term.

- Example: Typical asymmetry magnitude in a recoil proton polarimeter at "high" momentum is ~few percent.
- To measure a 5% asymmetry with a relative precision of 1%, one needs $N = 10{,}000 \times \frac{1-A^2}{A^2} \approx 4\times10^6$ events!

→ Asymmetry measurement must maximize beam and/or target polarization, and luminosity × acceptance!

SBS Apparatus, I: Hadron Arm

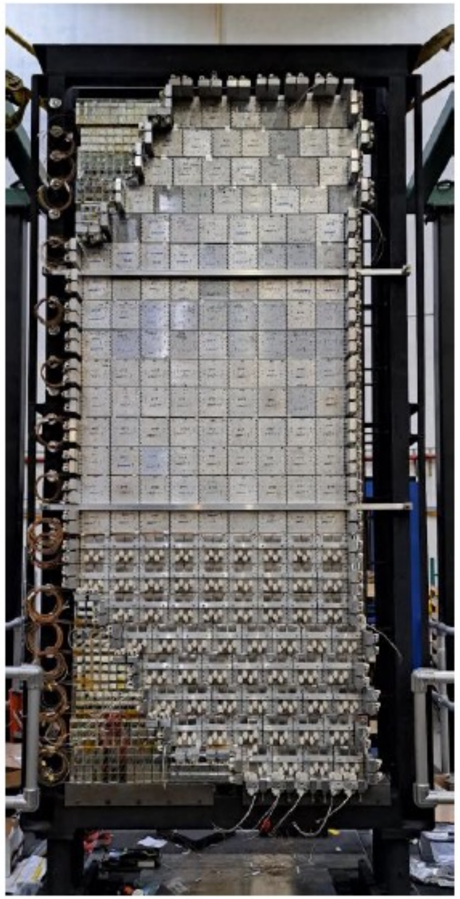




Common to ALL SBS experiments:

- 48D48 magnet: dipole with a cut in iron yoke for passage of the beam → reach forward scattering angles
- Hadron Calorimeter (HCAL) → efficient detector for high-energy hadrons (protons, neutrons, pions, etc)
- Gas Electron Multipliers (GEMs) → high-rate charged-particle tracking

SBS Apparatus, II: Electron Arm

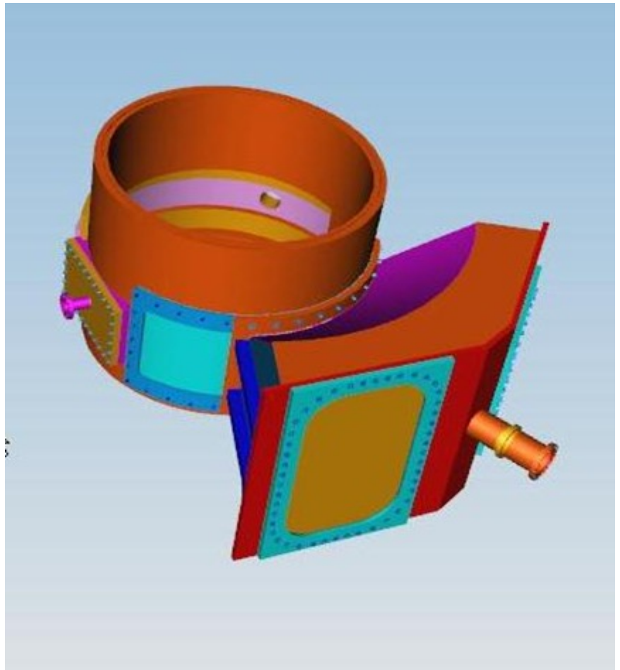


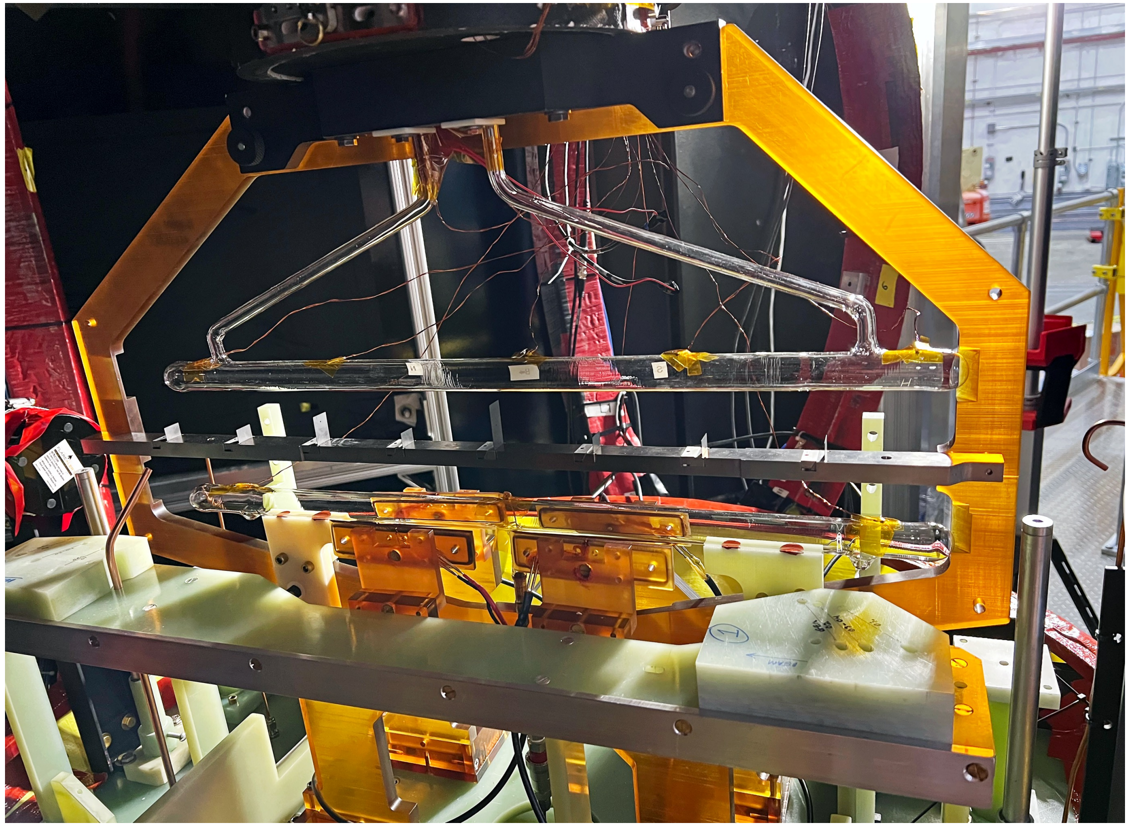
ECal Front view.
All Supermodules
(1700 blocks) installed.
Installing heaters

ECal Rear view.

- Left: BigBite Spectrometer (neutron FFs, SIDIS, A_1^n, …). Full spectrometer magnet/detector package optimized for electron detection
- Right: the "hot" electron calorimeter ECAL (GEP)
- Not shown: scintillator-based "Coordinate Detector" for GEP

SBS Apparatus, III: Targets

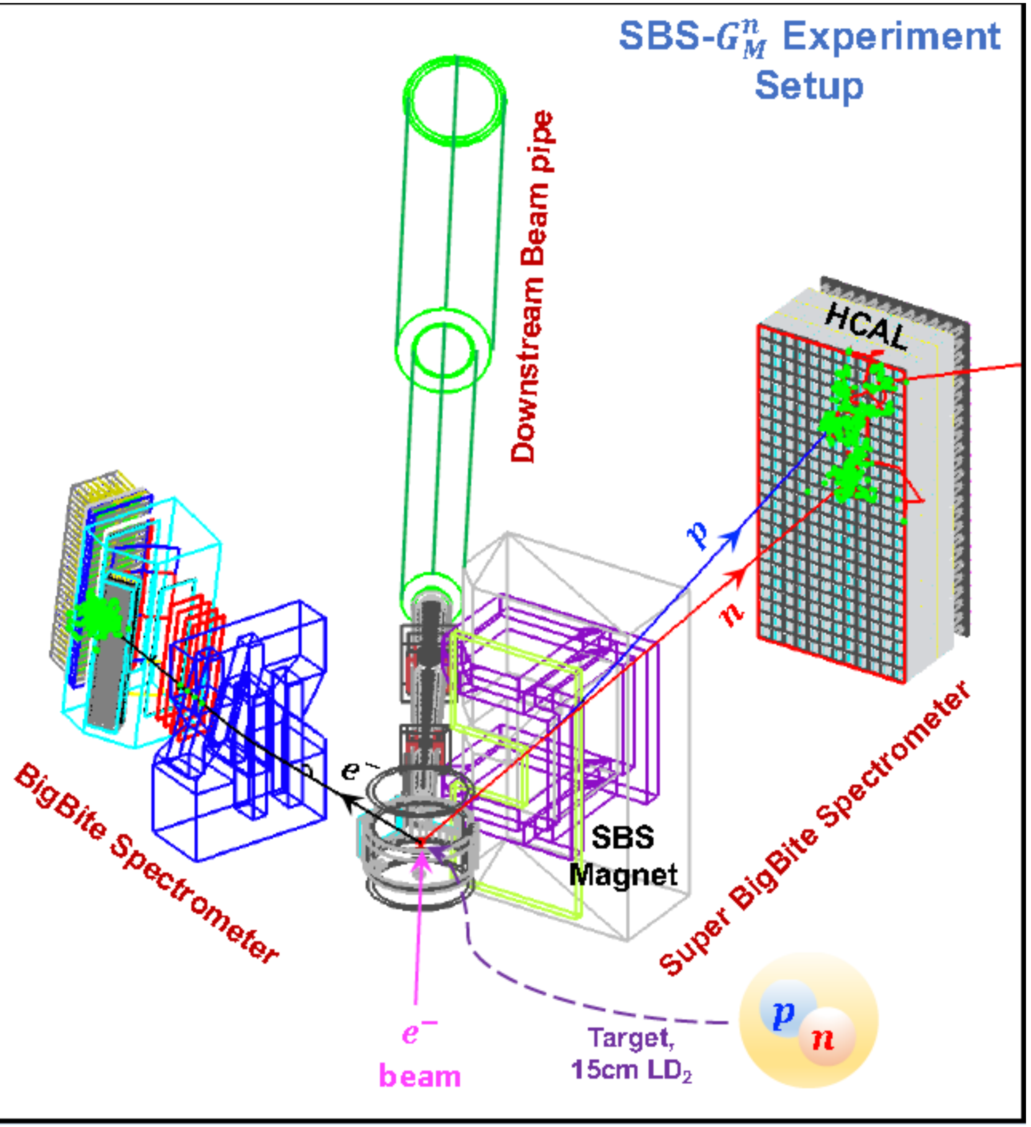


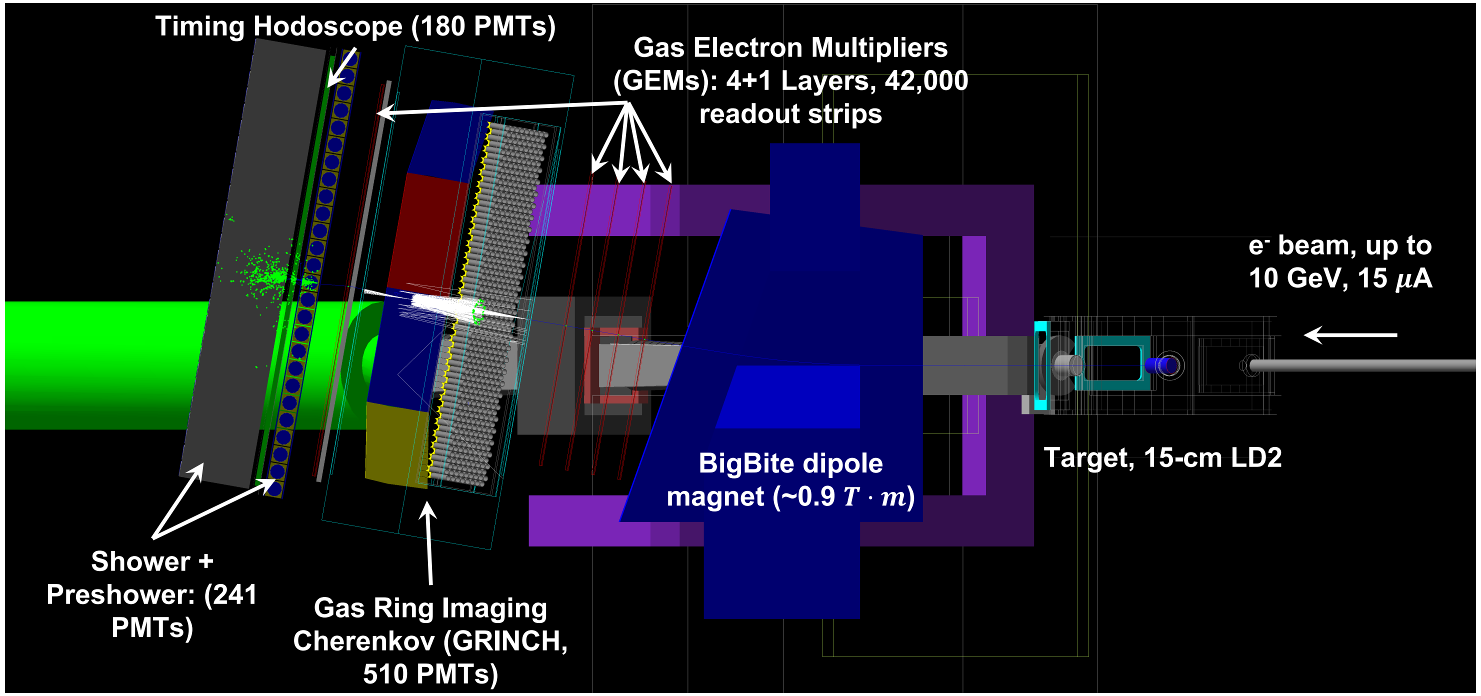


- Above: cryotarget and optics ladder for GMN/GEN-RP/Pion-KLL
- Middle: scattering chamber "vacuum snout" for GEP

- Above: Polarized Helium-3 target for GEN with optics foils/reference cell/NMR pickup coils/etc.

Experiments E12-09-019/E12-20-010 (GMN/nTPE)





- Measure cross section ratio d(e,e'n)/d(e,e'p) on liquid deuterium.
- e^- arm: BigBite with upgraded detectors for high-luminosity running
- n/p arm: SBS with HCAL
- Ran Oct. 2021-Feb. 2022

“Ratio” method for G_M^n

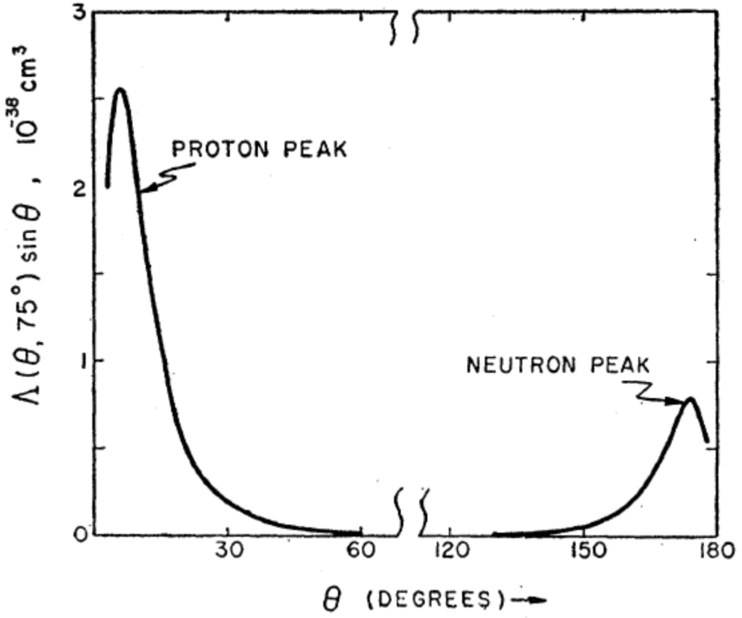


FIG. 1. The angular distribution function $\Lambda(\theta,\vartheta)\sin\theta$ in the absence of final-state interactions is plotted as a function of the proton scattering angle in the nucleon center-of-mass system $[\cos\theta=\hat{p}\cdot\hat{q}]$ for the scattering of 500-Mev electrons through an angle $\vartheta=75°$ with a momentum transfer giving $p=\frac{1}{2}q=1.3\times10^{13}$ cm^{-1}. $\Lambda(\theta,\vartheta)$ is defined in Eq. (11.2); the function $F(\theta)$ entering the definition was evaluated using a Hulthén wave function for the deuteron. The cross section $d^3\sigma/(d\theta d\Omega_e dE_e')$ is given by $(4.71\times10^5$ cm^{-1} rad^{-1} sterad^{-1} Mev$^{-1})$ $\Lambda(\theta,\vartheta)\sin\theta$. No nucleon form factors have been introduced into the results.

