GEP Analysis Status

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SBS Collaboration Meeting
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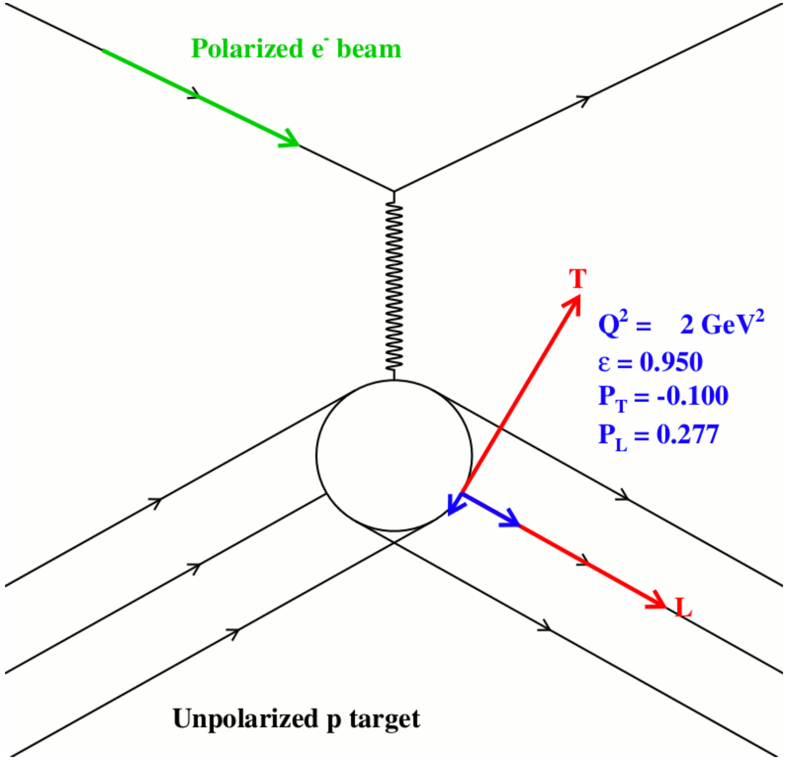
Outline

- Introduction
- Recoil Polarization Technique
- SBS GEP layout
- Statistics—what we "should" have versus what we can already more-or-less project that we have
- Event Reconstruction in GEP
- Efficiency challenges and plans to overcome
- First look at FPP asymmetries
- Summary and Conclusions

Polarization Transfer Method



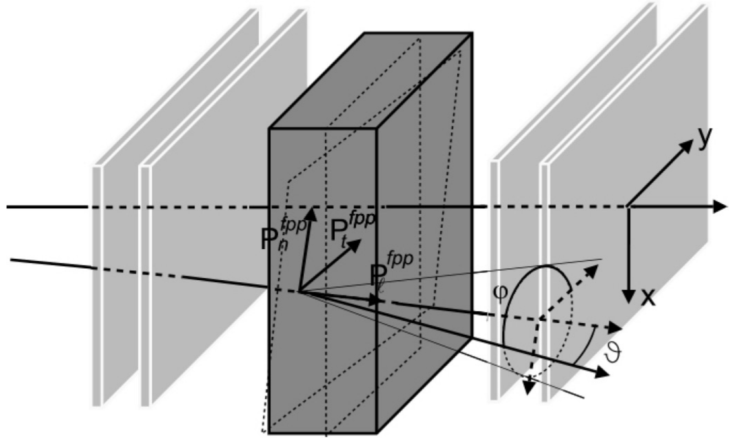


FIG. 9. Principle of the polarimeter, showing a noncentral trajectory through the front chambers, scattering in the analyzer, and a track through the back chambers; ϑ is the polar angle, and φ is the azimuthal angle from the y direction counterclockwise.

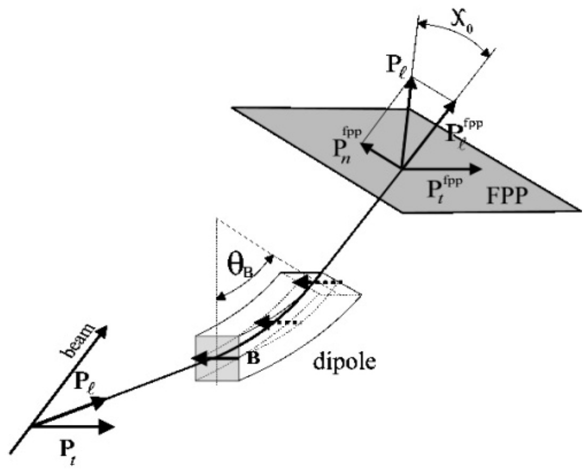
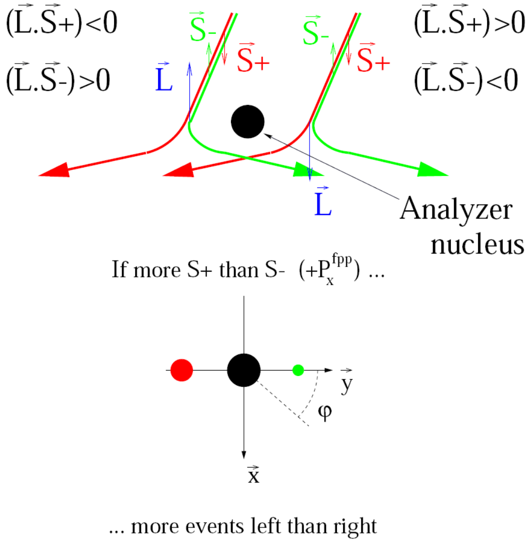


FIG. 15. Precession of the polarization component P_ℓ in the dipole of the HRS by an angle χ_θ.

- Based on spin-orbit coupling in proton-nucleus scattering



- A spin-1/2 particle, such as a proton, is preferentially deflected by the nuclear spin-obrit force along the direction of $\vec{p}\times\vec{S}$, where $\vec{p}$ is the incident proton momentum, and $\vec{S}$ is the proton spin.
    - A spin-orbit force is insensitive to longitudinal polarization!
    - Precession in a magnetic field rotates P_L into a transverse component that can be measured
- Azimuthal asymmetry in the angular distribution of secondary scatterings measures $\vec{S}$

Polarization transfer and the ratio $\mu_p G_E^p / G_M^p$: 6 GeV era Hall A/C results

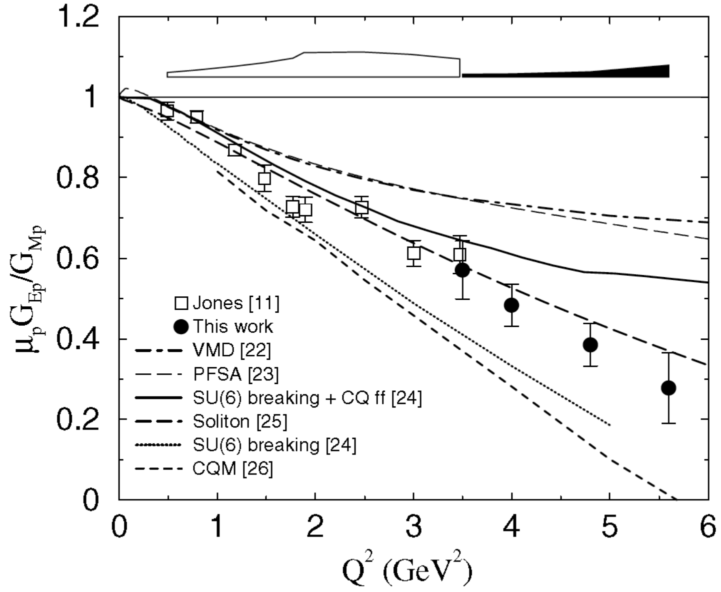


FIG. 2. The ratio $\mu_p G_{E_p}/G_{M_p}$ from this experiment and Jones *et al.* (Ref. [11]), compared with theoretical calculations. Systematic errors for both experiments are shown as a band at the top of the figure.

Gayou *et al.*, PRL 88, 092301 (2002) ("GEp-II")

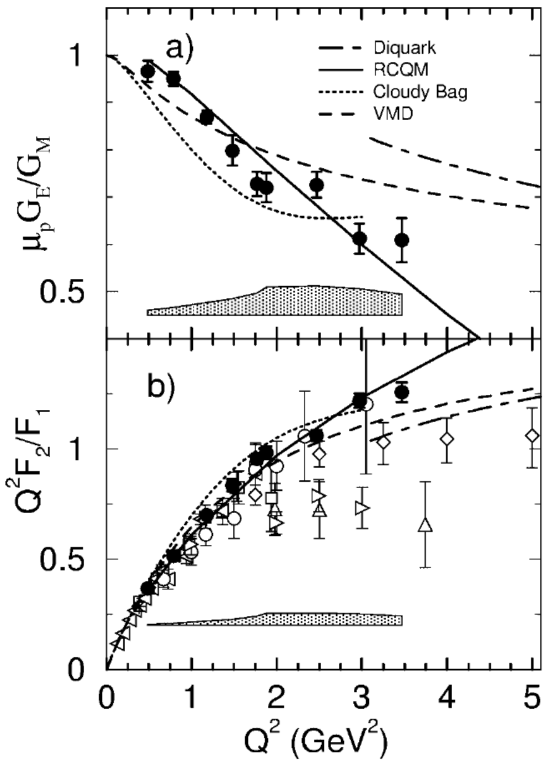
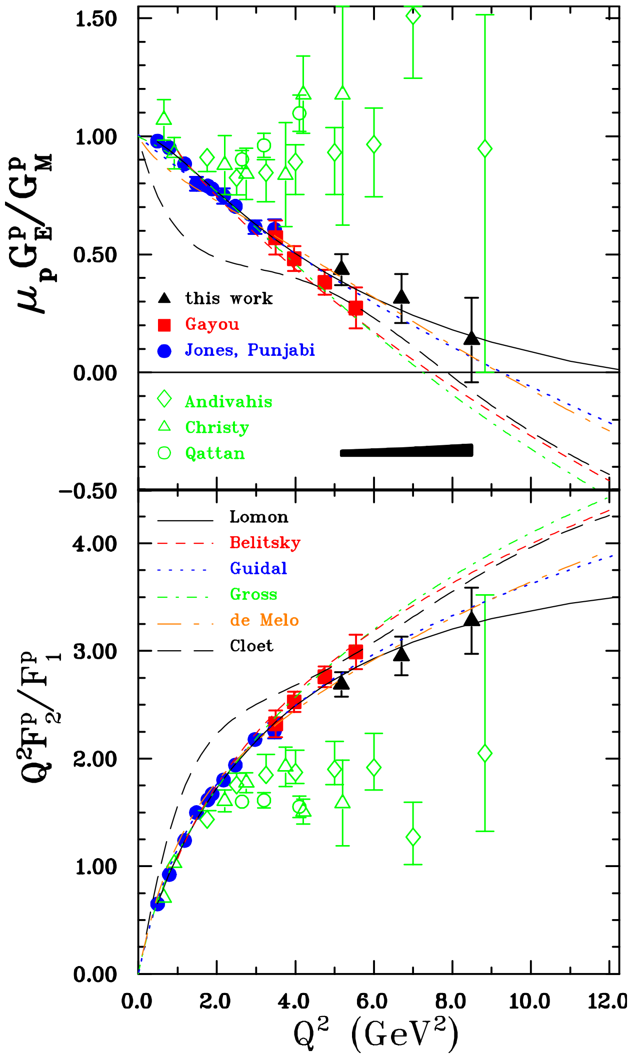


FIG. 2. (a) The ratio $\mu_p G_{E_p}/G_{M_p}$ from this experiment, compared with theoretical calculations. (b) The ratio $Q^2 F_{2_p}/F_{1_p}$ for the same data, compared to the same theoretical models as in (a) and world data; symbols as in Fig. 1. In both (a) and (b) the absolute value of systematic error from this experiment is shown by the shaded area.

Jones *et al.*, PRL 84, 1398 (2000) ("GEp-I")



Puckett *et al.*, PRL 104, 242301 (2010)

- Figures at right are from Punjabi *et al.,* PRC 71, 055202 (2005)

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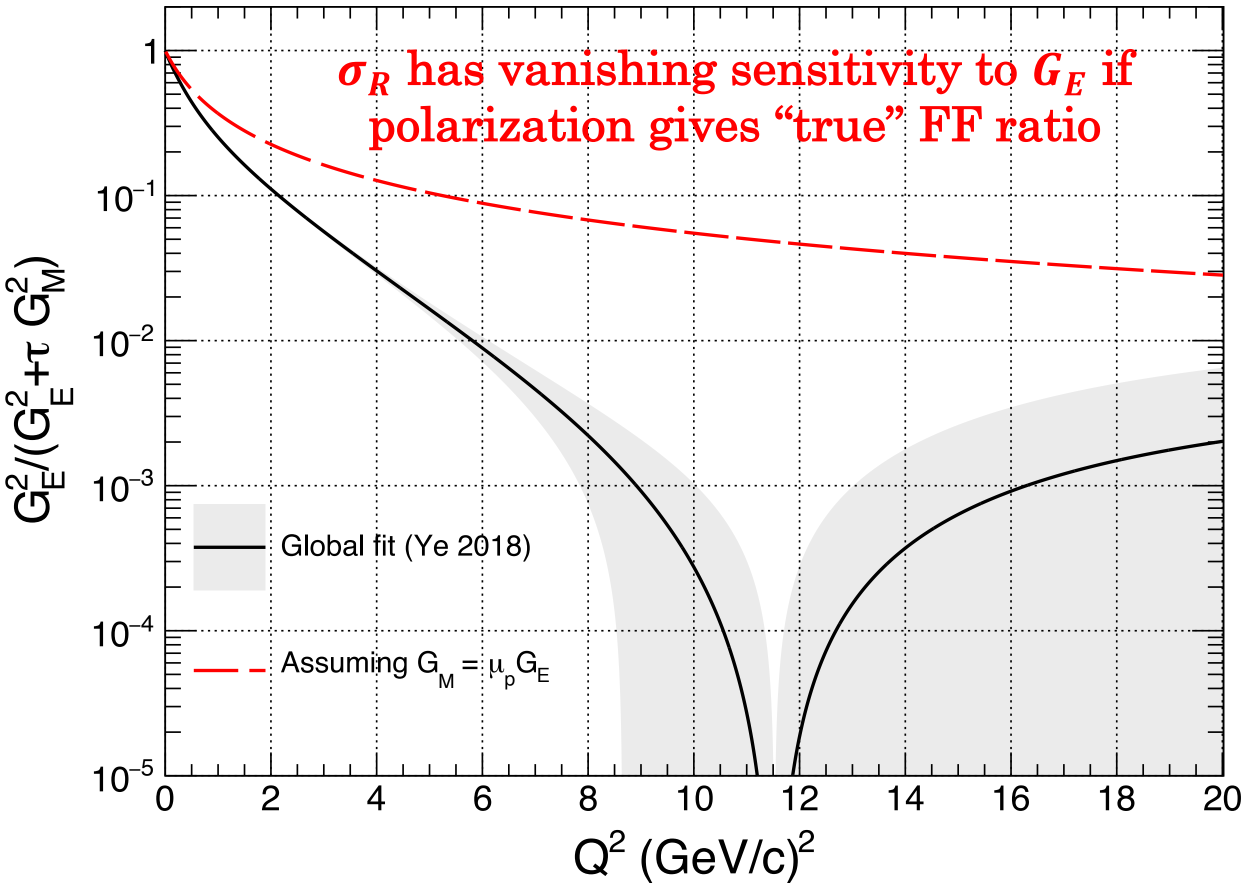
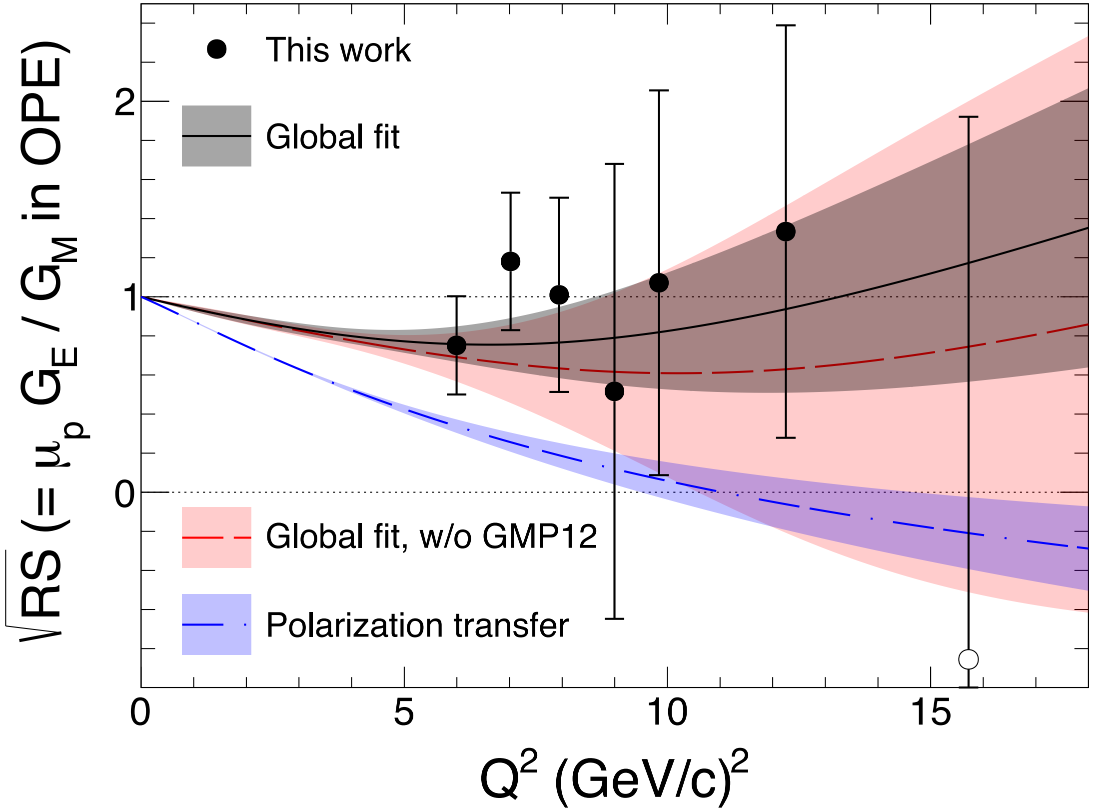
The Problem with Rosenbluth Separations