Figure from Durand, 1959 (Phys. Rev. 115, 1020 (1959))

- Idea: simultaneous measurement of $d(e,e'n)p$ and $d(e,e'p)n$ in quasi-elastic kinematics
- Simultaneous measurement cancels many sources of experimental systematic uncertainty (electron acceptance/detection efficiency, luminosity, detector and DAQ livetime, etc).
- Small nuclear model dependence—nuclear (and radiative) effects similar/nearly identical for (e,e’n) and (e,e’p) cross sections
- Combine with existing knowledge of free proton cross section to extract free neutron cross section
- **Major remaining source of systematic uncertainty is the relative acceptance/efficiency between protons and neutrons! → SBS-HCAL was designed to minimize this**

High-Q^2 G_M^n and quark flavor FFs

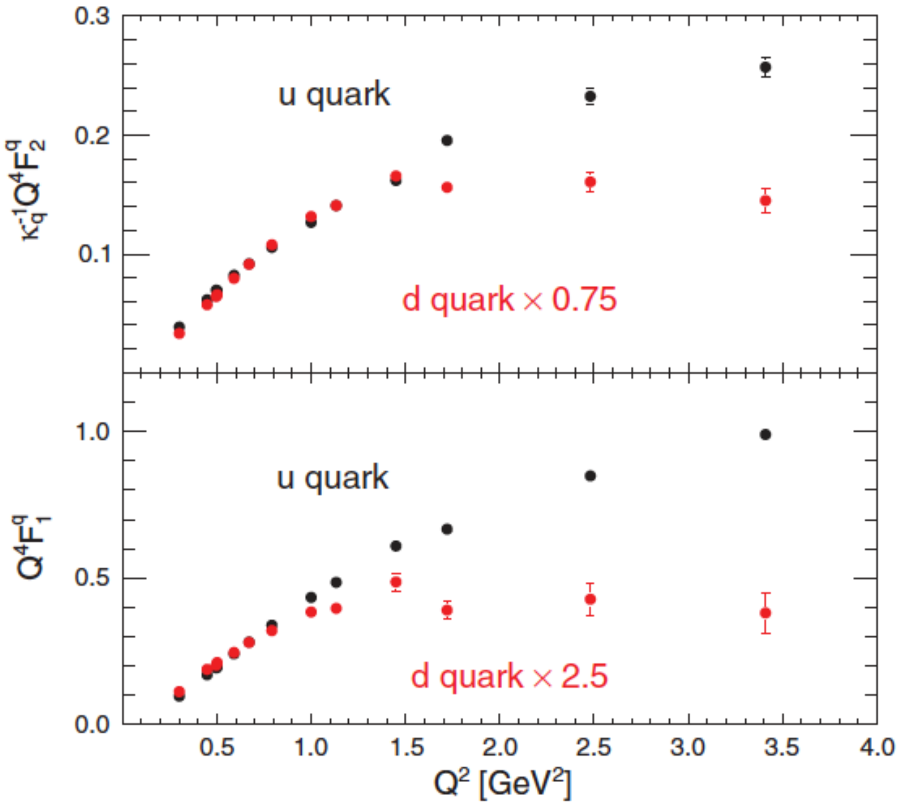
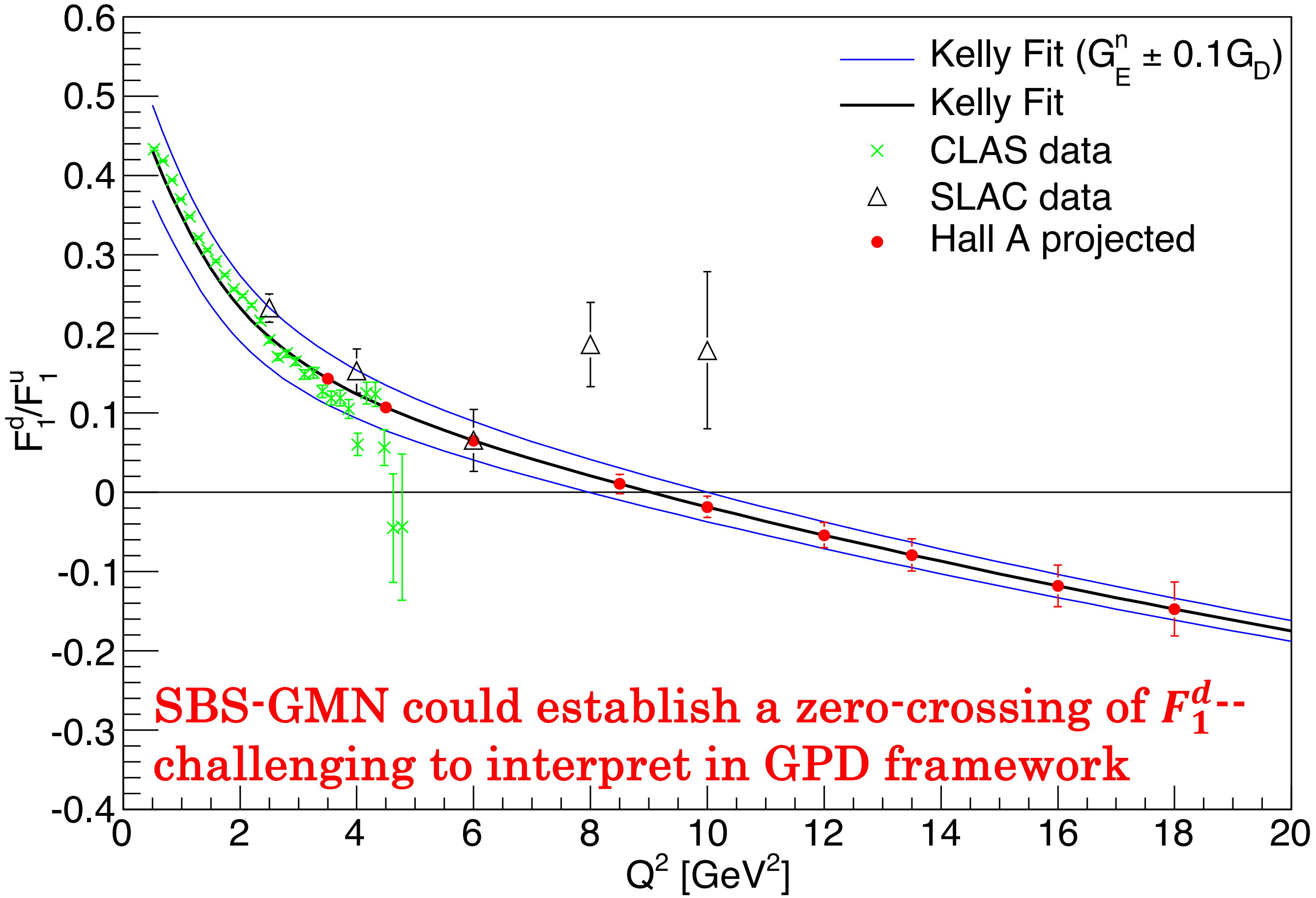


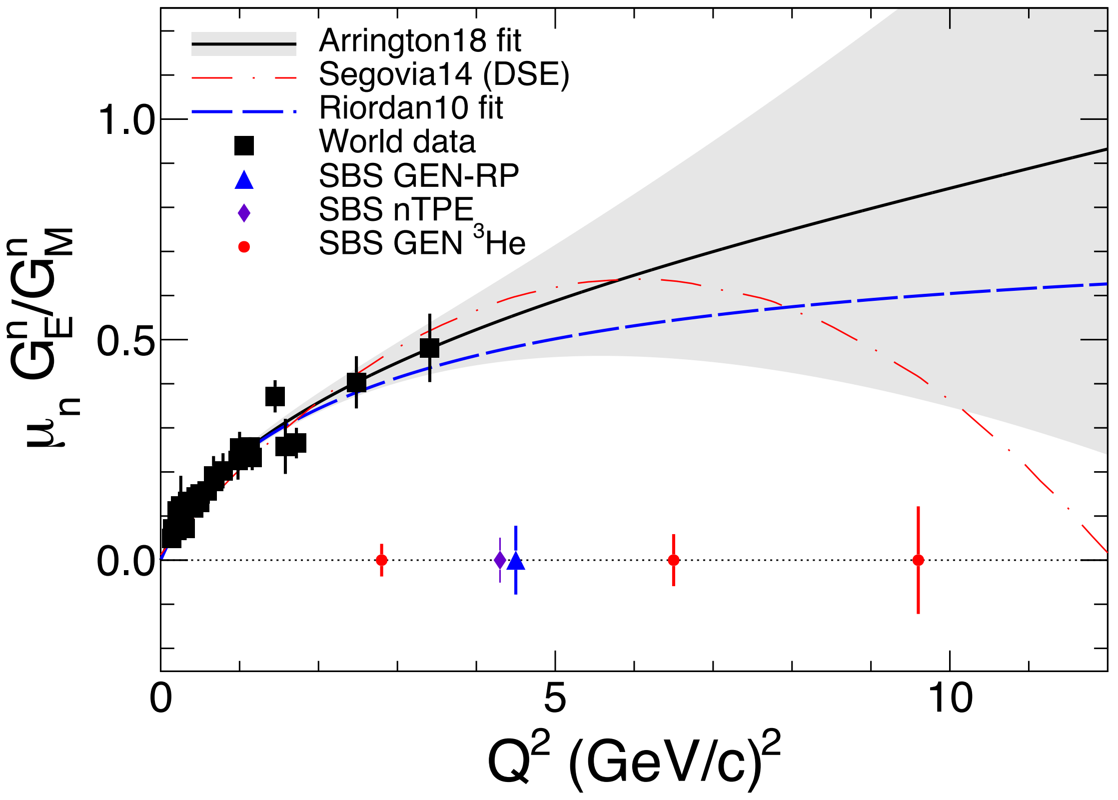
FIG. 3 (color). The Q^2 dependence for the u and d contributions to the proton form factors (multiplied by Q^4). The data points are explained in the text.

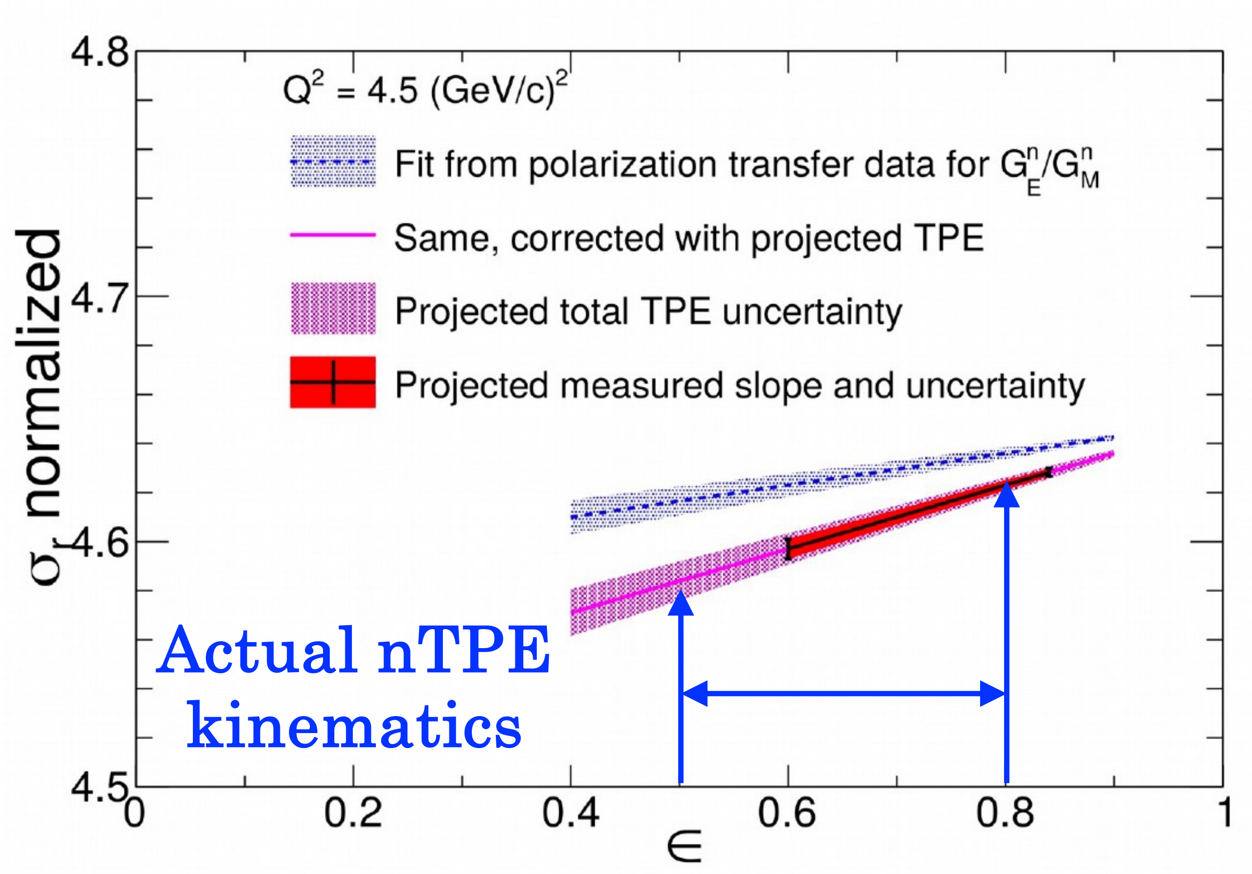
Cates *et al*., PRL 106, 252003 (2011)



- Notable behaviors: d and u quark FFs show dramatically different Q^2 dependence.
- Flavor FF ratios F_2^q/F_1^q almost constant for both u and d above 1 GeV²

nTPE experiment: Precision Rosenbluth Separation of $en \to en$





- Left: $\mu_n G_E^n/G_M^n$ world data and projected uncertainties from SBS program
- Right: projected nTPE sensitivity from proposal 12-20-010 (**Eric Fuchey contact**)
- Actual kinematics have $\Delta\epsilon \approx 0.3$, compared to 0.24 from the proposal

GMN extraction using ratio method—basic idea

- Goal is to extract σ_n/σ_p in quasi-elastic kinematics with small uncertainties.
- Nuclear and radiative effects are expected to (mostly) cancel in the ratio, especially at high Q^2
- Electron acceptance, efficiency, luminosity/etc also cancel
- Most important known sources of systematic uncertainty:
  - Relative acceptance/efficiency between neutrons and protons (if any)
  - Inelastic contamination (and other backgrounds, e.g., accidentals, fake GEM tracks/etc)
- SBS HCAL was designed to minimize n/p acceptance/efficiency difference!
  - Large acceptance
  - High (and very similar) efficiencies for p, n (by design)

$$R_{np} \equiv \frac{\sigma_{d(e,e'n)p}}{\sigma_{d(e,e'p)n}} \approx \frac{\sigma_{en\to en}}{\sigma_{ep\to ep}}$$

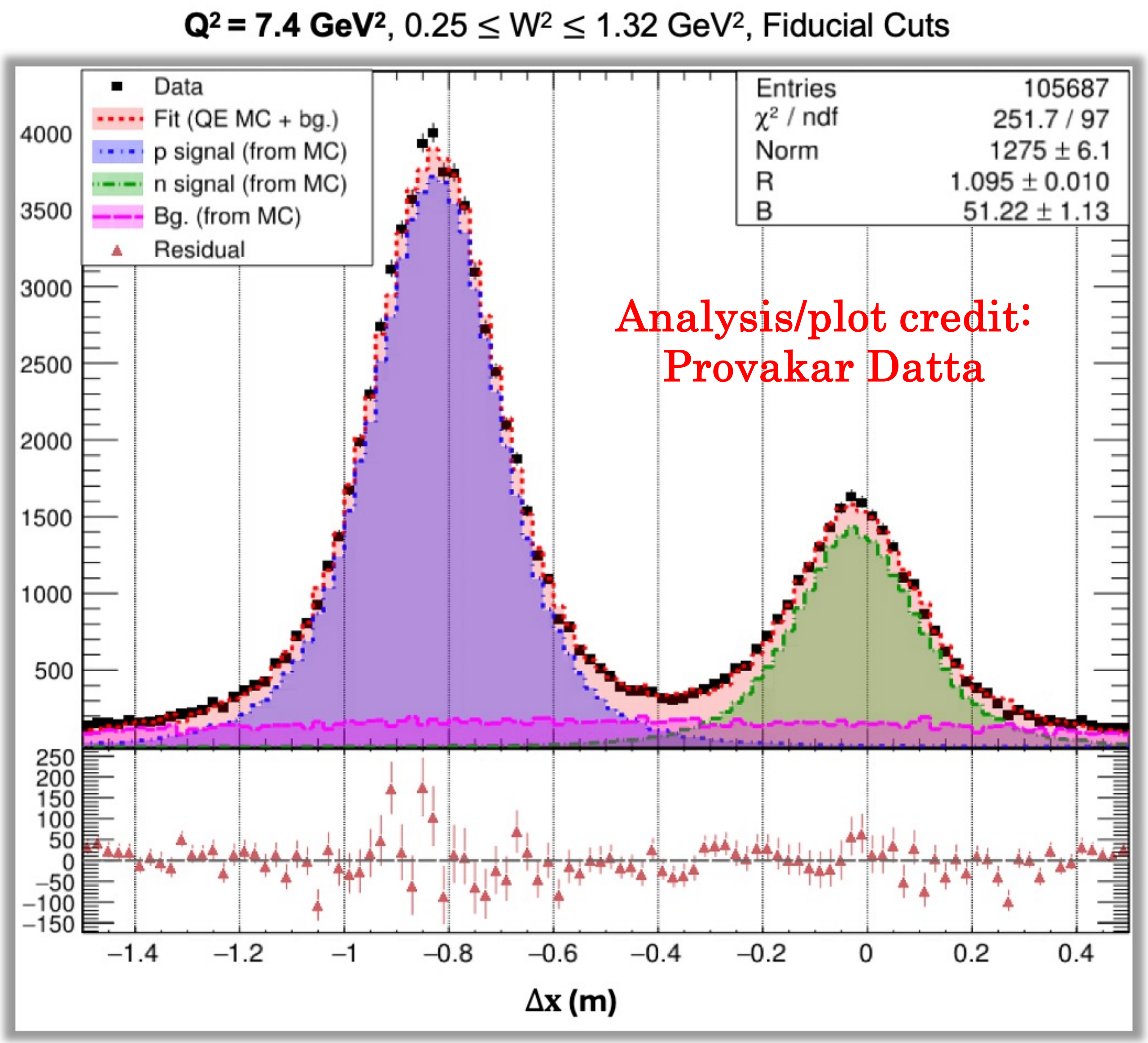
$$\approx \frac{\epsilon {G_E^n}^2 + \tau {G_M^n}^2}{\epsilon {G_E^p}^2 + \tau {G_M^p}^2}$$

$$\implies G_M^n \approx \sqrt{\frac{R_{np}\sigma_R^p - \epsilon {G_E^n}^2}{\tau}}$$

- BigBite gives $\vec{q}$ vector and interaction vertex
- Project to the surface of HCAL and compare to detected nucleon position/energy/time.