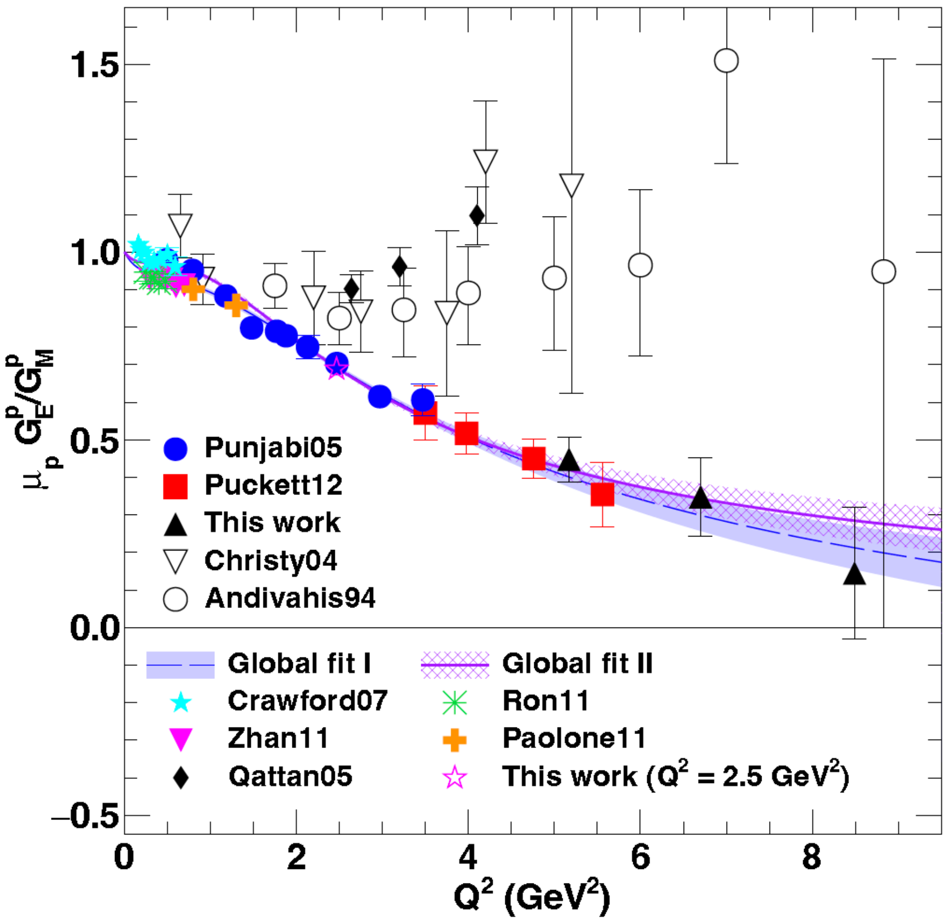


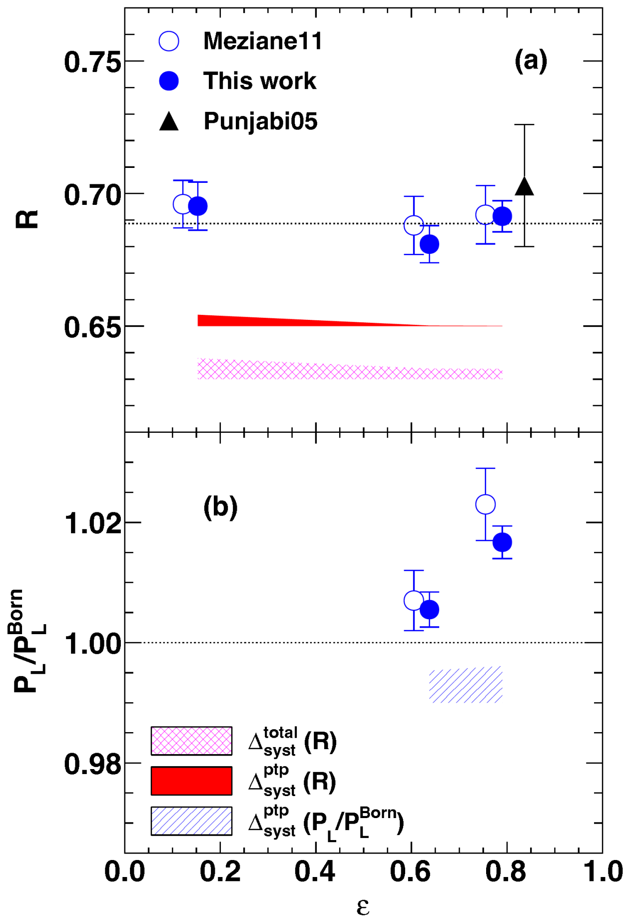
Maximum Fraction of the Reduced Cross Section Carried by the electric term versus Q^2 (50 years of QCD: EPJ C 83:1125 (2023))



High-Q^2 Rosenbluth Separations from Hall A: Christy *et al.*, **Phys. Rev. Lett.** 128, 102002 (2022)

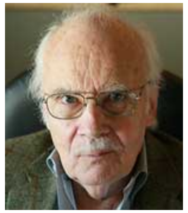
The APS Bonner Prize in Nuclear Physics, 2017





Puckett *et al.*, PRC 96, 055203 (2017)

2017 Tom W. Bonner Prize in Nuclear Physics Recipient



Charles F. Perdrisat
College of William and Mary

Citation:

"For groundbreaking measurements of nucleon structure, and discovering the unexpected behavior of the magnetic and electric nucleon form factors with changing momentum transfer."