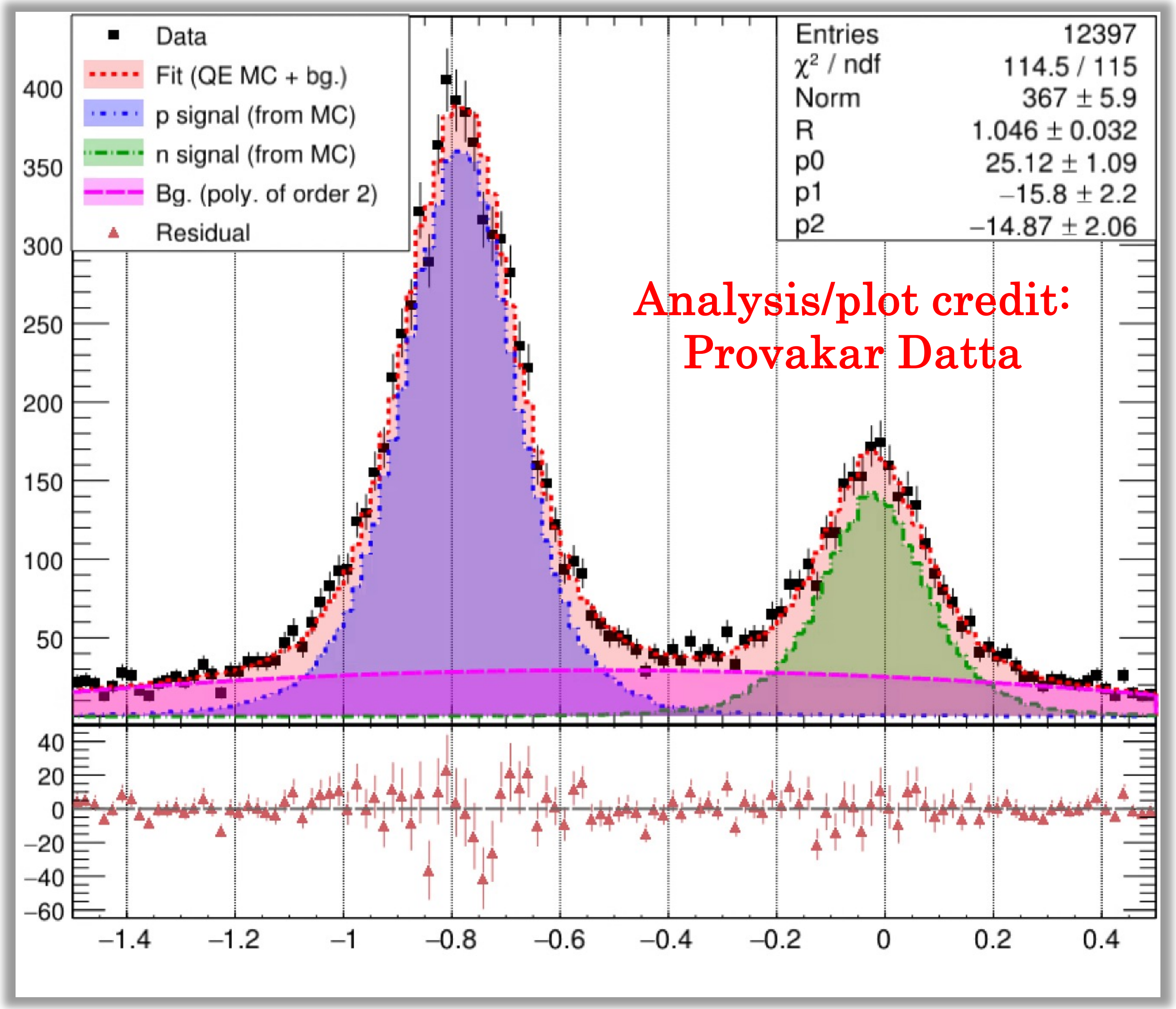
SBS GMN analysis methodology

- All relevant (known) physics and detector effects are built in to the Monte Carlo simulation:
  - SIMC: quasi-elastic $d(e,e'N)$ event generation with realistic nuclear and radiative effects (suitable modifications for GMN analysis by Provakar Datta, Mark Jones)
  - G4sbs: SBS detector simulation (GEANT4-based) (many contributors)
  - Libsbsdig: translate simulation output to pseudo-raw data that can be processed by the same reconstruction code as the real data (Eric Fuchey)
  - SBS-offline: event reconstruction (A. Puckett, E. Fuchey, J.-C. Cornejo, many others)
- Fit real data to the sum of simulated quasi-elastic n and p scattering (plus inelastic background)
  - We interpret the relative normalization between MC n and p distributions as the ratio of the "measured" σ_n/σ_p to the "predicted" ratio from the MC cross section model.

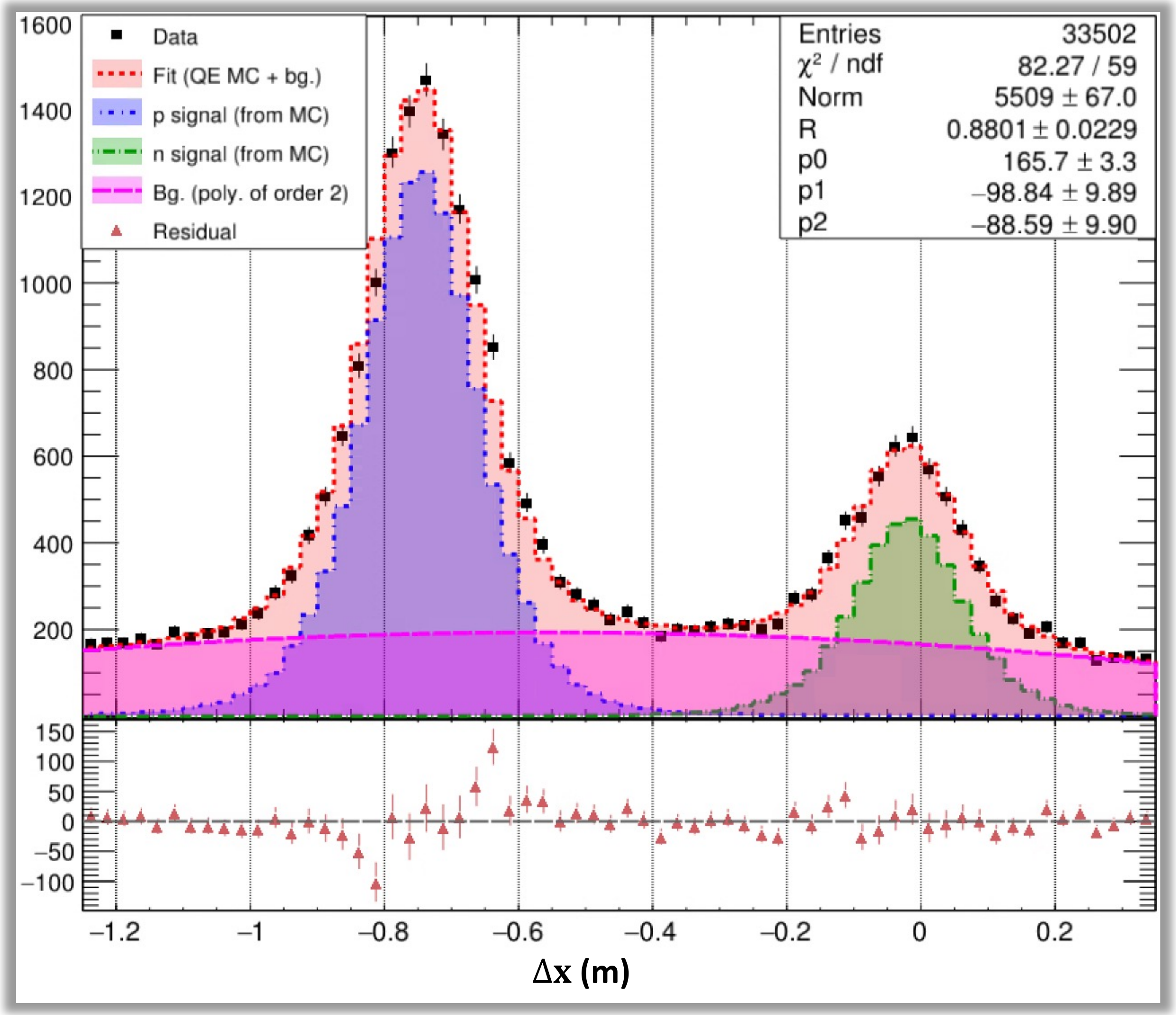


High-Q^2 GMN Data

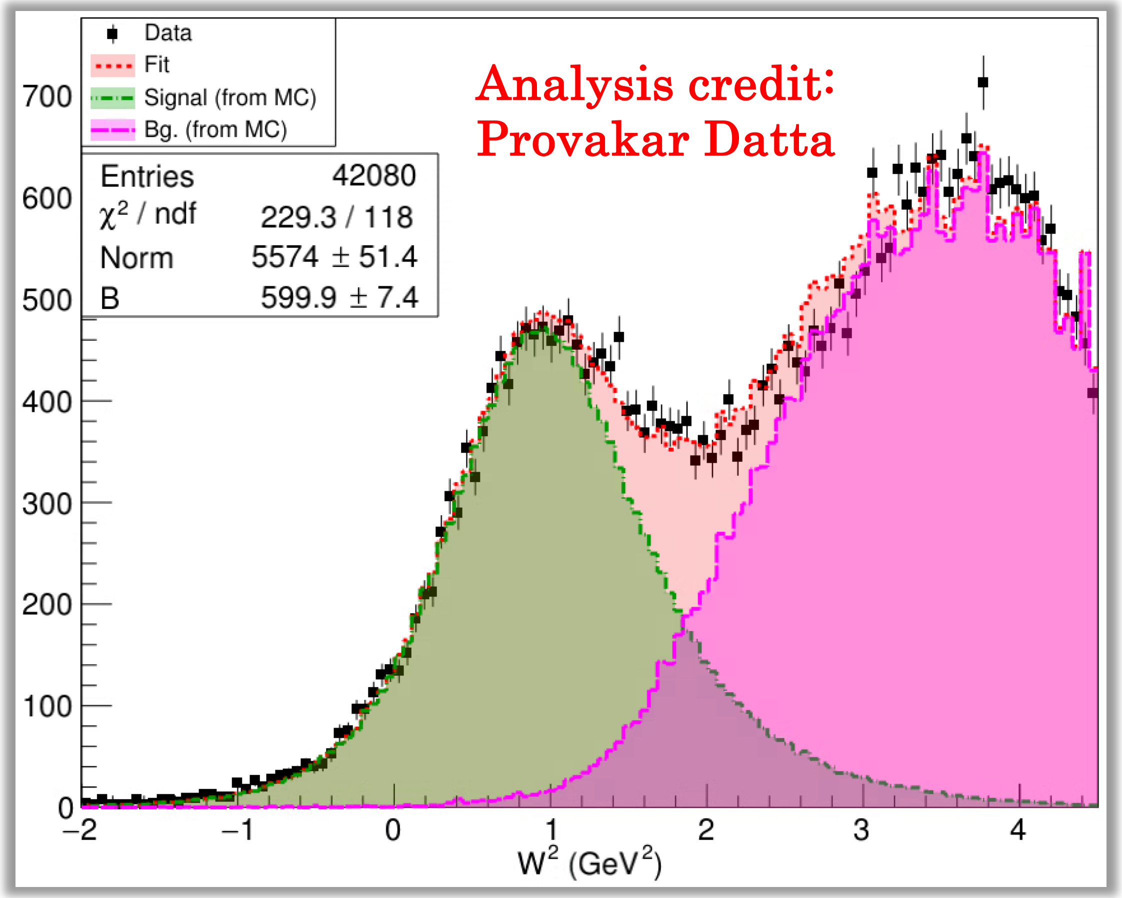
Q^2 = 9.9 GeV^2, $0.2 \le W^2 \le 1.32$ GeV^2, Fiducial Cuts



Q^2 = 13.6 GeV^2, $0.16 \le W^2 \le 1.44$ GeV^2, Fiducial Cuts



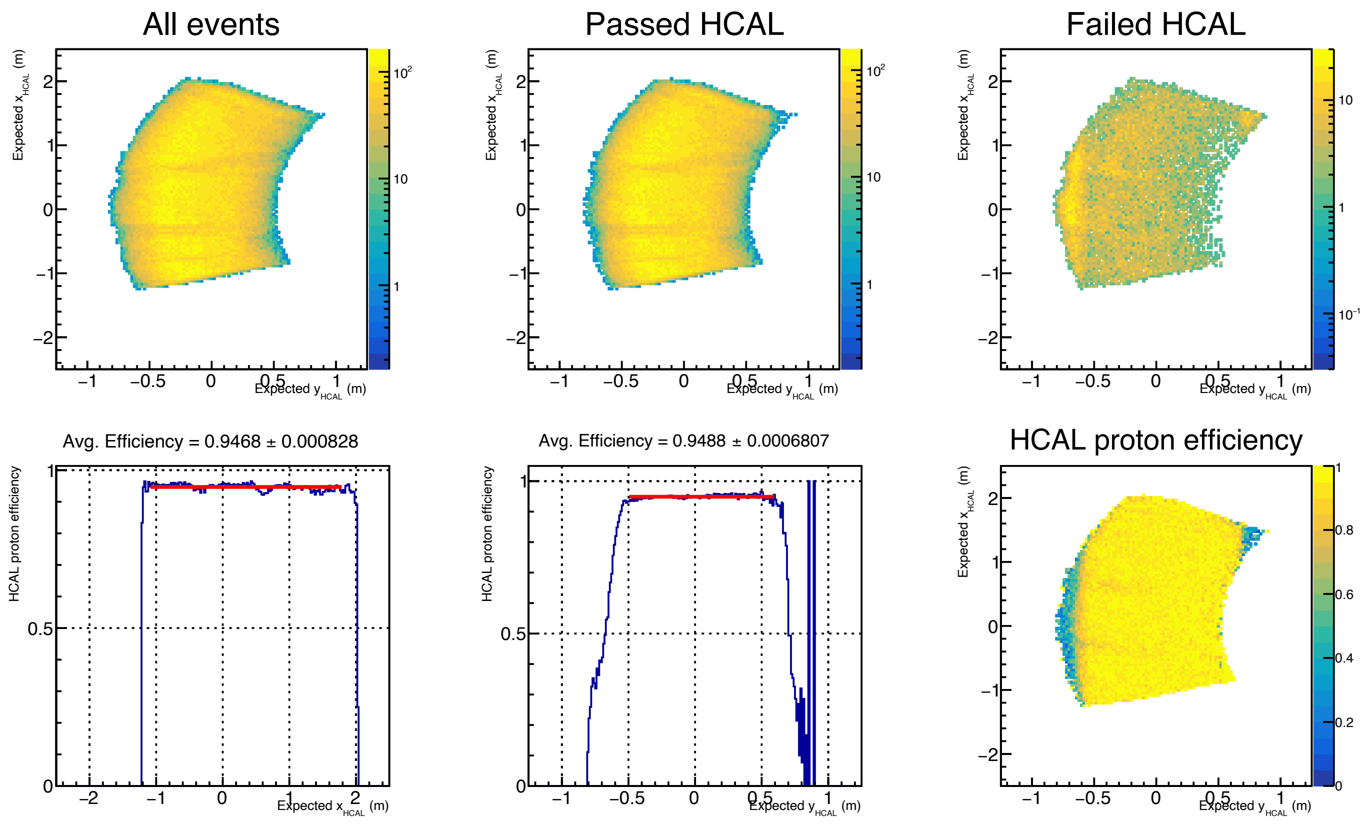
Data/MC comparison for W^2 distribution



Q^2 = 13.6 $(GeV/c)^2$

- At high-Q^2, Fermi-smearing and kinematic broadening lead to very wide W^2 distribution for quasi-elastic scattering from deuterium.
- SIMC (quasi-elastic) plus built-in *g4sbs* inelastic generator (based on Christy-Bosted) qualitatively reproduce the shape of the W^2 distribution very well even at the highest Q^2

HCAL proton detection efficiency from H(e,e'p) and from MC



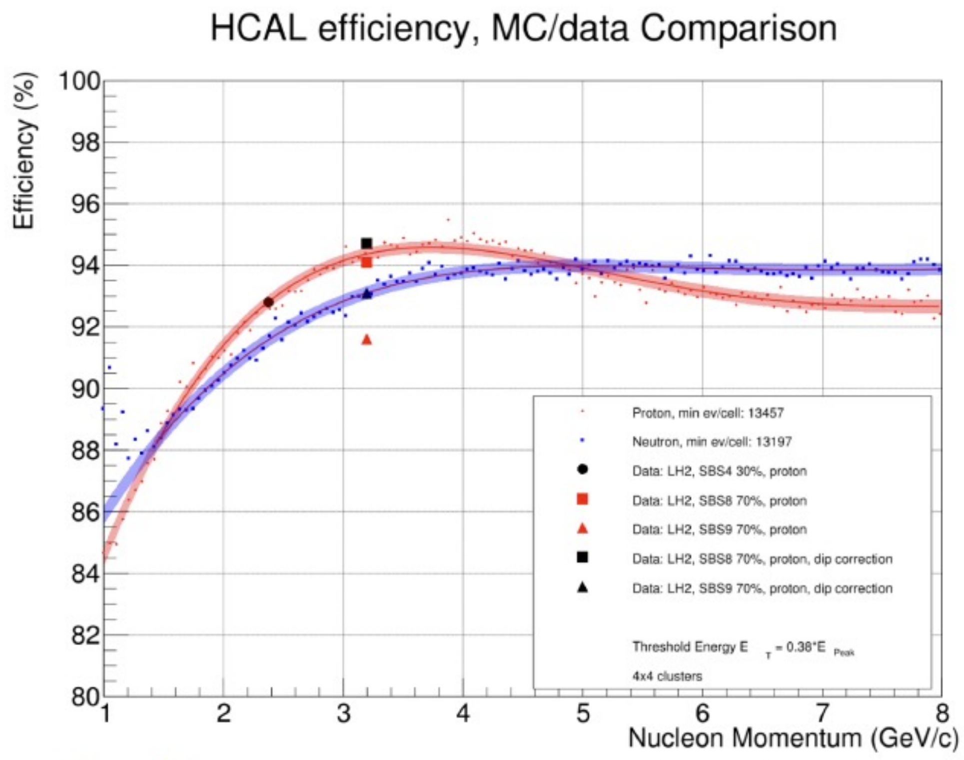
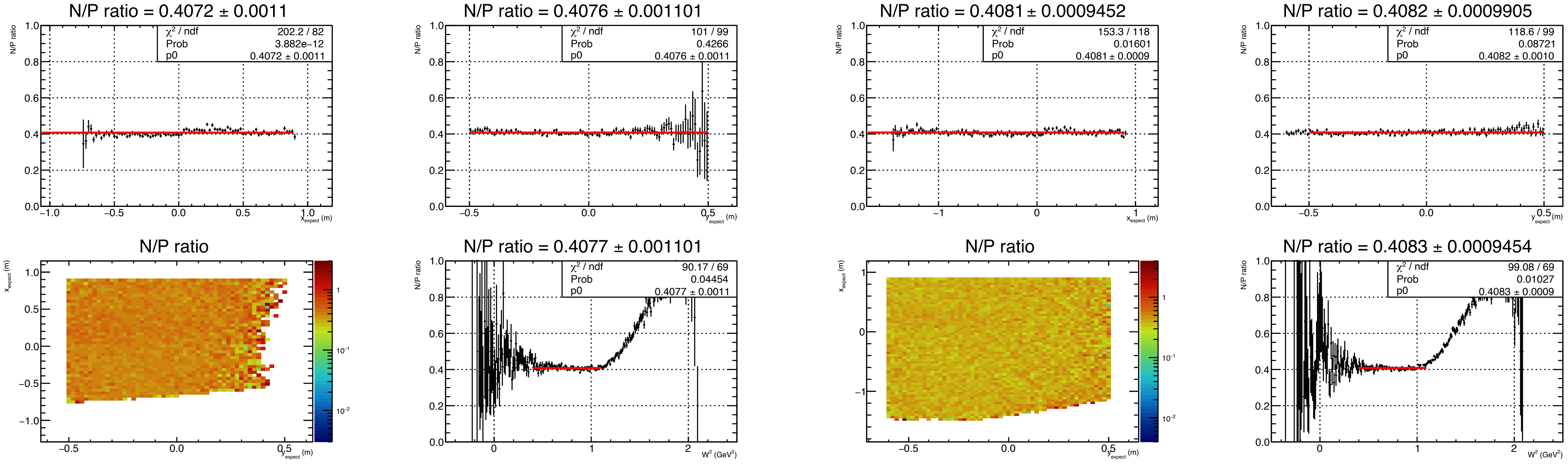


Figure 85: Comparison of HCal HDE for proton between data and MC. The match at $p_N = 2.4$ GeV (SBS-4) is arbitrary while the comparisons at $p_N = 3.2$ GeV (SBS-8 and SBS-9) are not and represent the ability of the MC to reproduce the measured proton HDE. MC error band is binomial error. The MC energy threshold is indicated in the legend. Real data includes error bars.