Background:

Charles F. Perdrisat, Ph.D., was a professor at the College of William and Mary (Williamsburg, Va.) for the last 50 years having retired earlier this year. Throughout his career, Dr. Perdrisat's research focus included nuclear reactions with proton and deuteron beams, both polarized and unpolarized. He conducted research at SATURNE in Saclay, France, TRIUMF in Vancouver, B.C., LAMPF in Los Alamos, New Mexico, Brookhaven National Laboratory in Upton, N.Y., and JINR in Dubna, Russia. During the last half of his career, he was committed to the investigation of the structure of the proton at Jefferson Laboratory, concentrating in obtaining polarization transfer data in the scattering of polarized electrons on unpolarized protons. These data, from 3 distinct experiments organized in close collaboration with Vina Punjabi, Ph.D., Mark K. Jones, Ph.D., Edward J. Brash, Ph.D., and Lubomir Pentchev, Ph.D., have resulted in a significant change of paradigm in the understanding of the structure of the nucleon. After completing his undergraduate training in physics and mathematics at the University of Geneva in 1956, Dr. Perdrisat became an assistant in the physics department at the Swiss Federal Institute of Technology in Zurich) in Switzerland, under Prof. Paul Scherrer; he received his Ph.D. in 1962. He completed a three-year postdoctoral fellowship at the University of Illinois Urbana-Champaign, before heading to William and Mary in 1966.

Selection Committee:

2017 Selection Committee Members: Rocco Schiavilla (Chair), D. Hertzog, P. Jacobs, Kate Jones, I-Y. Lee

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:

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

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

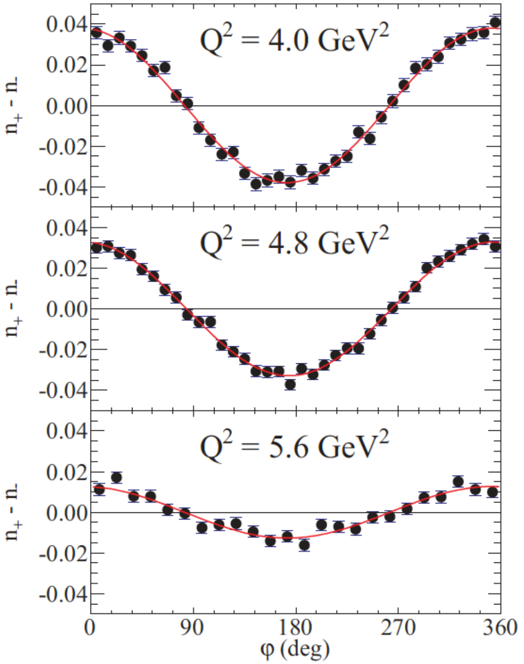


FIG. 6. (Color online) Focal-plane helicity-difference asymmetry $n_+ - n_- \equiv (N_{\text{bins}}/2)[N^+(\varphi)/N_0^+ - N^-(\varphi)/N_0^-]$, where N_{bins} is the number of φ bins and $N^{\pm}(\varphi)$, $N_0^{\pm}$ are defined as in Eq. (4), for the three highest Q^2 points from GEp-II. Curves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

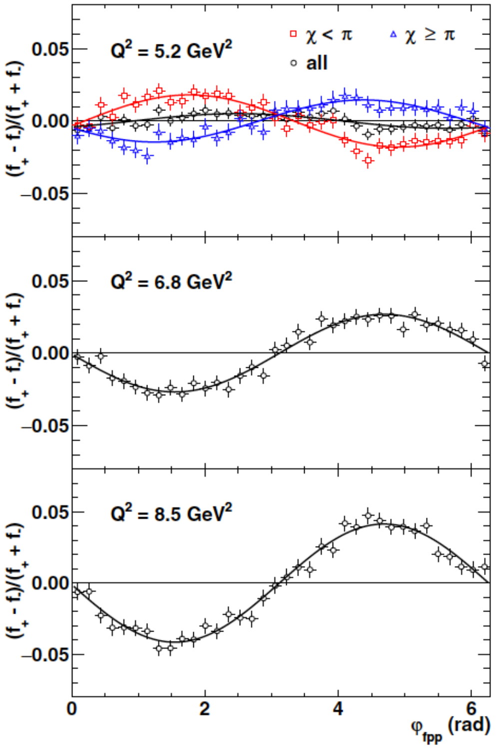


FIG. 10. Focal plane helicity difference/sum ratio asymmetry $(f_+ - f_-)/(f_+ + f_-)$, defined as in Eq. (20), for the GEp-III kinematics, for FPP1 and FPP2 data combined, for single-track events selected according to the criteria discussed in Sec. III B 2. Asymmetry fit results are shown in Table V. 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!

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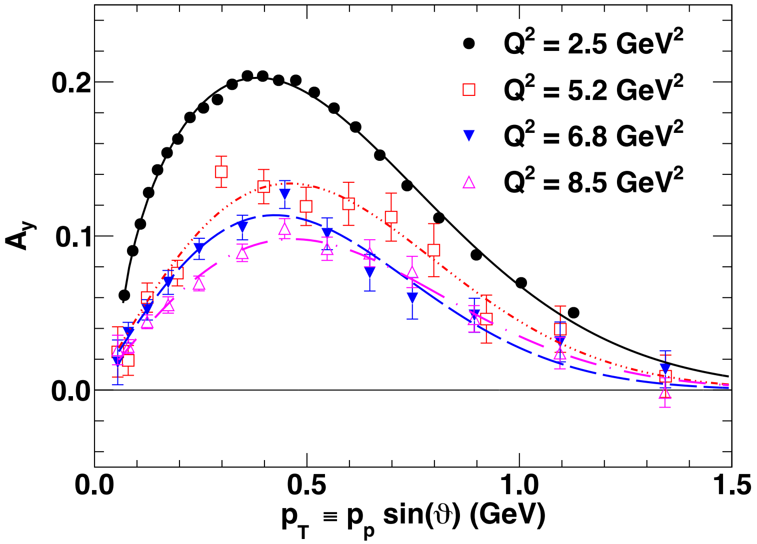
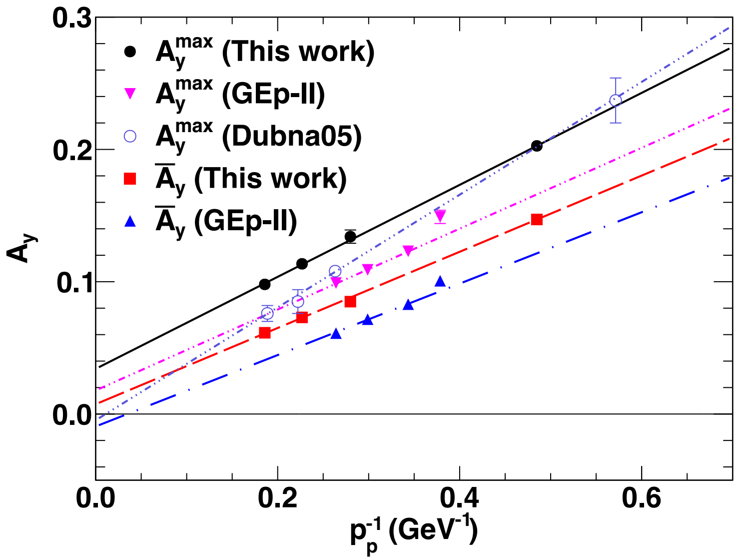
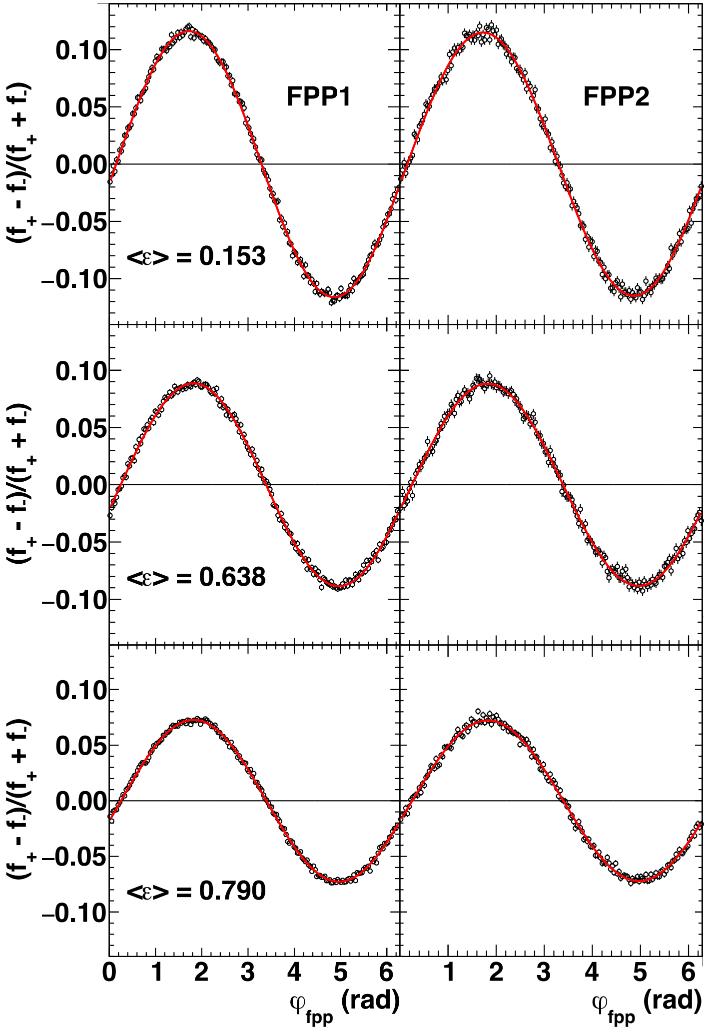
Proton Polarimetry Figure-of-Merit Ingredients