- At $Q^2 = 3, 4.5\ GeV^2$, we can achieve a clean selection of elastically scattered protons with cuts on only BigBite (electron) variables.
- With equivalent cuts, MC simulation reproduces observed proton efficiencies→Currently relying on MC for neutron detection efficiency
- Implement position-dependent efficiency corrections in MC. Assume effect is same for protons and neutrons→major remaining analysis task

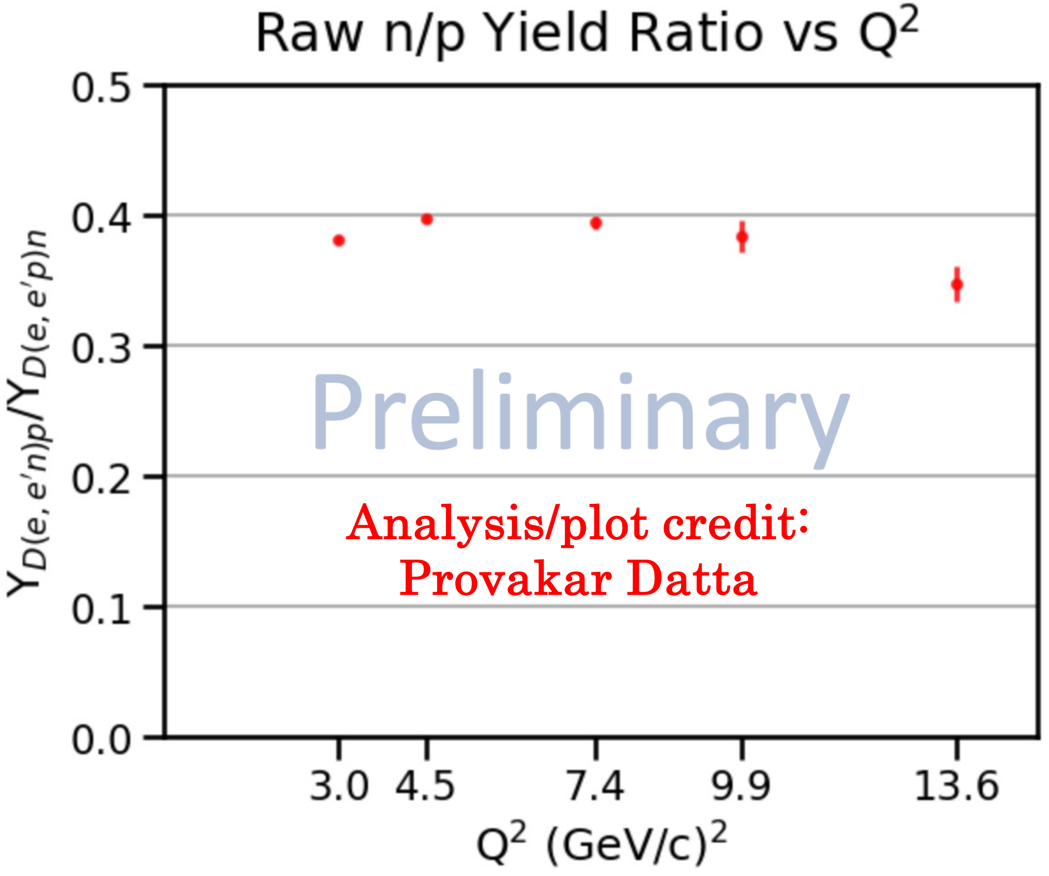
Analysis/plot credit: Sebastian Seeds

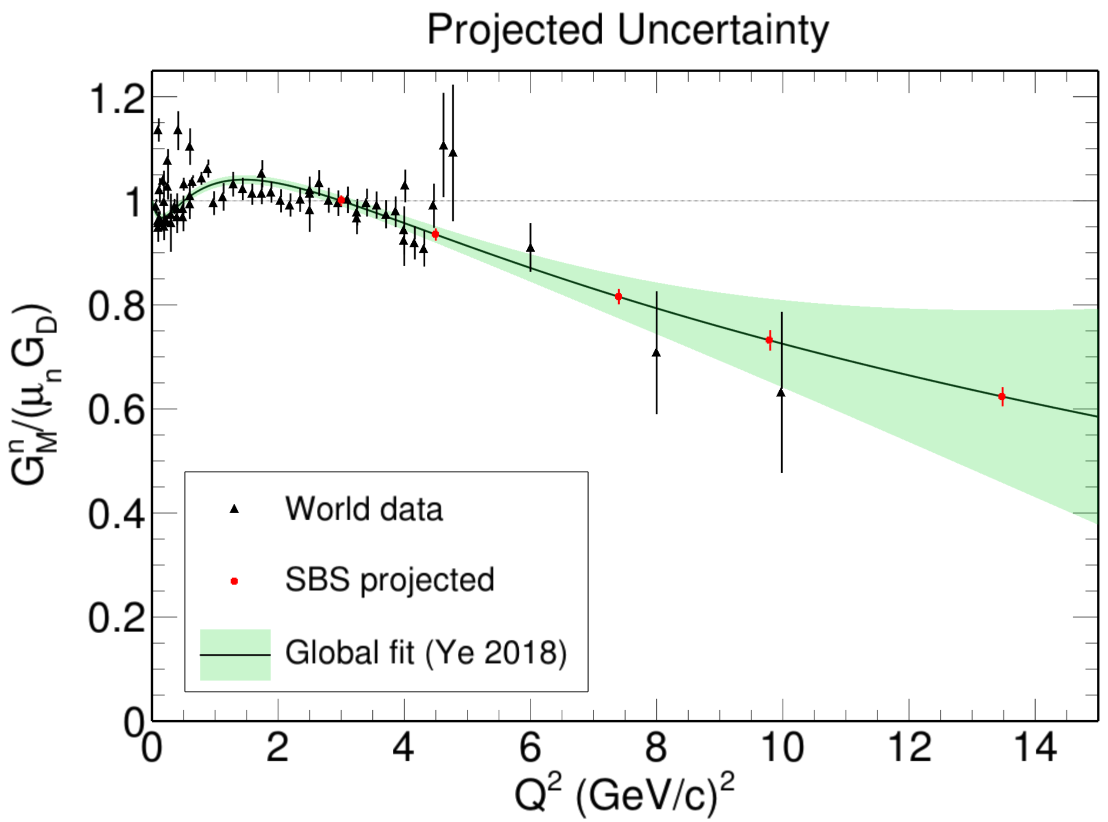
Uniformity of raw n/p ratios from LD2, $Q^2 = 4.5\ GeV^2$



- Raw n/p ratios versus predicted nucleon positions at HCAL, at $\epsilon = 0.5$ (left) and $\epsilon = 0.8$ (right), with same SBS magnetic field setting (70% of maximum)
- Observed non-statistical variations consistent with known regions of low HCAL detection efficiency, affecting n/p ratio due to different distributions of protons/neutrons on HCAL surface (bigger fraction of protons in the low-efficiency region(s)).
- For the nTPE Rosenbluth separation, we expect significant cancellations of n/p detection efficiency systematics in the “super-ratio” between the two ϵ points, particularly after acceptance-matching cuts.

GMN: preliminary σ_n/σ_p ratios and G_M^n extractions



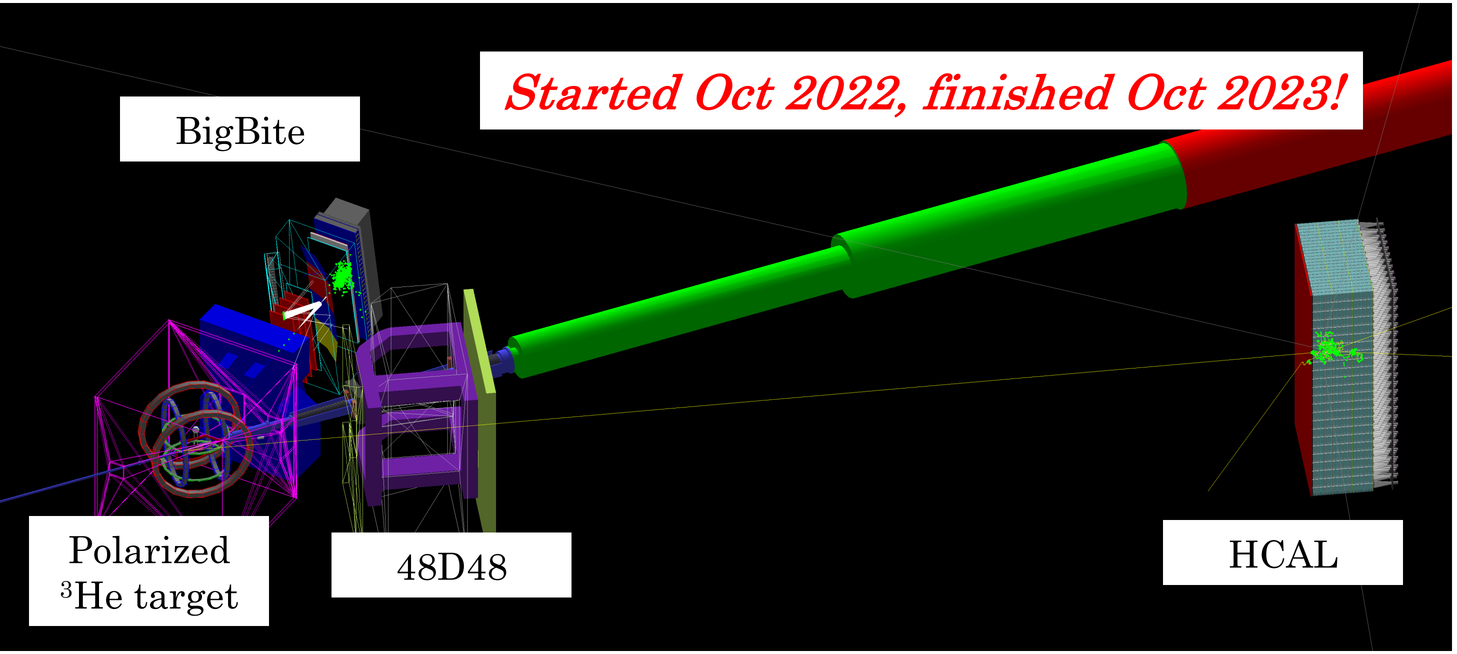


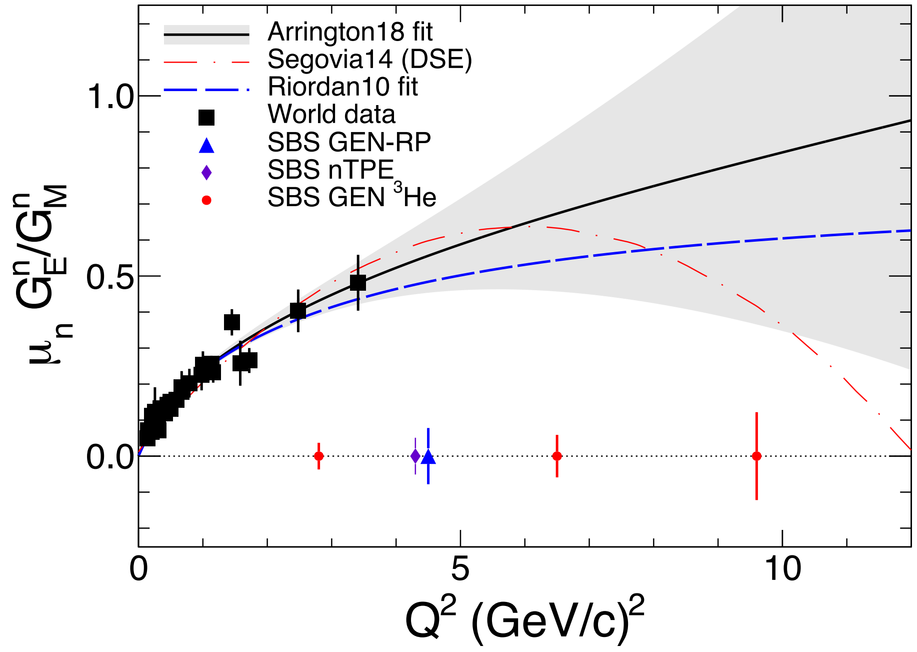
- Left: preliminary n/p cross section ratios versus Q^2. (Uncertainties are statistical only)
- Right: Projected final uncertainties (statistical + systematic combined in quadrature); data points plotted arbitrarily on the global fit curve. I COULD show you preliminary G_M^n extractions today, but I won't

Path forward for GMN/nTPE analysis

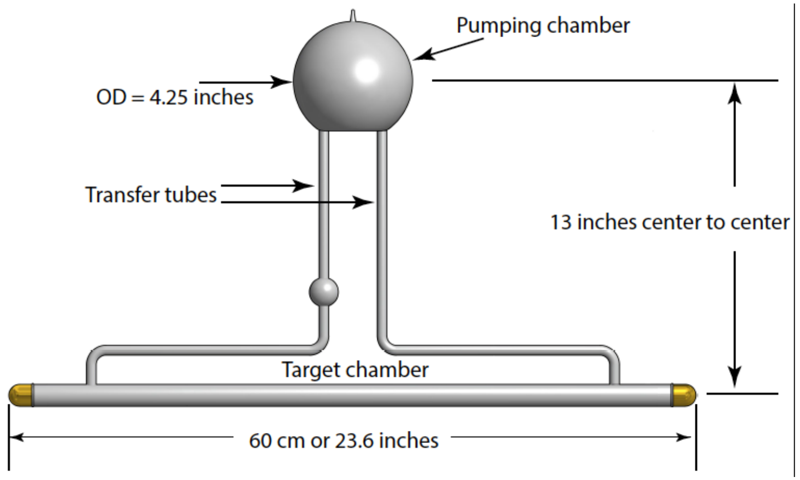
- Two full calibration/reconstruction passes completed
- Physics analysis machinery fairly mature
- Major remaining work is systematic error analysis/implementation of corrections for HCAL efficiency non-uniformity
- Several thesis students graduated already
- Estimated time to first publication ~1 year