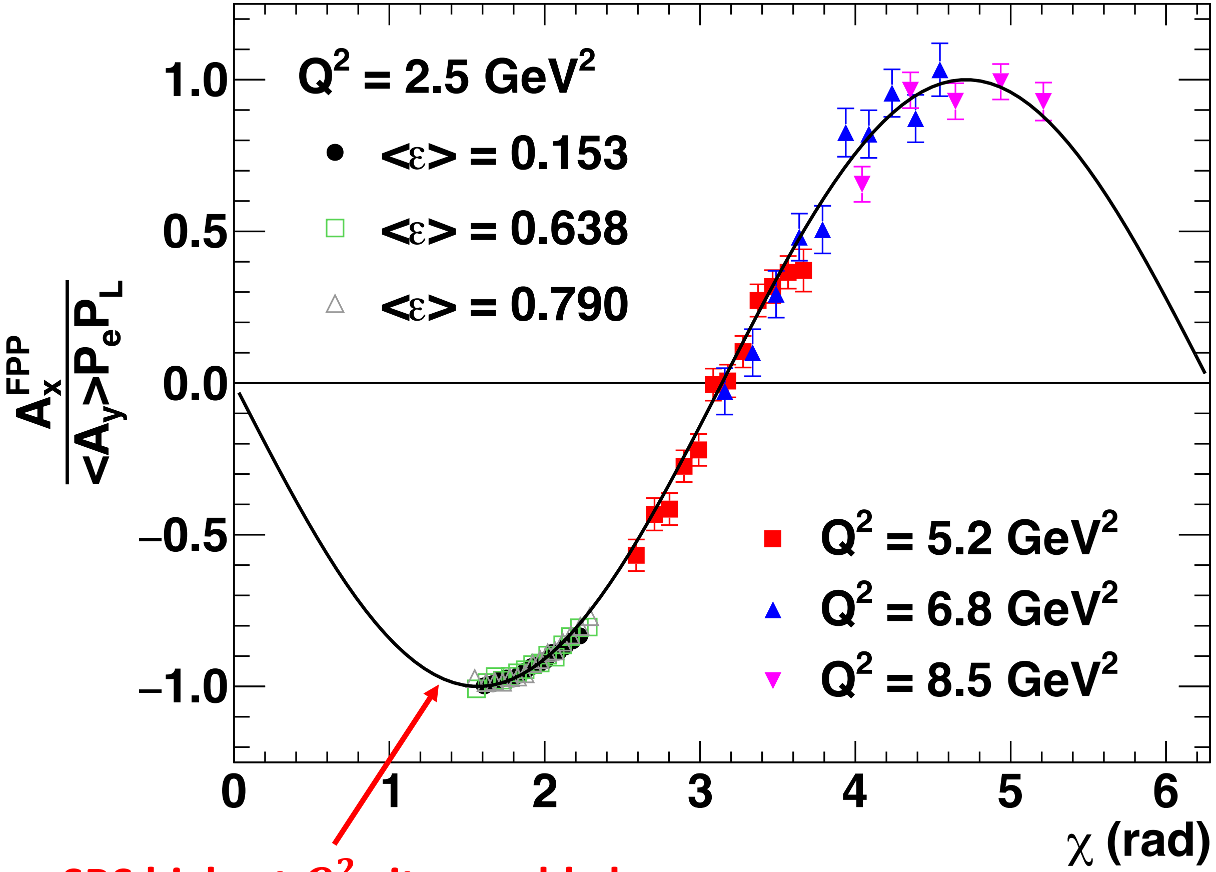






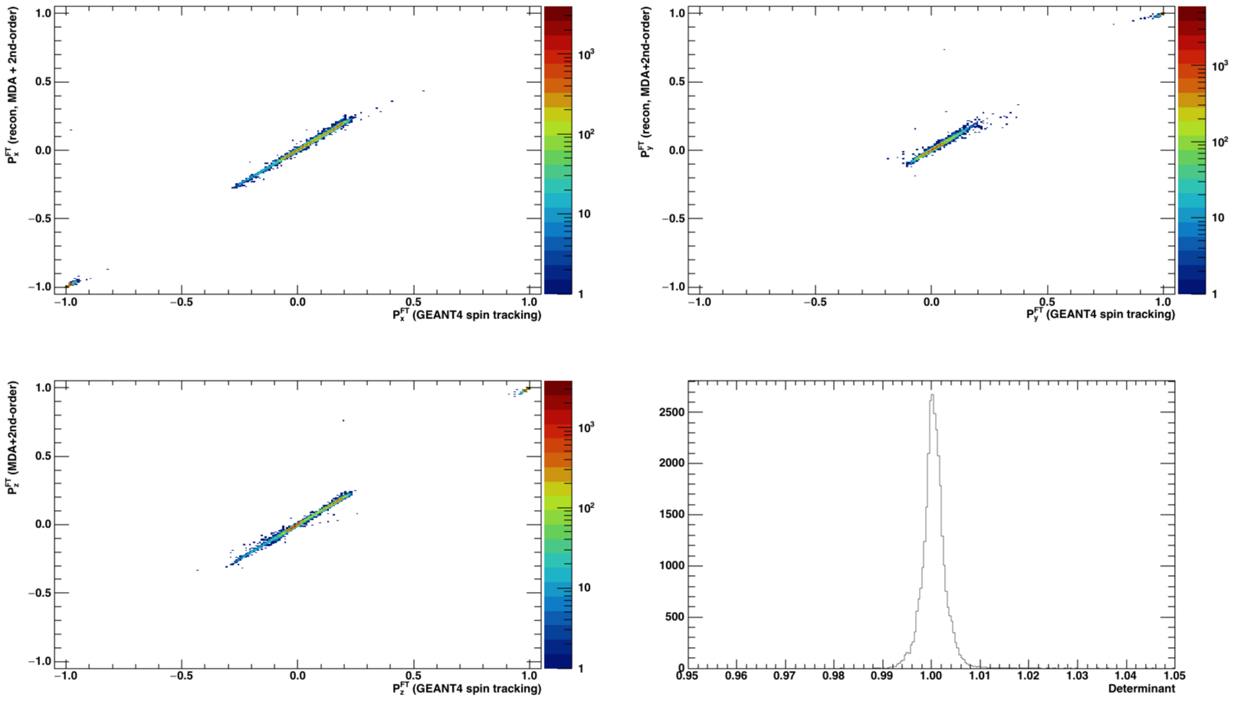
- Figures from **Puckett *et al.*, PRC 96, 055203 (2017)**
- Elastic *ep* reaction is self-calibrating for analyzing power.
- Analyzing power estimates for $p + CH_2$ parametrized from GEp-III data.
- Angular distribution has roughly constant shape versus “transverse momentum” and overall $\frac{1}{p_p}$ scaling with incident proton momentum
- SBS GEP FOM estimates were done using GEANT4 simulation of SBS polarimeter and parametrized angular/momentum dependence of analyzing power, with modest extrapolation to highest Q^2 of SBS GEP

Spin Precession



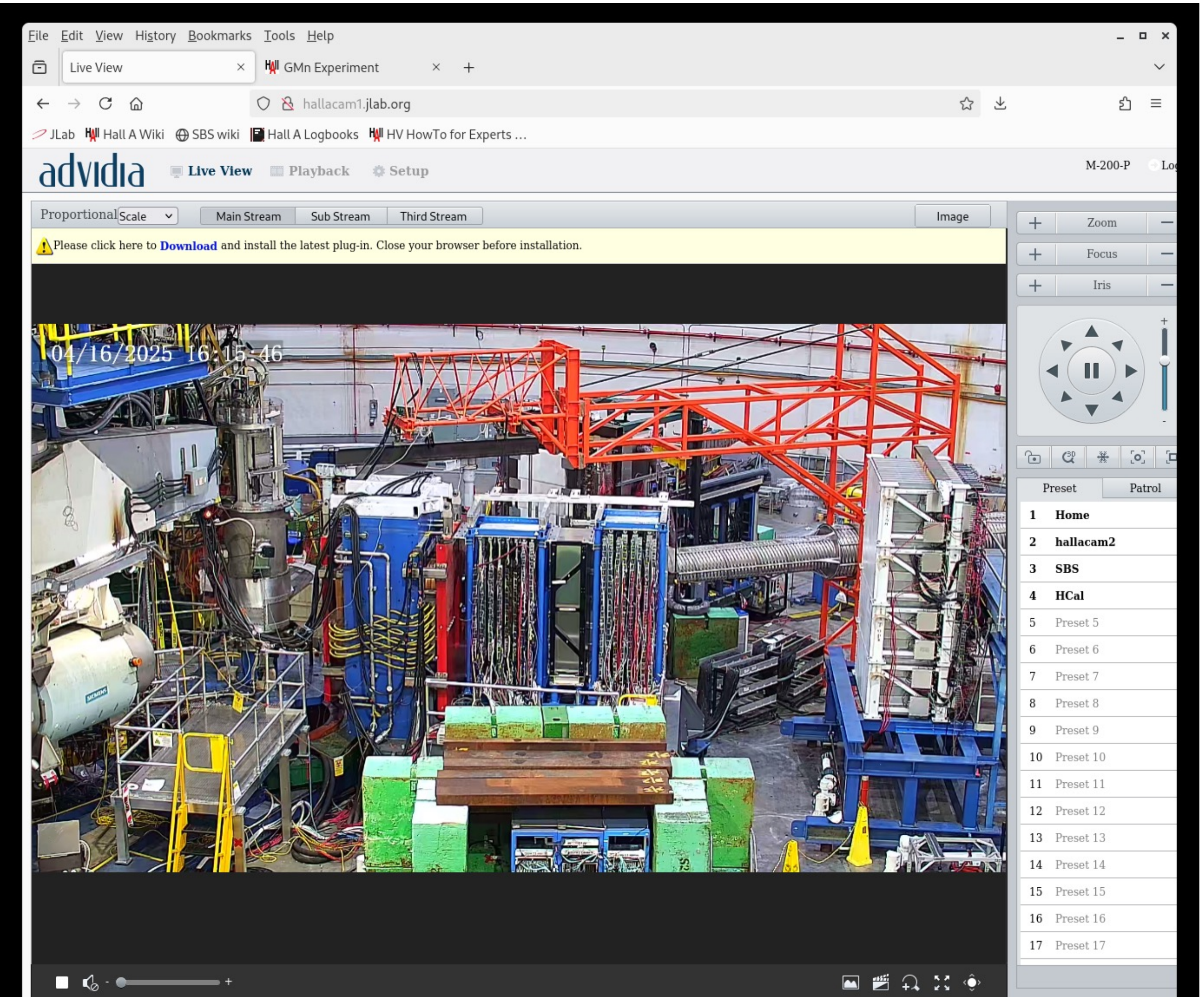
SBS highest Q^2 sits roughly here

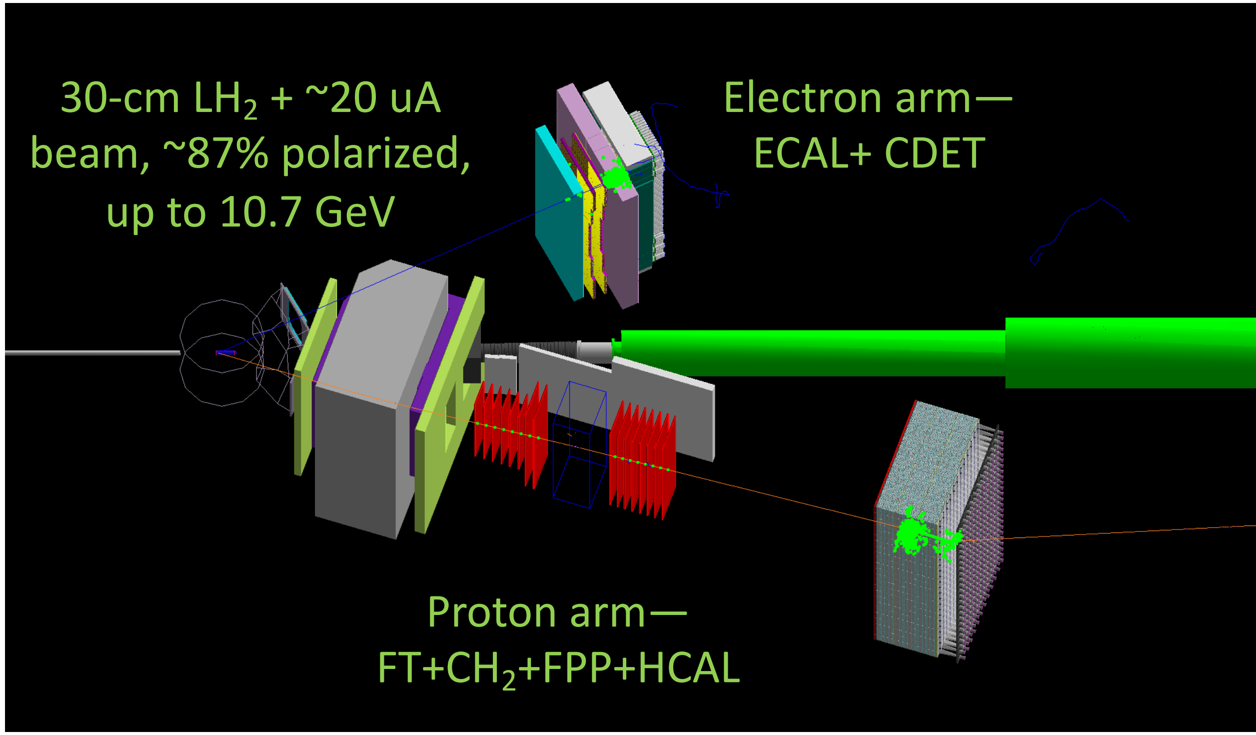
- Above: normal asymmetry versus precession angle from GEp-III and GEp-2γ, illustrating primary $-\sin(\chi)$ dependence. Figure from *Phys.Rev.C* 96 (2017) 5, 055203



- Above: Correlations between fitted and “true” proton polarization components at the ”focal plane” using GEANT4 spin tracking and determinant of resulting 3x3 rotation matrix.