E12-09-016: G_E^n/G_M^n to 10 GeV^2 using polarized ^{3}He(e,e'n)pp

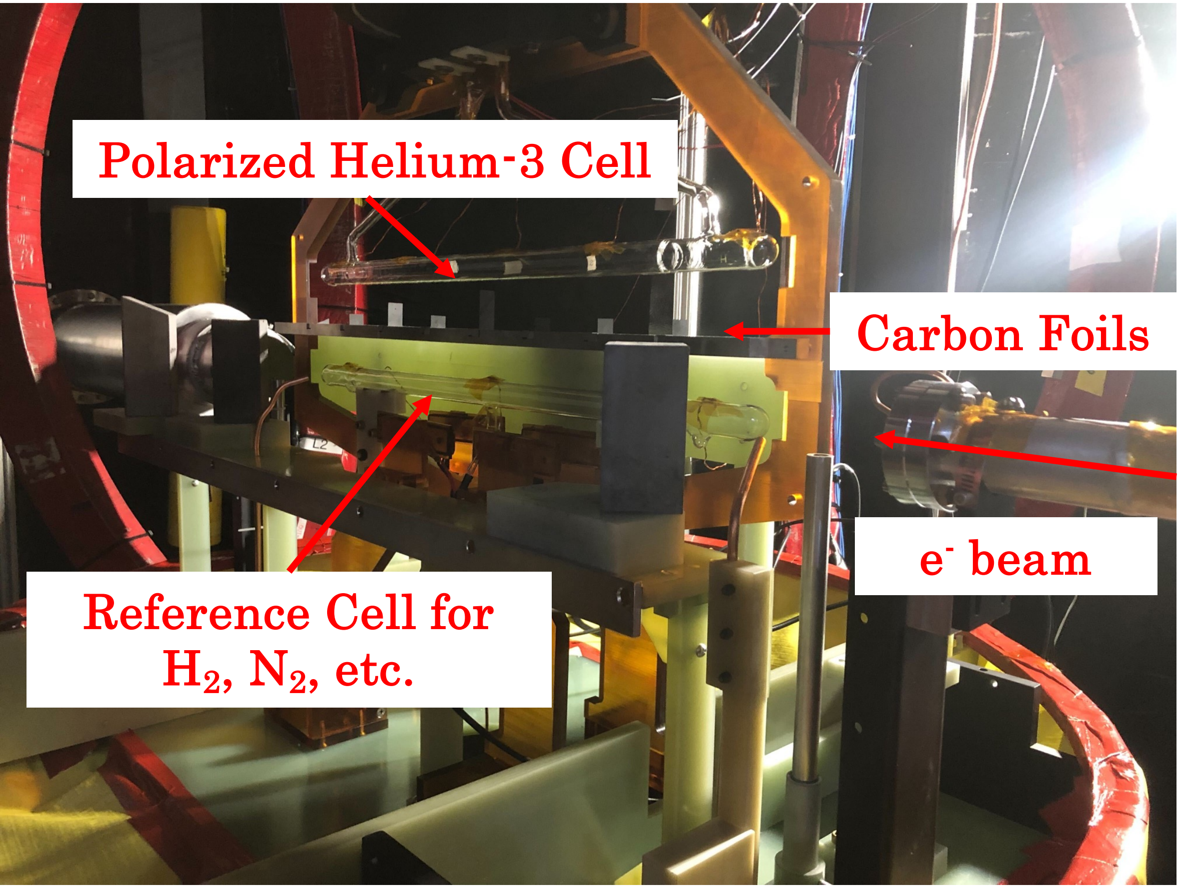


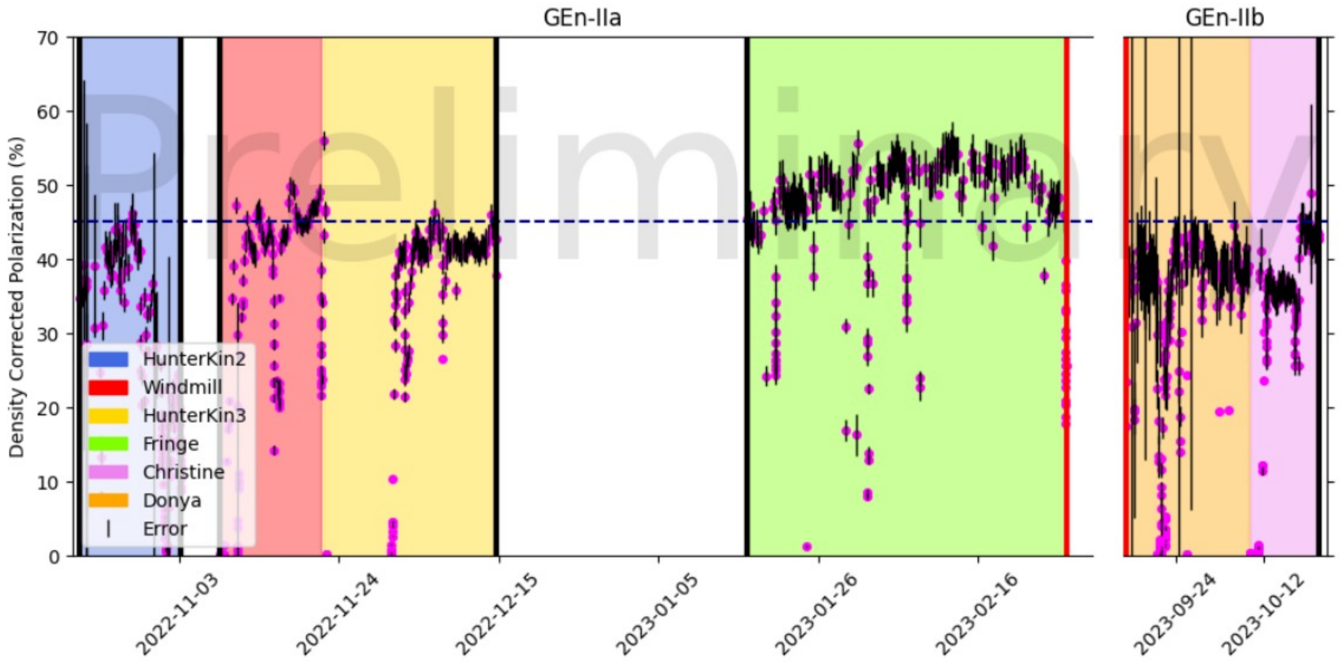


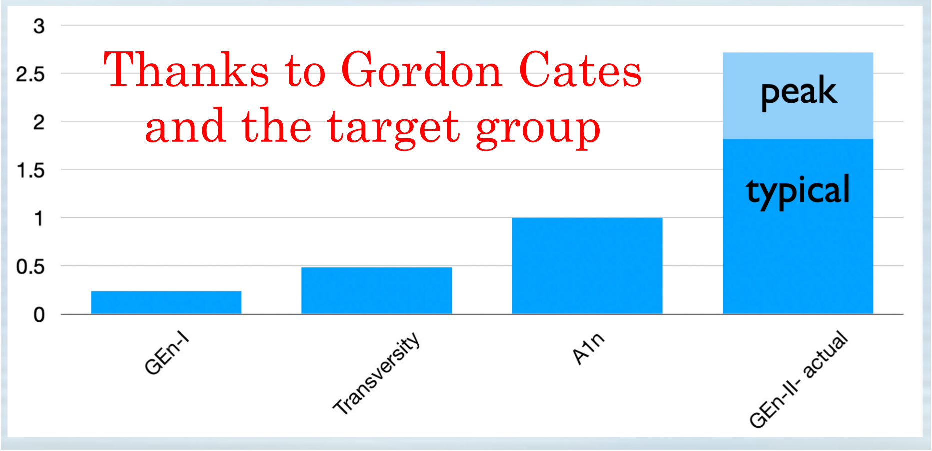
- Same detector configuration as GMN (E12-09-019) (with GEMs added to SBS for commissioning)
- High-luminosity polarized ^{3}He target with convection-driven circulation of polarized gas.
- Measurement to 10 GeV^2 has enormous discrimination power among theoretical models
- **Data-taking completed Oct. 29, 2023!**



The SBS-GEN polarized Helium-3 target

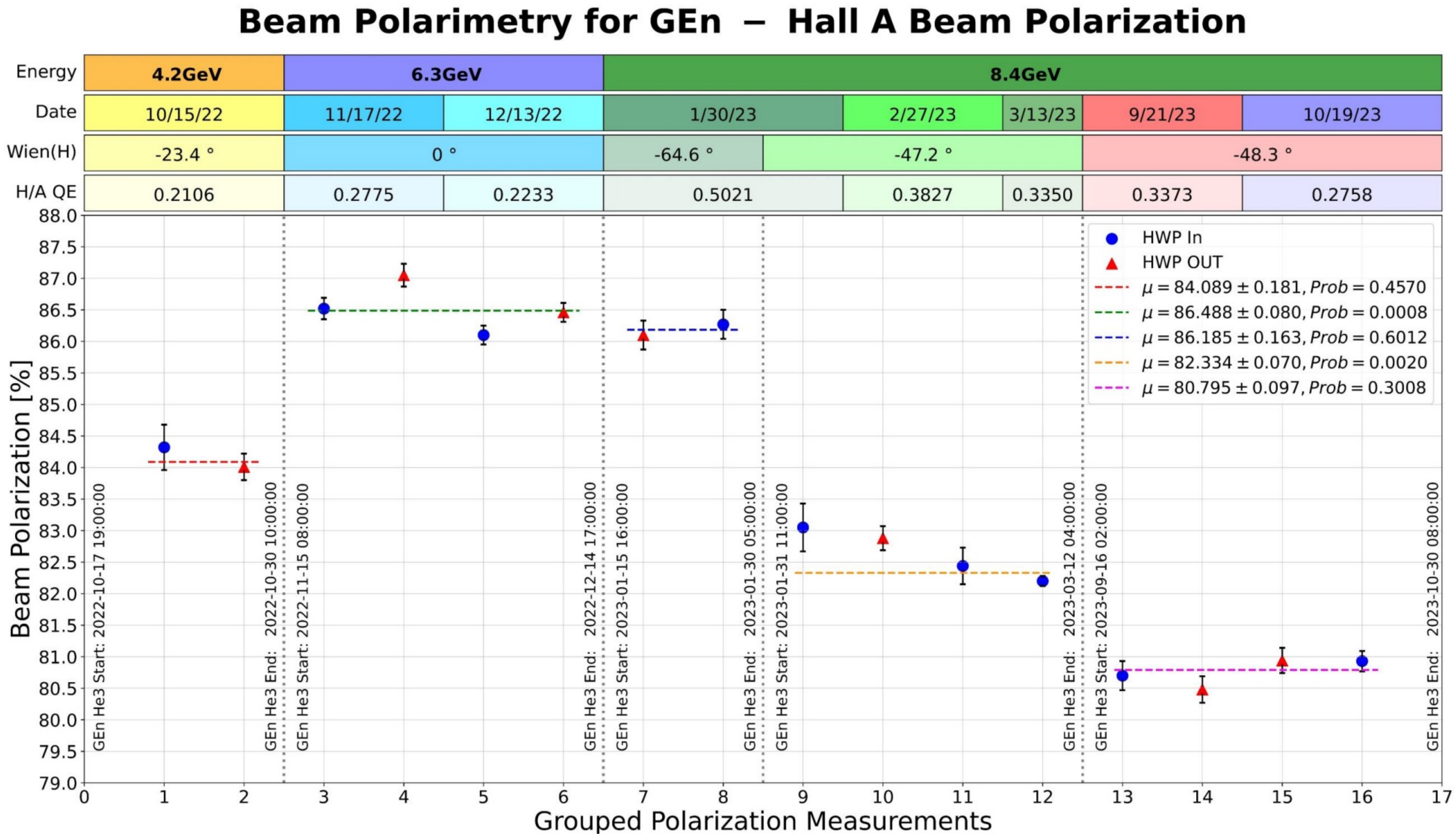






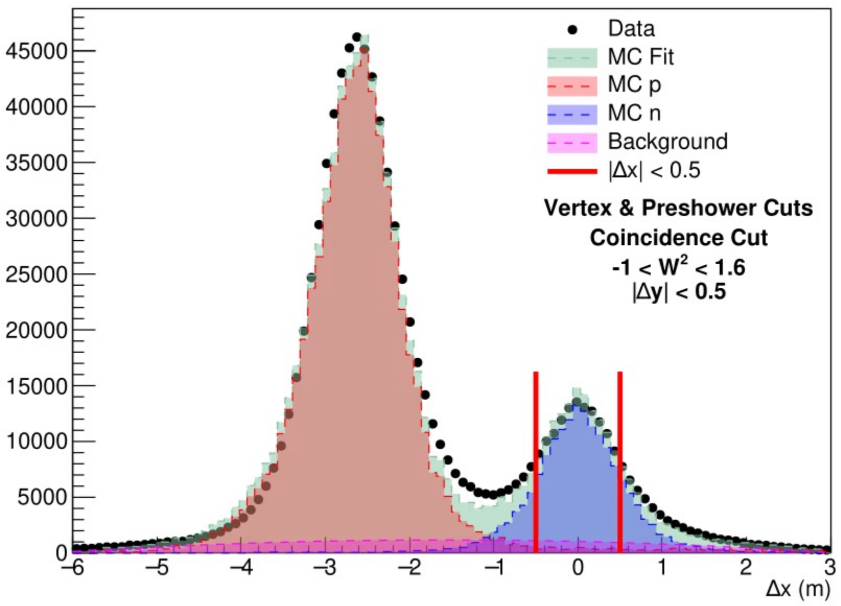
- Above, left: Inside the target enclosure
- Above, right: preliminary target polarization results
- Below, right: estimated FOM compared to previous experiments

SBS GEN analysis: Moller Polarimetry: Faraz Chahili and Don Jones



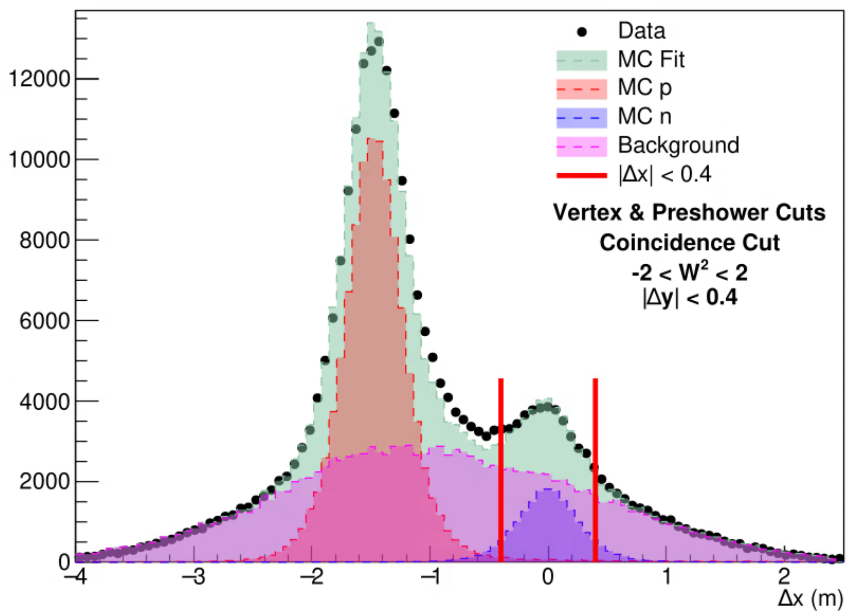
SBS GEN analysis: Quasi-elastic ^{3}He(e,e'n)pp event selection

Kin2 Data/Simulation Comparisons



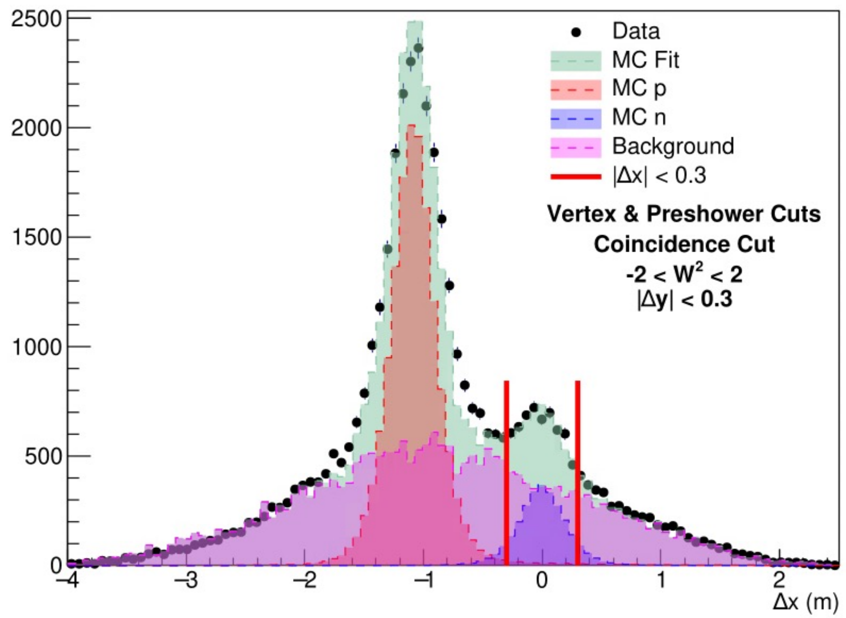
$$Q^2 = 3.0 \text{ GeV}^2$$

Kin3 Data/Simulation Comparisons



$$Q^2 = 6.8 \text{ GeV}^2$$

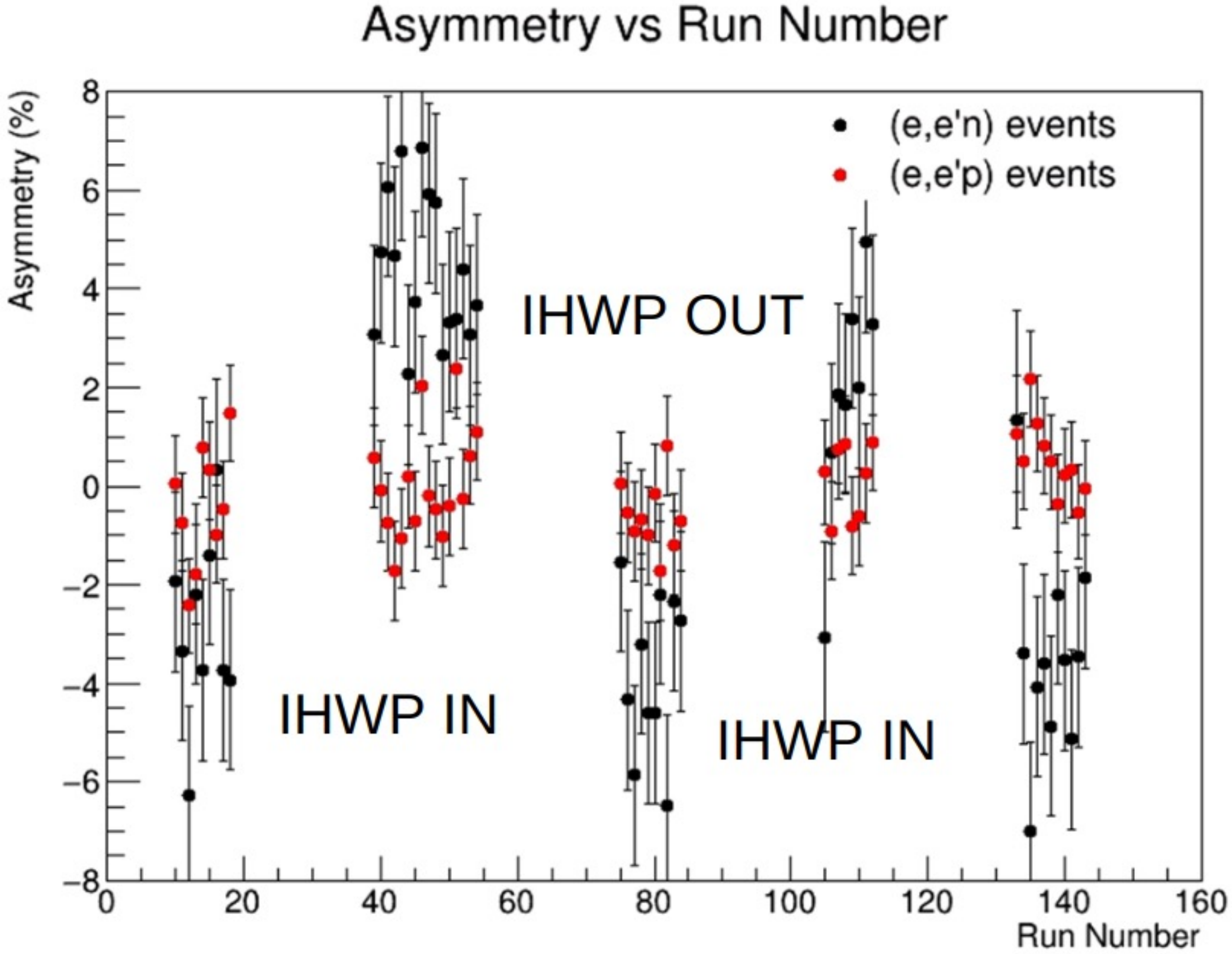
Kin4 Data/Simulation Comparisons



$$Q^2 = 9.8 \text{ GeV}^2$$

- Plots/analysis credit: Sean Jeffas (UVA)
- Histograms include all (or substantially all) of the data from the first reconstruction pass (does not include Fall 2023 data which are expected to roughly double statistics at the highest Q^2)
- n/p separation for quasi-elastic scattering is very clean due to magnetic deflection
- Substantial, essentially irreducible inelastic background is present, especially at large Q^2

Preliminary raw ^{3}He(e,e'n) asymmetries (Sean Jeffas)