SBS GEP Layout

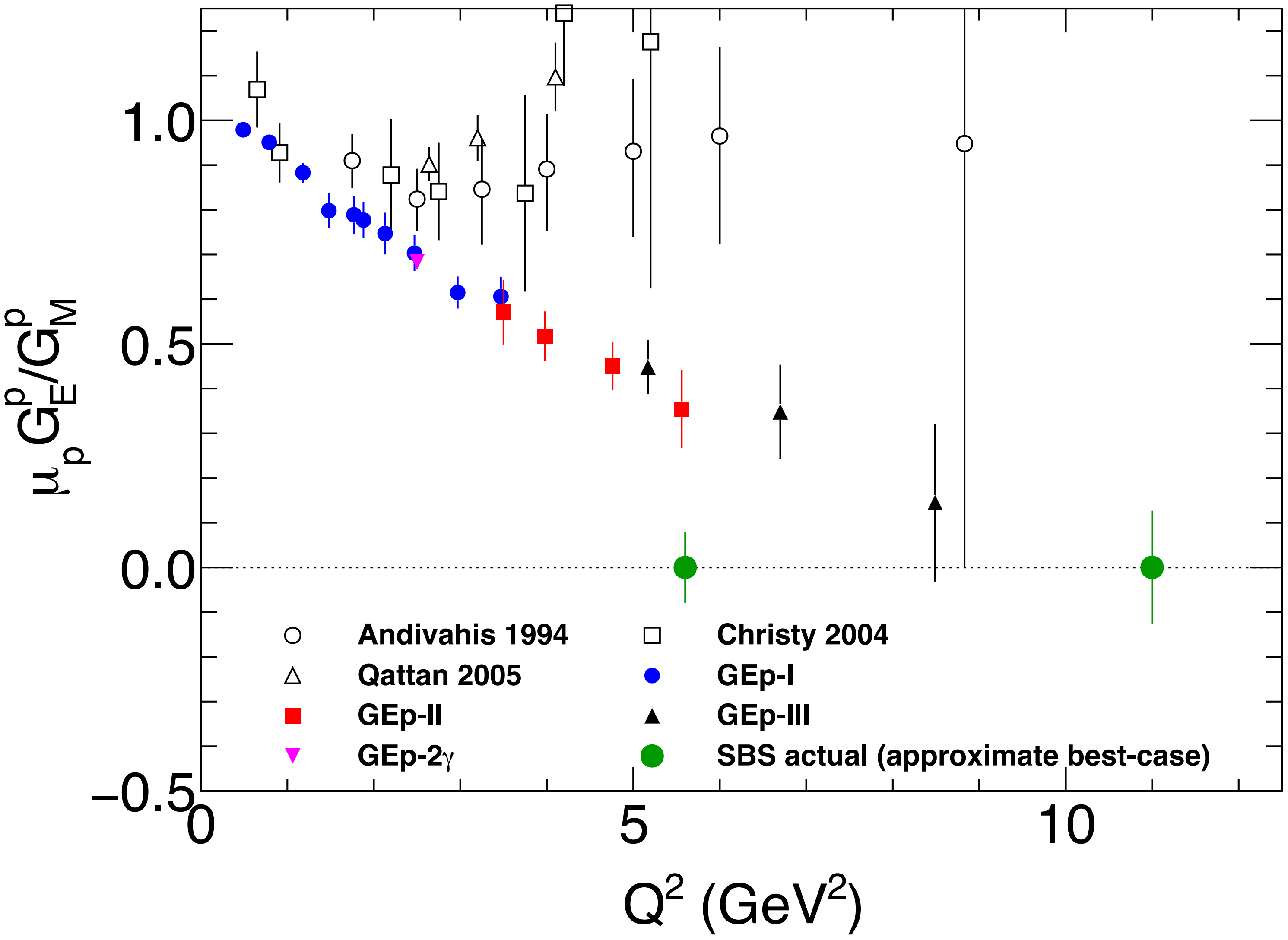




- Left: Hall Camera During GEP
- Right: A simulated elastic *ep* event in *g4sbs*

Summary of data collected and best-case scenario for physics result

- Total charge collected (live-time corrected):
  - $Q^2 = 5.6\ GeV^2$: 3.7 C
  - $Q^2 = 11\ GeV^2$: 94.2 C
- Note: these estimates are based on the "GEp5 Run Sheet" and may be slight under (or over) estimates.
- These projections represent somewhat optimistic *best-case* scenarios assuming overall trigger/detection/reconstruction efficiency of 70% (not accounting for radiative losses).
- Reality will fall short of this projection, perhaps significantly.

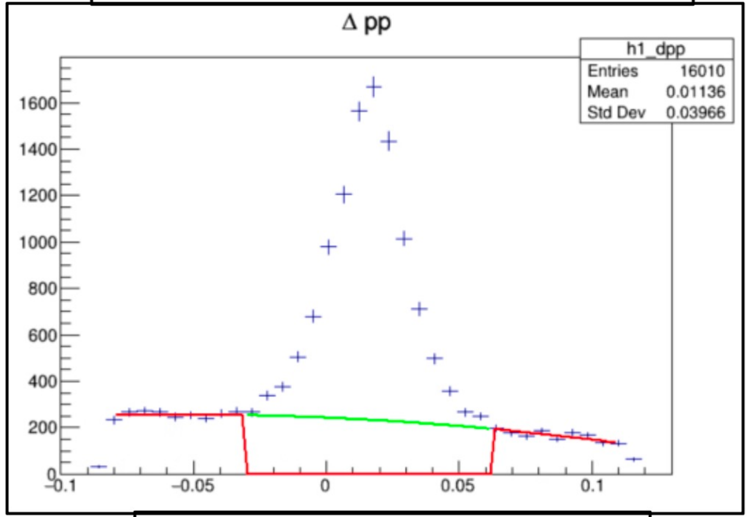


GEP statistics—what we “should” have at 11 GeV^2

- For 94.2 C of (live-time corrected) beam charge, *g4sbs* (+ dig. + recon) predicts that we should have ~8.9M events passing trigger + tracking + exclusivity cuts (including small-angle scattering events in the FPP), assuming 70% ”overall” (trigger/detection/reconstruction) efficiency (relative to “ideal” case), and extrapolating GEp-III analyzing power parametrization assuming a $1/p_p$ scaling.
- This leads to a projected absolute statistical uncertainty of $\Delta_{stat}\left(\frac{\mu_p G_E^p}{G_M^p}\right) \approx 0.13$ at $Q^2 = 11$ GeV^2 as conservative “best case” scenario (not accounting for radiative losses).
- The “best case scenario” for physics error bar would be closer to 0.11 with efficiency at 100% of ”ideal” (”ideal” here means “expected from background-free MC simulation with full digitization and reconstruction”)

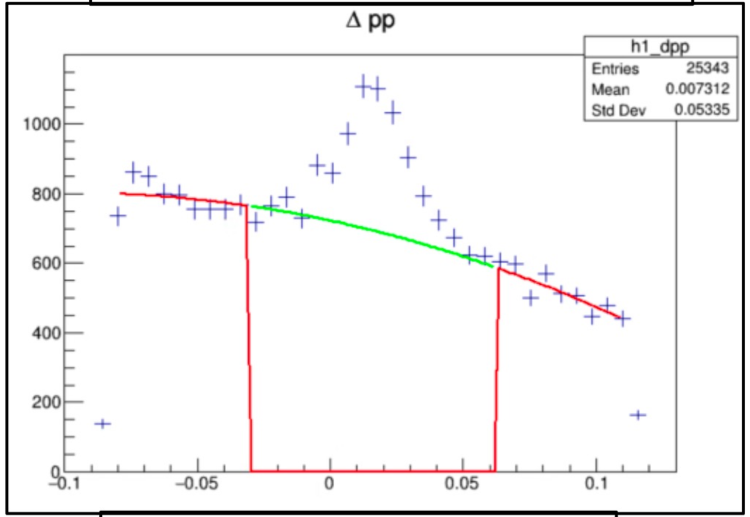
GEP Statistics—What about "worst case" scenarios?