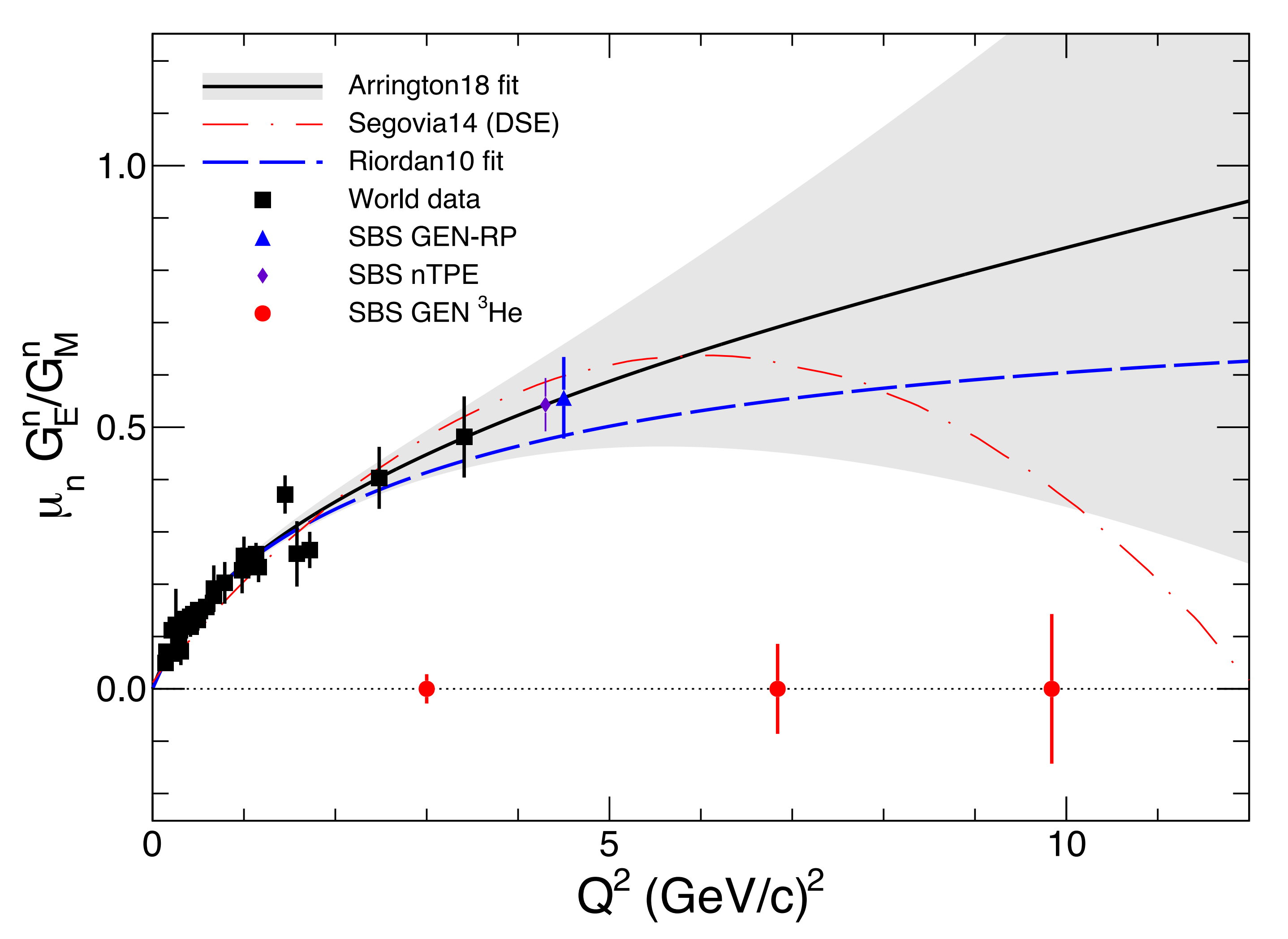


$$Q^2 \quad = \quad 3.0 \text{ GeV}^2$$

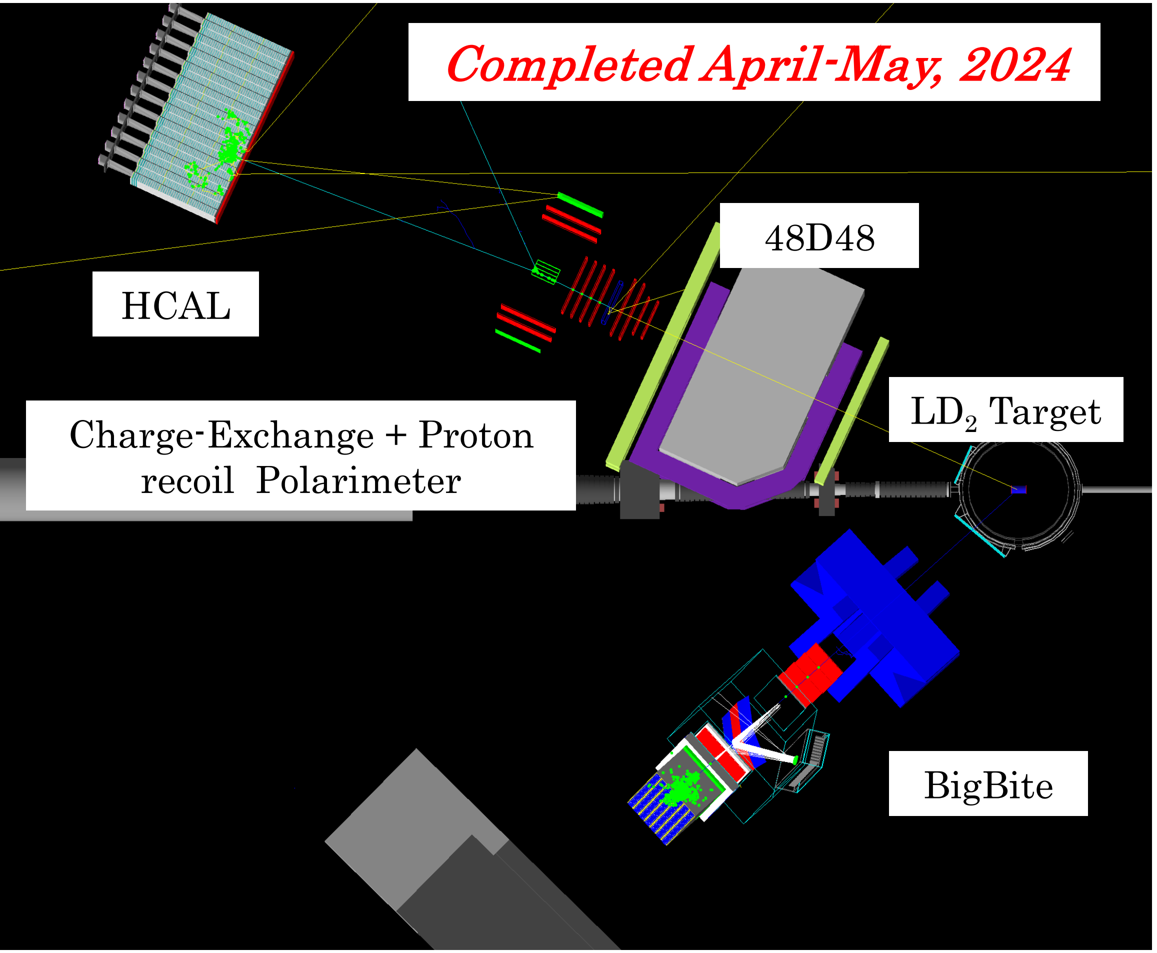
- Preliminary (e,e'n) asymmetries at lowest Q^2 (overlapping existing GEN data) consistent in sign, magnitude with expectatation
- Neutron asymmetries large, change sign with IHWP as expected
- Proton asymmetries small

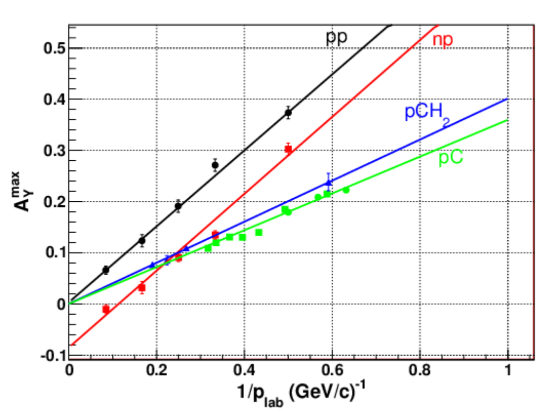
Path forward for GEN analysis

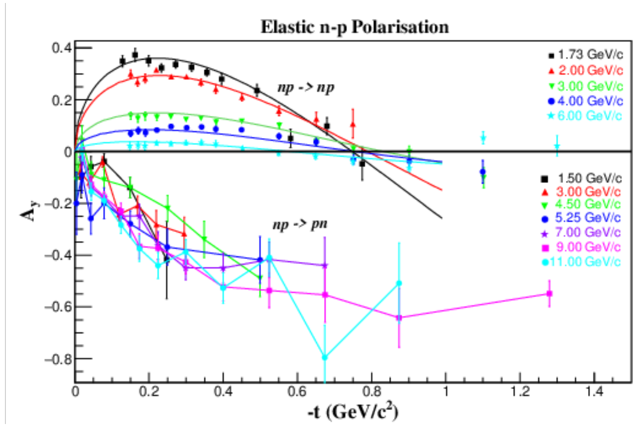
- Detector calibrations still require substantial work toward a 2nd full reconstruction pass—expect significant increase in statistics (and somewhat improved resolution) for higher Q^2's with improved calibrations
- Nuclear corrections: updated Generalized Eikonal Approximation code obtained from Misak Sargsian
- Proper definition of estimators, background contamination, background asymmetry, background subtraction
- Finalize polarimetry
- Substantial remaining analysis work—students graduating → we are several years from publishable physics results from GEN



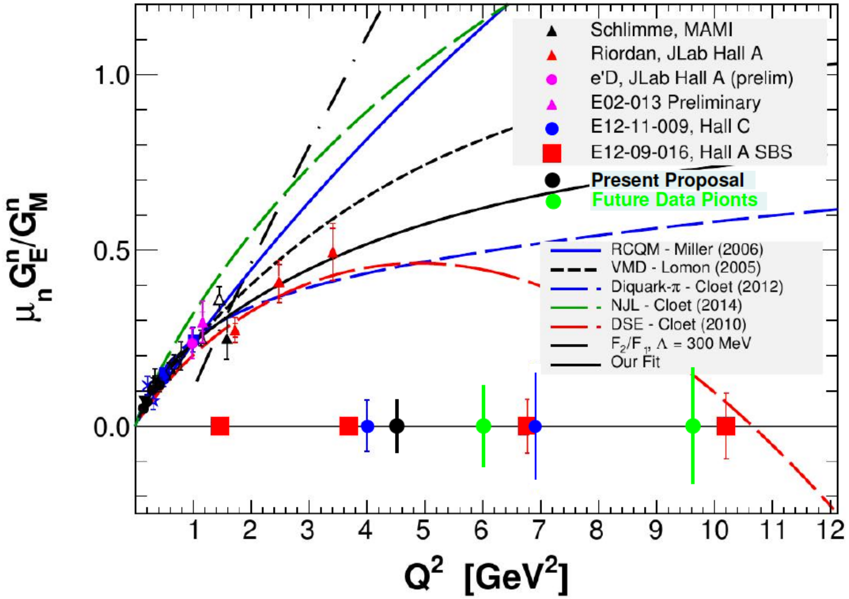
E12-17-004 (GEN-RP): G_E^n/G_M^n to 4.5 GeV^2 via charge-exchange recoil polarimetry







Analyzing powers for np, pp, pA scattering vs. initial momentum (left) and vs. transferred momentum (right)



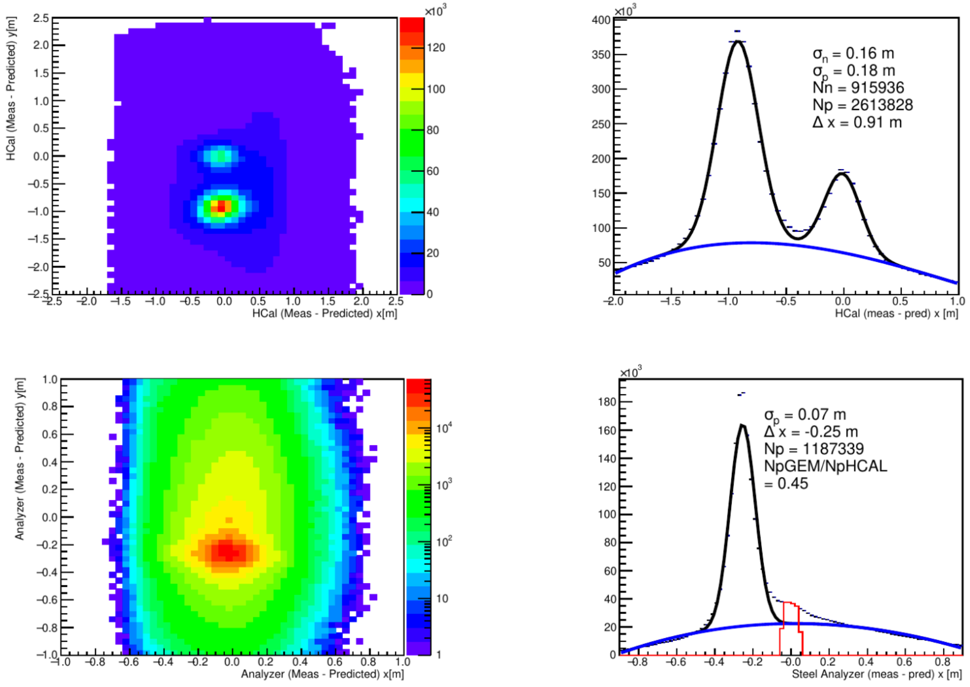
- E12-17-004 layout (above) and projected results (right):
  - First use of charge-exchange polarimetry in a FF experiment
- E12-20-008 approved as add-on to measure K_{LL} for $\gamma n \rightarrow \pi^- p$

GEN-RP Analysis Progress—Quasi-Elastic Data (David Hamilton)

Reconstruction of quasi-elastic scattering

BB+HCAL

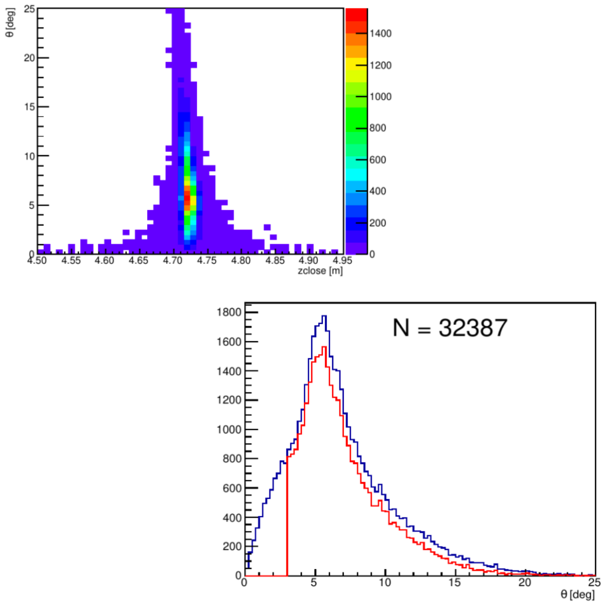
BB+SBS rear GEMs
(red region is where we expect ChEx)

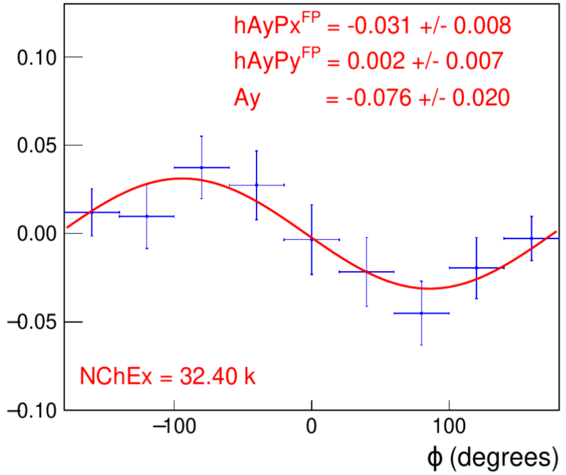


NewGENfig_April2024.pdf

Charge exchange polarimetry

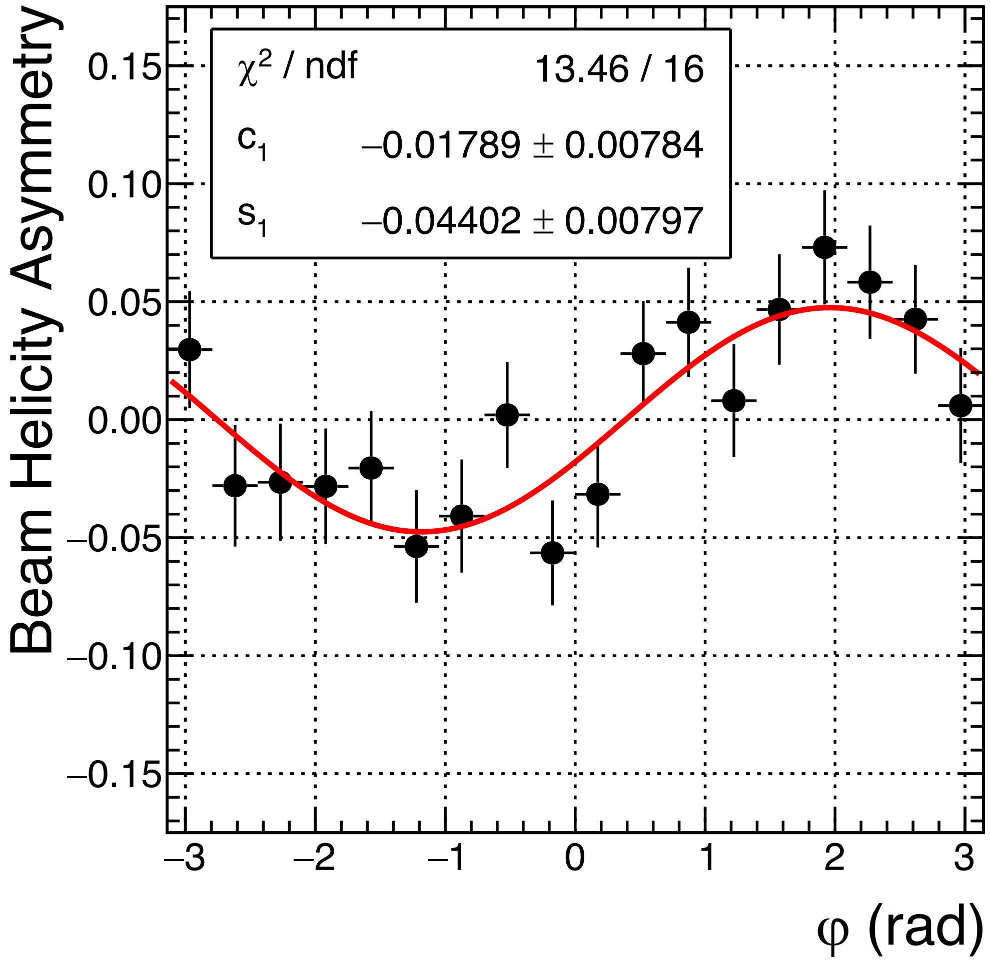
- More work needed in isolating the asymmetry in the neutron-to-proton (charge exchange) channel – and boosting the stats – but there is weak preliminary evidence for a non-zero beam helicity asymmetry.

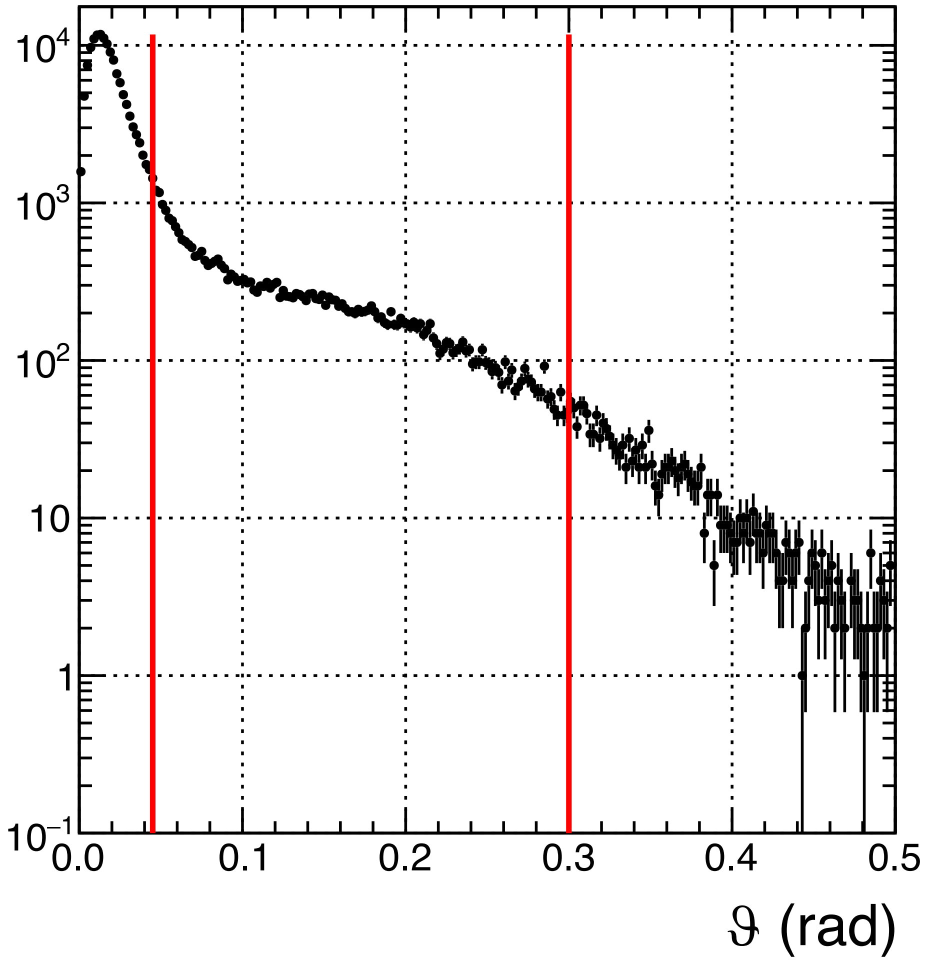




- “Online” asymmetry results promising, but a long, difficult, and statistically challenged analysis lies ahead

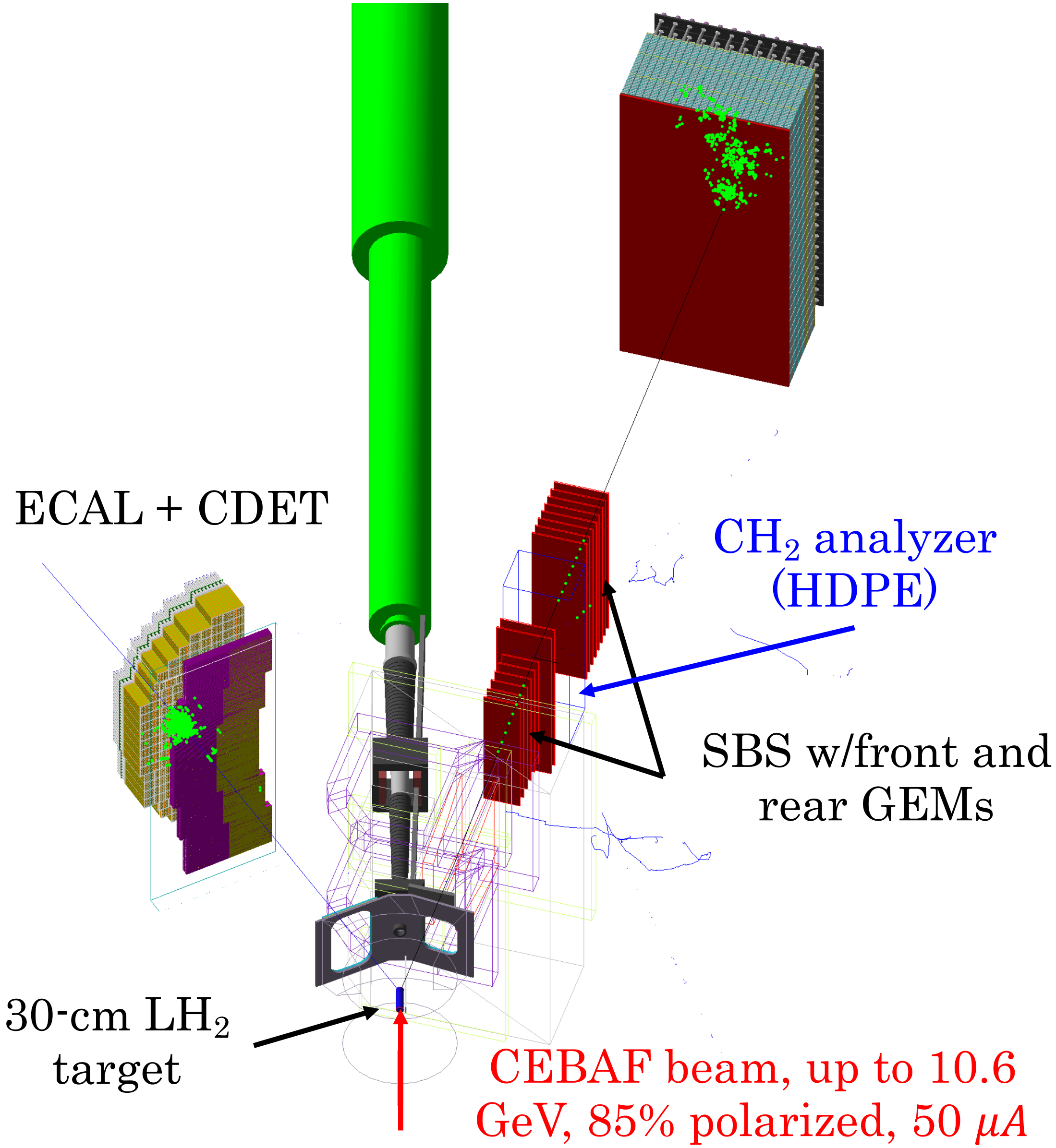
GEN-RP analysis progress: LH2 elastic asymmetry

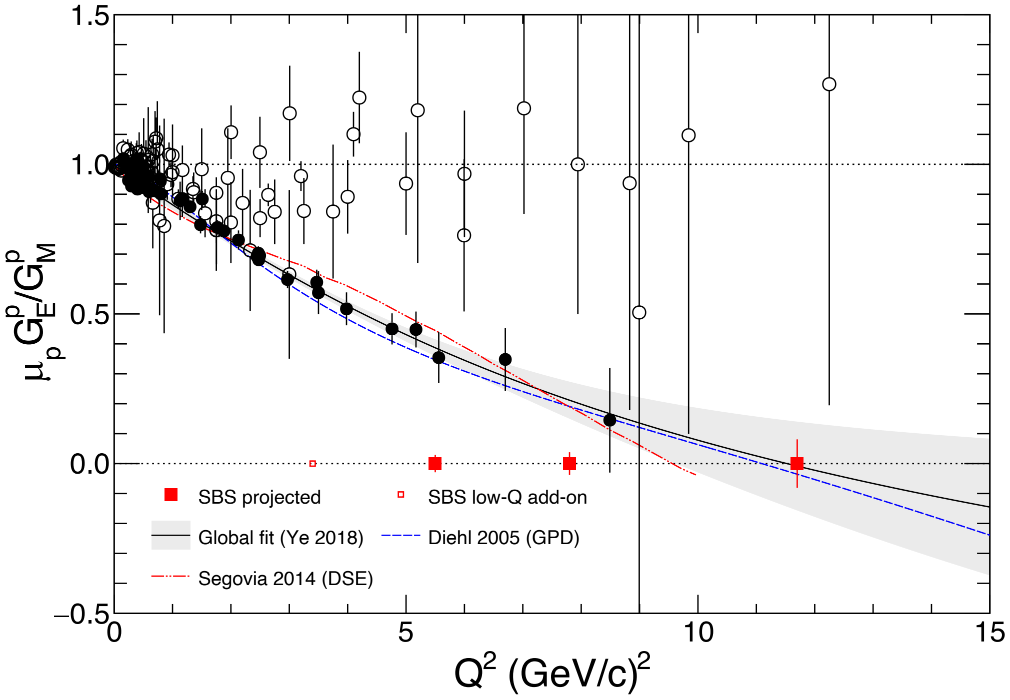




- "Online" LH2 asymmetry results from GEN-RP are promising—consistent with expectation

Coming soon: GEP+ (Scheduled 2025)





- **Proposed 2007, designated "High Impact Experiment" by JLab PAC41**
- Jeopardy proposal reapproved by PAC47 in 2019
- **Currently scheduled to run 2024-2025**
- **ERR April 2023**
- Novel high-temperature lead-glass calorimeter detects scattered electron with scintillator-based coordinate detector—trigger, aid tracking in front GEMs, and reject inelastics offline
- GEM-based trackers with CH$_2$ analyzer for proton polarimetry
- HCAL for trigger and preferential selection of nuclear scattering events with high analyzing power

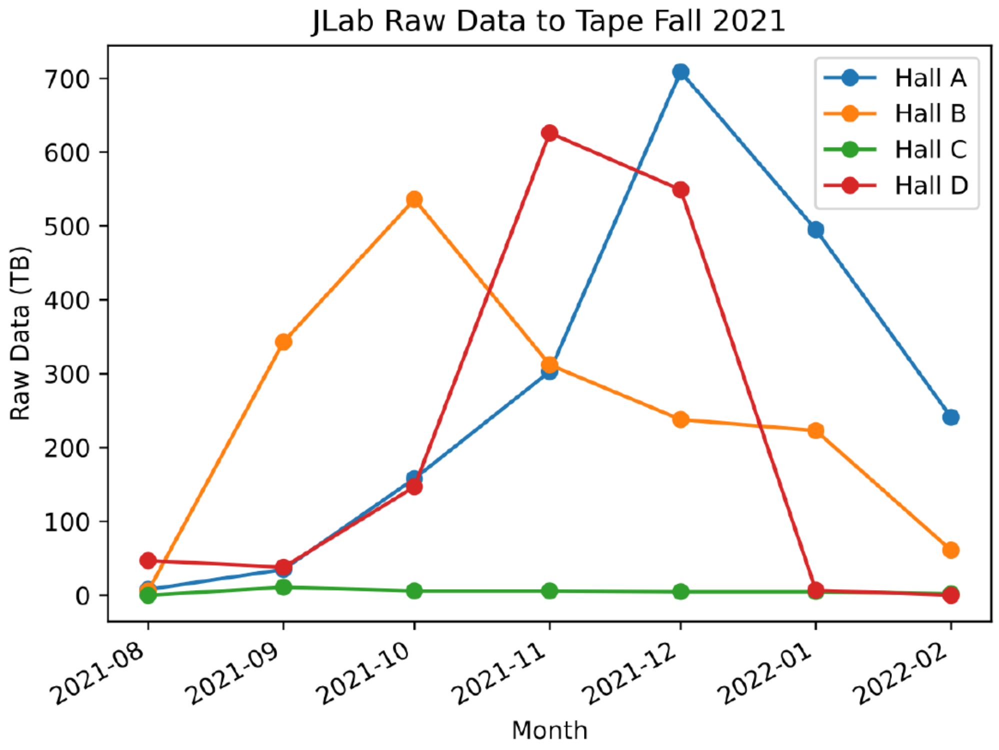
Summary and Conclusions

- SBS neutron form factor program complete
- Q^2 reach and accuracy goals mostly achieved
- GMN/nTPE analysis fairly mature—publication 2025?
- GEN analysis progressing well—publication 2026/2027?
- GEN-RP data-taking just completed—analysis getting underway
- GEP run upcoming, 2025
- Three major analyses ongoing, in one year there will be four!
- Lots of work to do!

Backups

SBS/BigBite with GEMs—Hall A enters the "Big Data" era

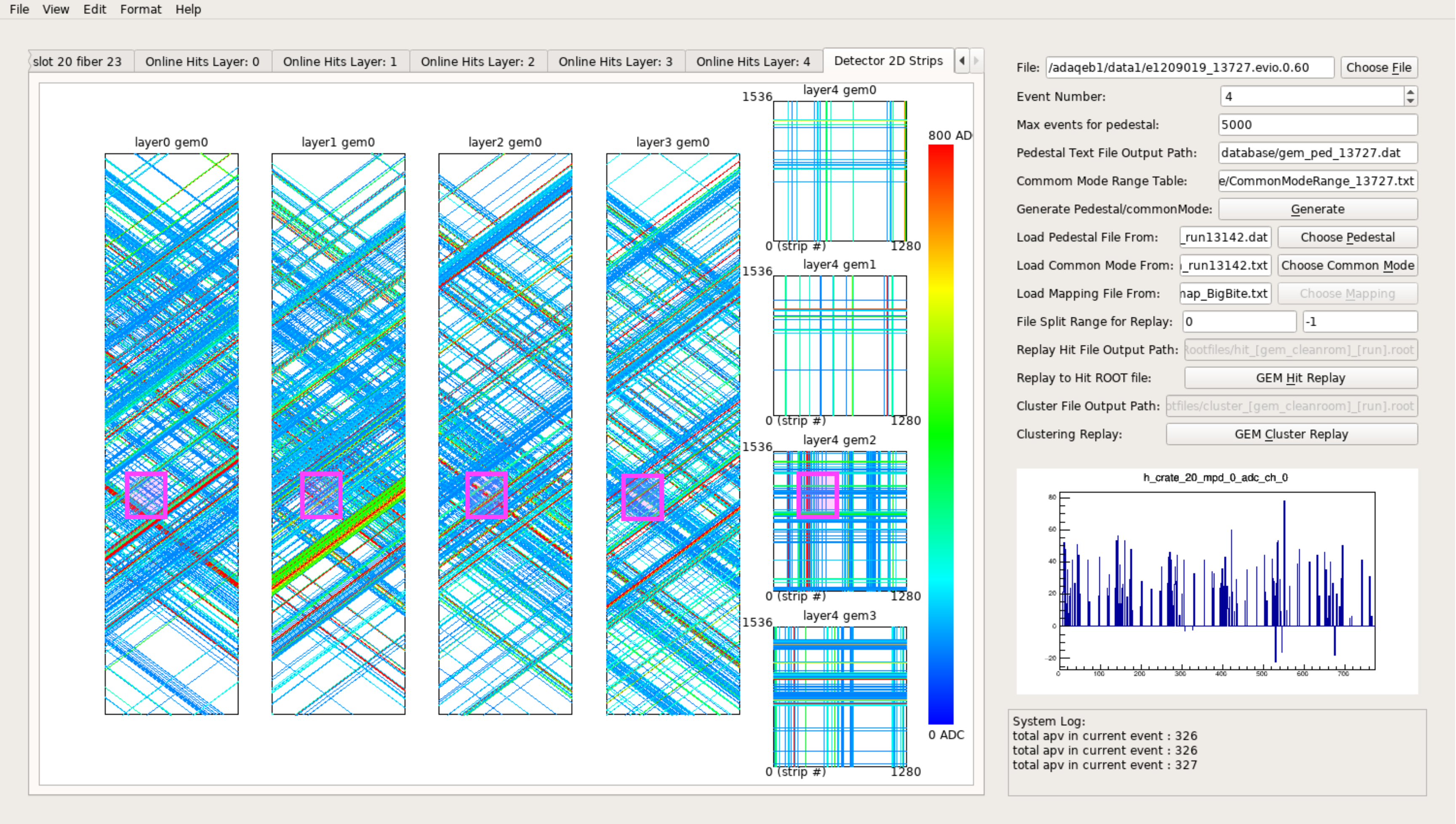
SBS G_M^n Data Acquisition (DAQ) Facts

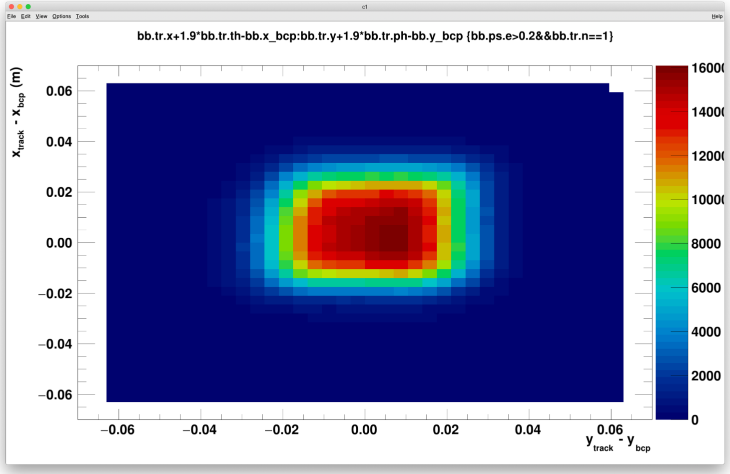


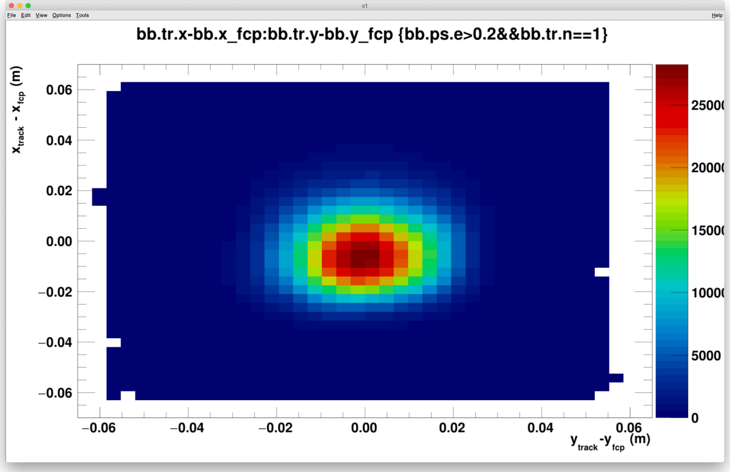
- Data Acquisition challenges:
  - 43,000+ detector readout channels!
  - Very high luminosity, $\sim 10^{38}\ cm^{-2}s^{-1}$
- During 5 months (Oct 2021 - Feb 2022) of SBS G_M^n running, Hall A has recorded ~2 PB worth of raw data!
  - This is more than any other Hall.
  - Also, 5 times more data than all prior Hall A experiments combined in 25 years!

[*] Graphic from Ole Hansen (JLab), Jan 2022

GEM-based tracking in BigBite: what we're up against (run 13727, 12 uA LD2, $Q^2 = 4.5\ GeV^2, E = 4\ GeV$)





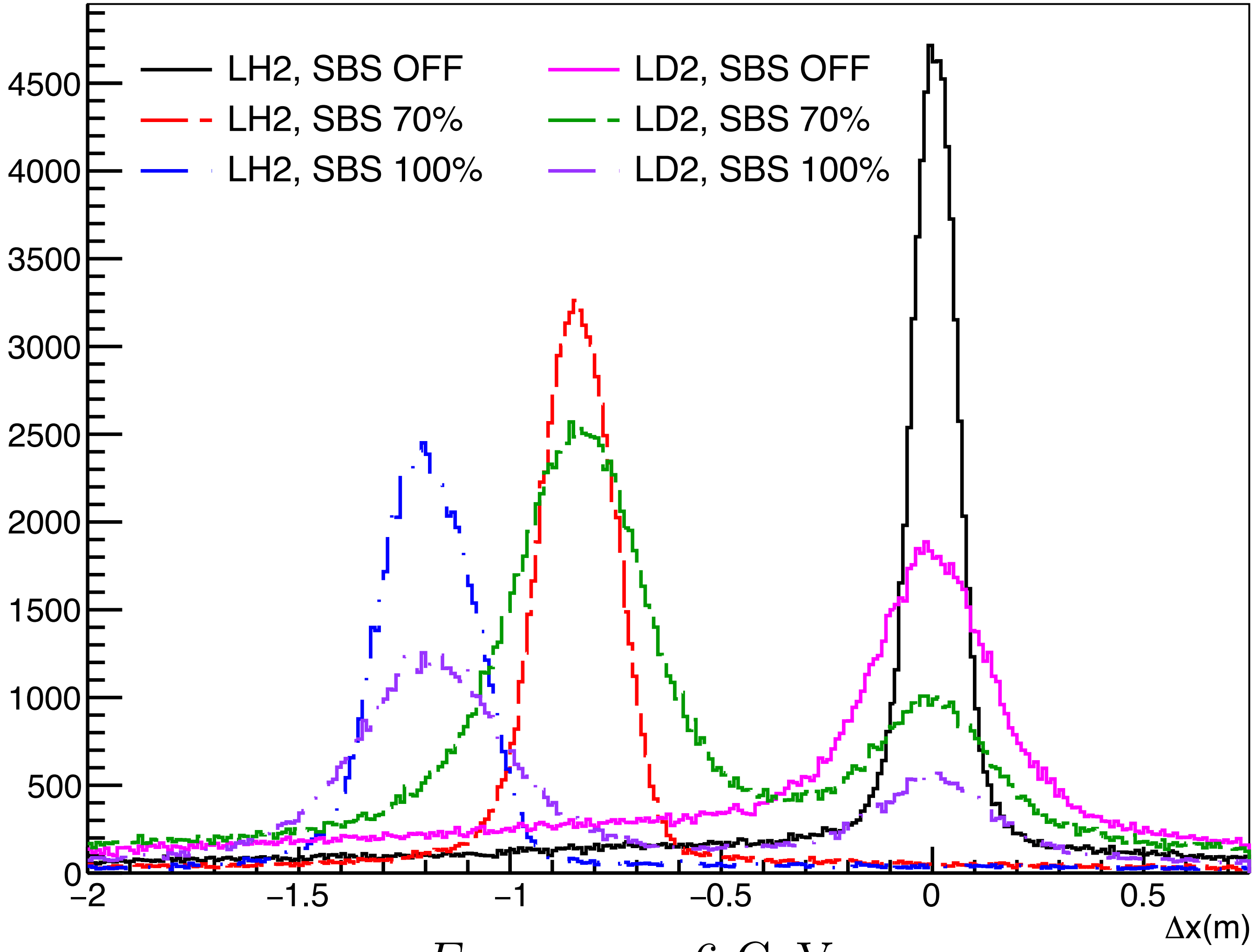


- Single-event display from BigBite GEM trackers during typical SBS GMN production run

BigBite calorimeter narrows search region for tracking

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

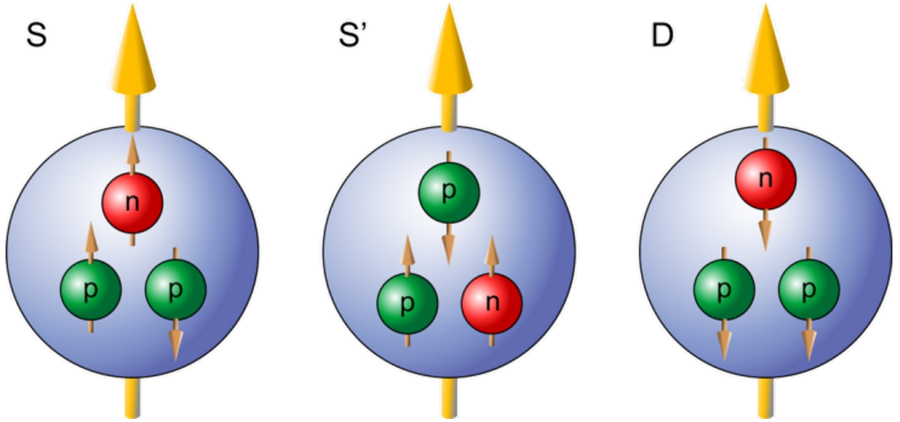
Neutron/proton separation



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

- Nucleon charge ID is accomplished by a small vertical deflection of protons in SBS magnet
- Optimal deflection is that which gives "clean" n/p separation while minimizing acceptance/efficiency difference between neutrons and protons
- "Fiducial cut" is calculated based on reconstructed *electron* kinematics—requires that both proton and neutron in quasi-elastic kinematics would hit HCAL active area with a safety margin equivalent to ~100 MeV Fermi smearing
- Plenty of hydrogen elastic scattering data (~1/8 of production data) for detector calibrations and cross checks

Helium-3 as an Effective Polarized Neutron Target



~87% ~8% ~1.5%

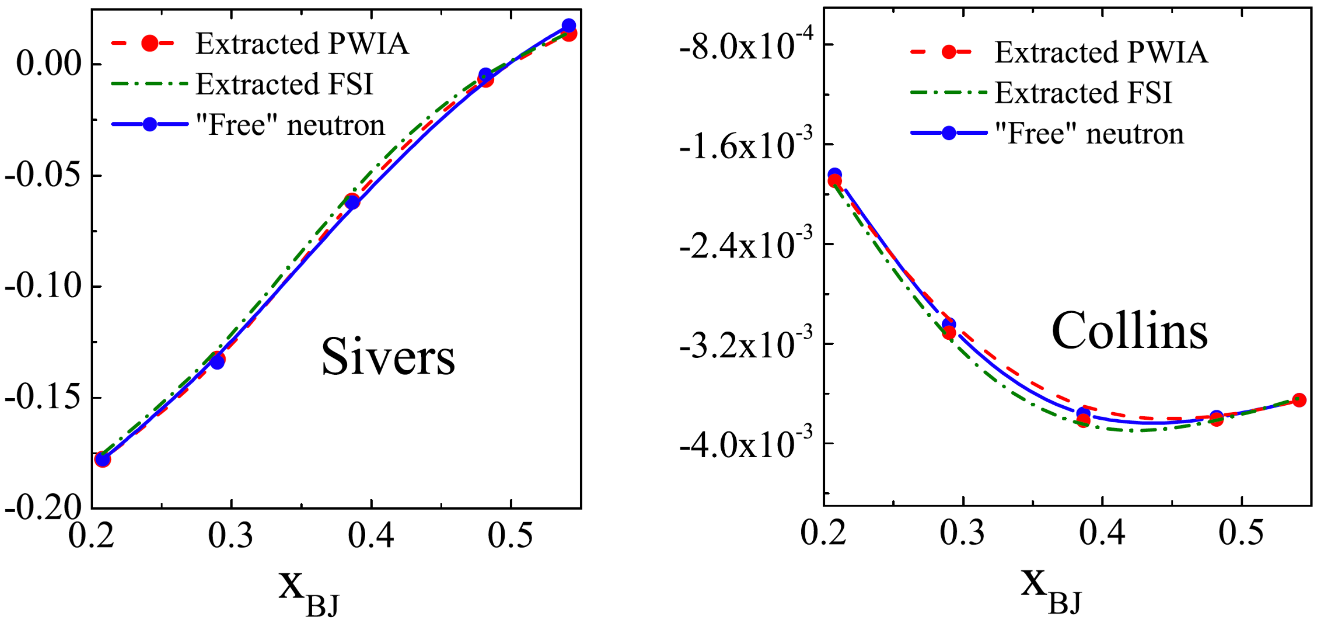
$$A_{^3\mathrm{He}} = P_n(1-f_p)A_n + P_p f_p A_p$$

$$P_n = 0.86^{+0.036}_{-0.02}$$

$$P_p = -0.028^{+0.009}_{-0.004}$$

$$f_p = \frac{2\sigma_p}{\sigma_{^3\mathrm{He}}}$$

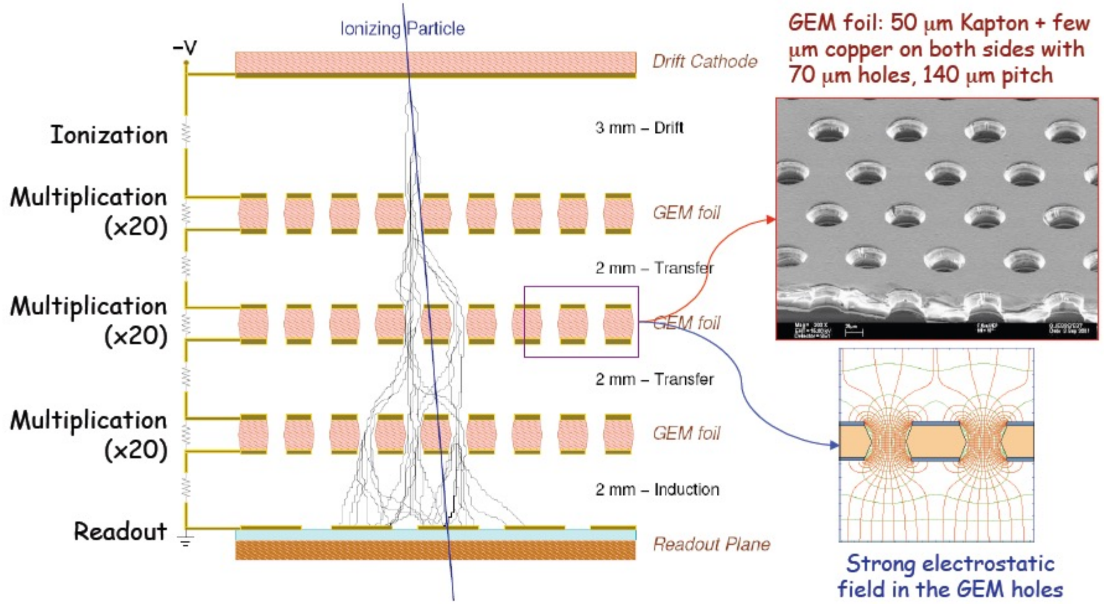
Effective nucleon polarization approximation for DIS on Helium-3:
Scopetta, Phys. Rev. D 75, 054005 (2007)



Del Dotto *et al.,* Phys. Rev. C 96, 065203 (2017)

- Effect of nuclear FSI on extraction of neutron Collins and Sivers effects from SIDIS on ^{3}He under good theoretical control
- Advantages of Helium-3 for study of polarized neutron:
  - Protons almost unpolarized
  - High luminosity capability (up to several 10^{37} cm^{-2} s^{-1})
  - Small holding field → small systematics of target spin flips

Gas Electron Multipliers (GEMs): High-Rate, High Resolution Charged-Particle Tracking



Recent technology: F. Sauli, NIM A 386, 531 (1997)

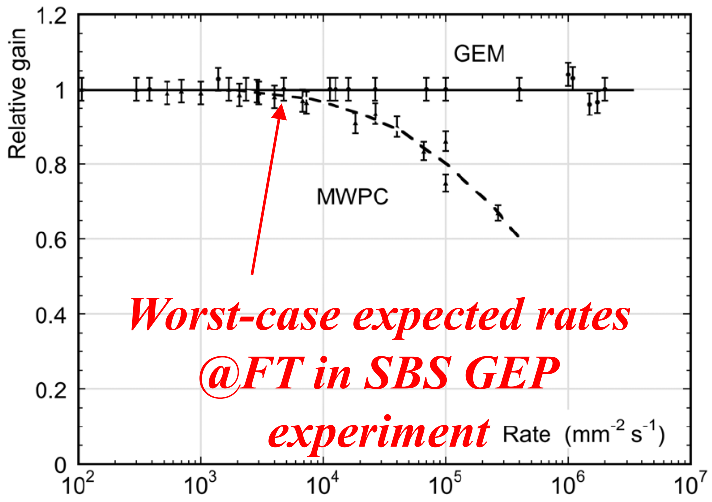
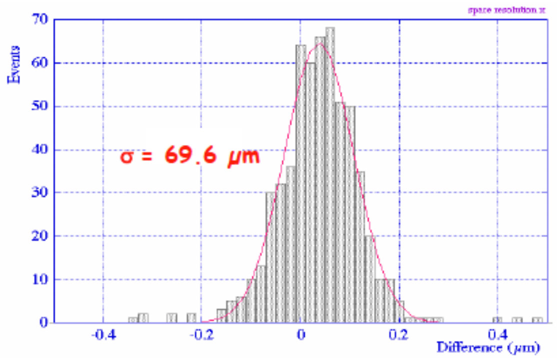


Figure 28.9: Normalized gas gain as a function of particle rate for MWPC [70] and GEM [84].

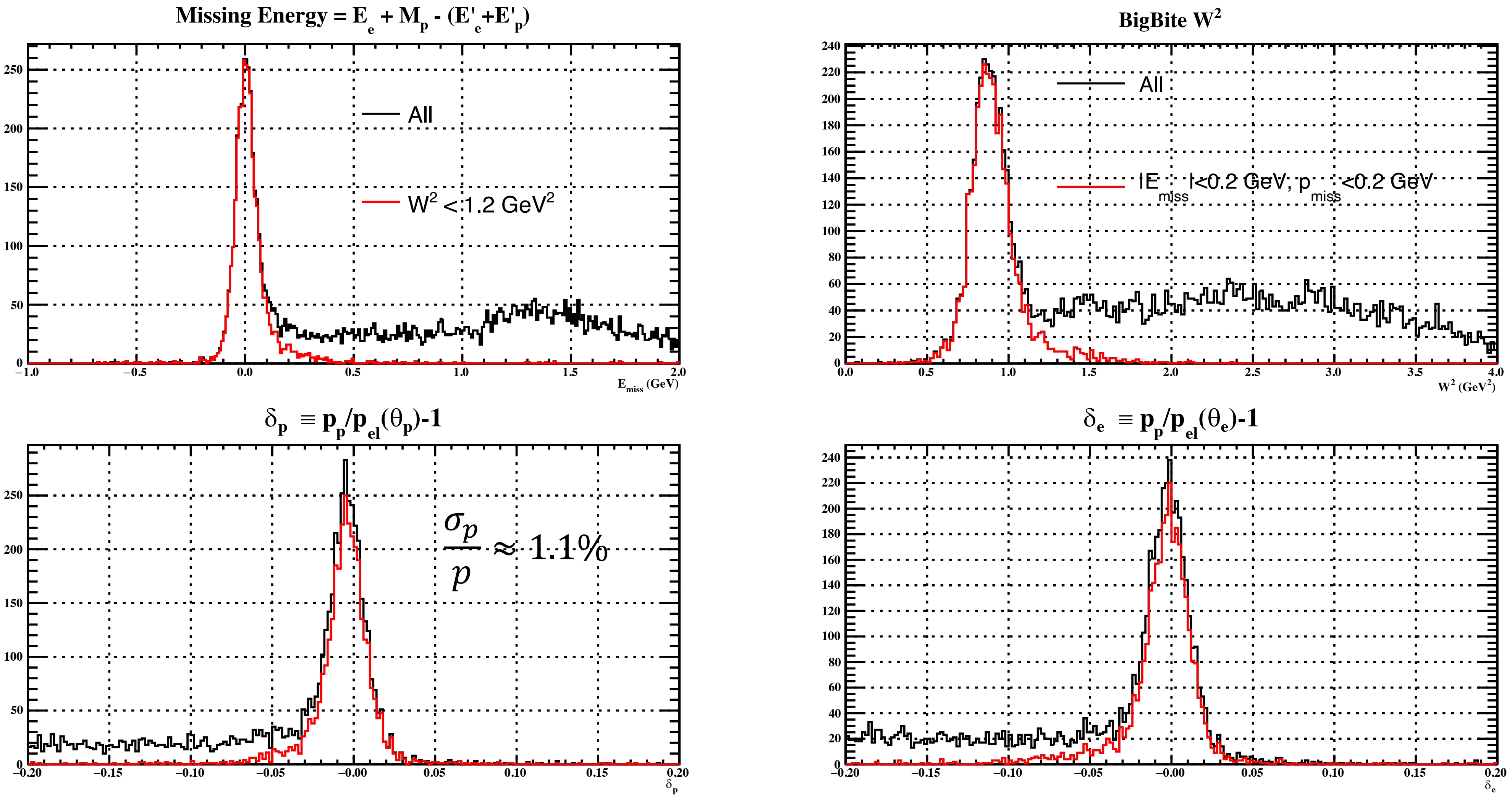
Stable gain up to very high rates

- High spatial granularity
- Ability to cascade several foils: higher gain at lower voltage, reduced discharge risk
- Readout and amplification stages decoupled
- Excellent spatial resolution ~70 μm
- Fast signals: intrinsic time resolution <10 ns
- **Enabling technology for SBS physics program!**



Space resolution

SBS optics after alignment (REAL H(e,e'p) DATA from GEN-RP!)



After zero-field GEM alignment, SBS optics model from TOSCA+GEANT4 gives expected resolution/accuracy of kinematic reconstruction with **no fine-tuning!**

SBS Optics: Missing Momentum Components