15 uA run elastic yield



Heep yield/C = **24K**

22 uA run elastic yield

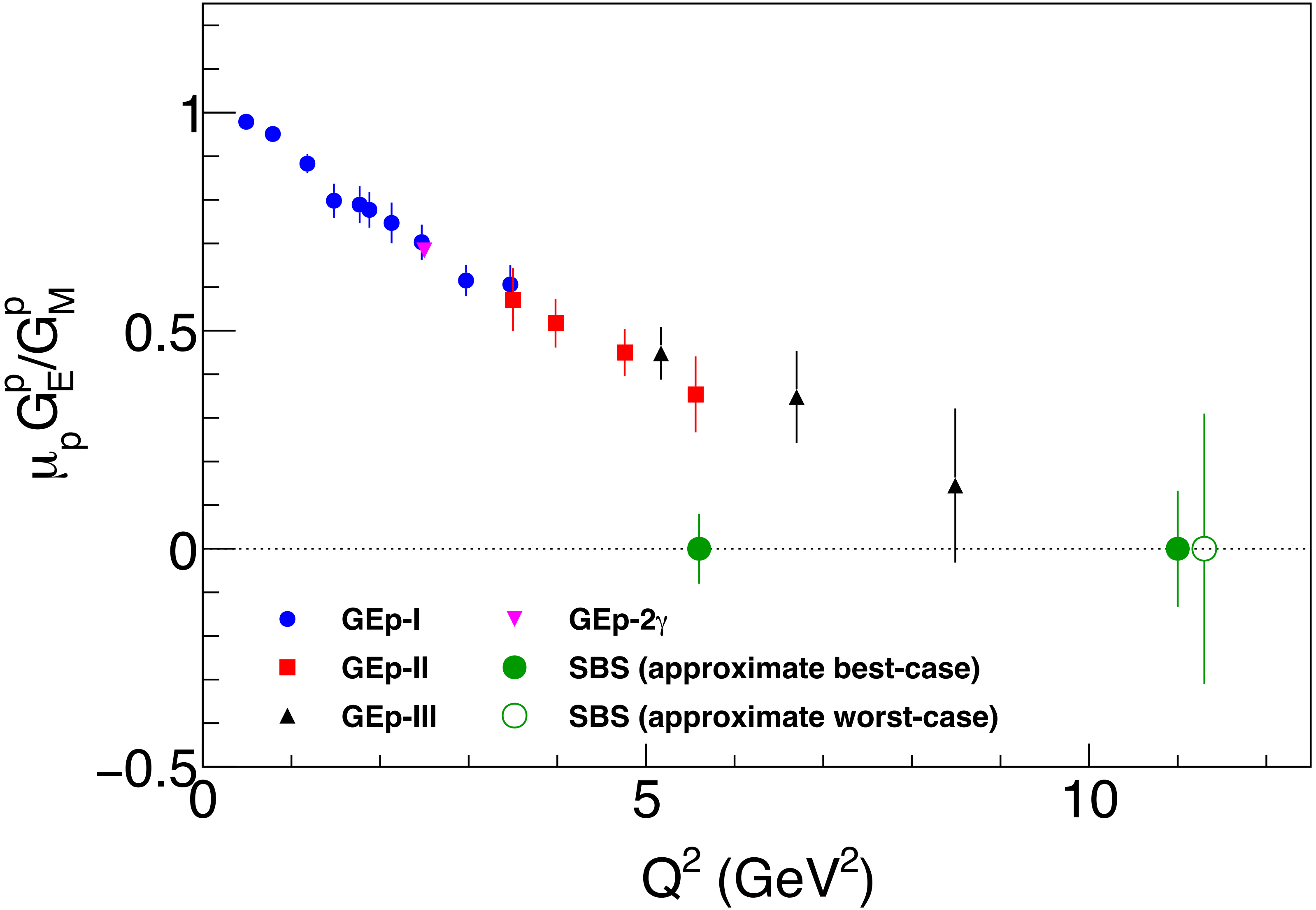


Heep yield/C = **11K**

- Yield extractions by Anuruddha Rathnayake (Uconn)
- NOTE: "ideal" expected elastic yield from *g4sbs+dig+recon* with zero background (w/o radiative corrections) and "typical" event selection cuts is approximately 94K/C

- I attempted a very rough estimate of our "worst case" elastic *ep* statistics for 11 GeV^2 (without benefit of a full cooking pass) based on what we have already demonstrated we can reconstruct.
- From the GEp "Run Sheet", I calculated a rough, charge-weighted average beam current during Kin. 3 running, obtaining a result of 18.8 uA.
- Interpolating between 15 uA and 22 uA yields reconstructed by Anu (representative examples), I estimated an "average" elastic yield of 17K/C (~18% overall "efficiency" relative to "ideal")
- In the "worst case" scenario, then, we should have ~1.6M "good" events passing our typical elastic ep cuts requiring both front and back tracks (including small-angle scatterings in the CH_2)

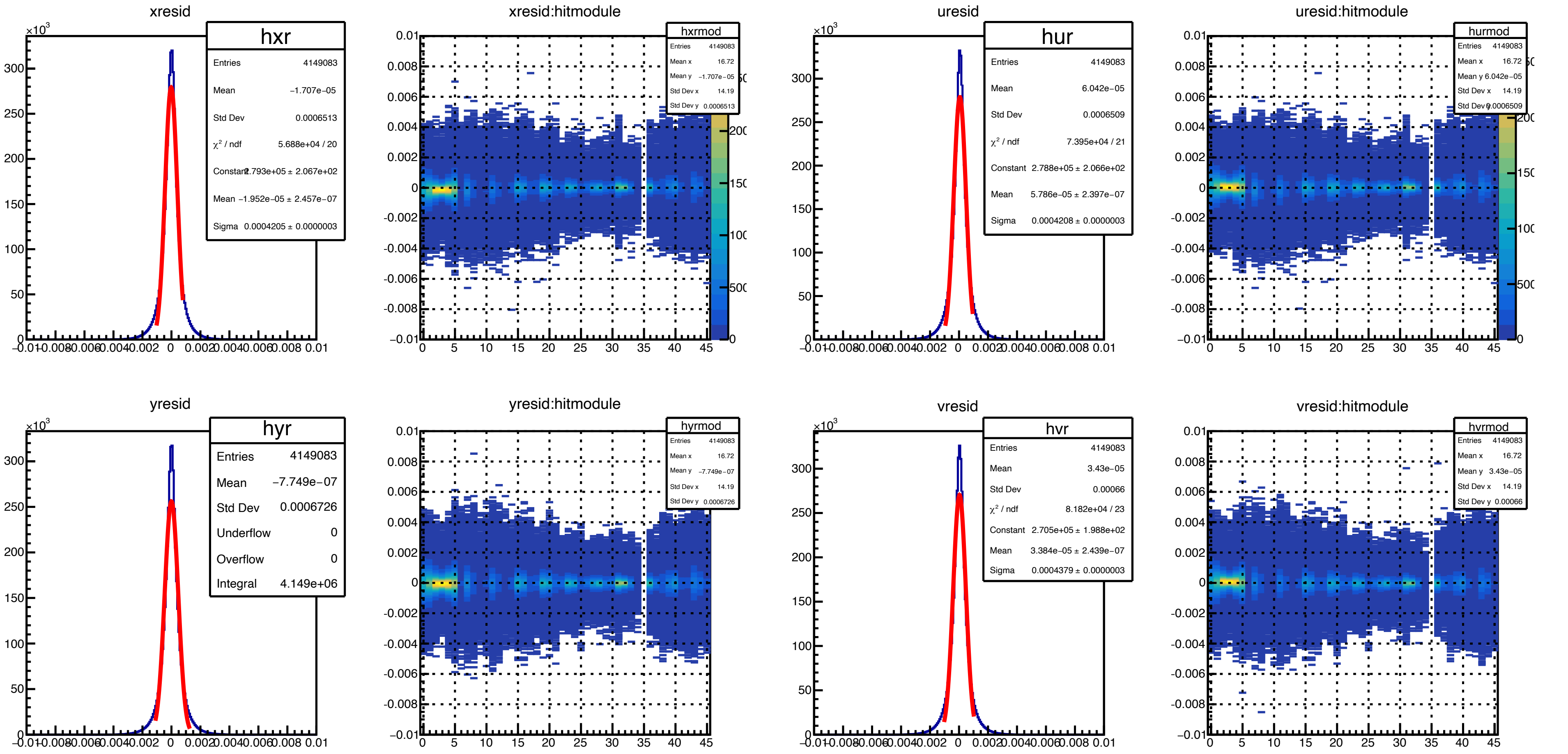
Approximate "Worst Case" Projection for 11 GeV^2



- Assuming no further improvements in reconstruction efficiency
- Still assumes analyzing power can be extrapolated from GEp-III parametrization with $1/p_p$ scaling→ this is still a wildcard!
- I didn't yet have time to repeat this exercise for Kin. 1, but a similar scaling from "best case" to "worst case" might be a reasonable assumption
- Actual result might land about halfway between best and worst-case scenarios in terms of stat. error bar

SBS GEP Event Reconstruction Strategy

Initial, ”perfect” alignment of all 46 SBS GEMs



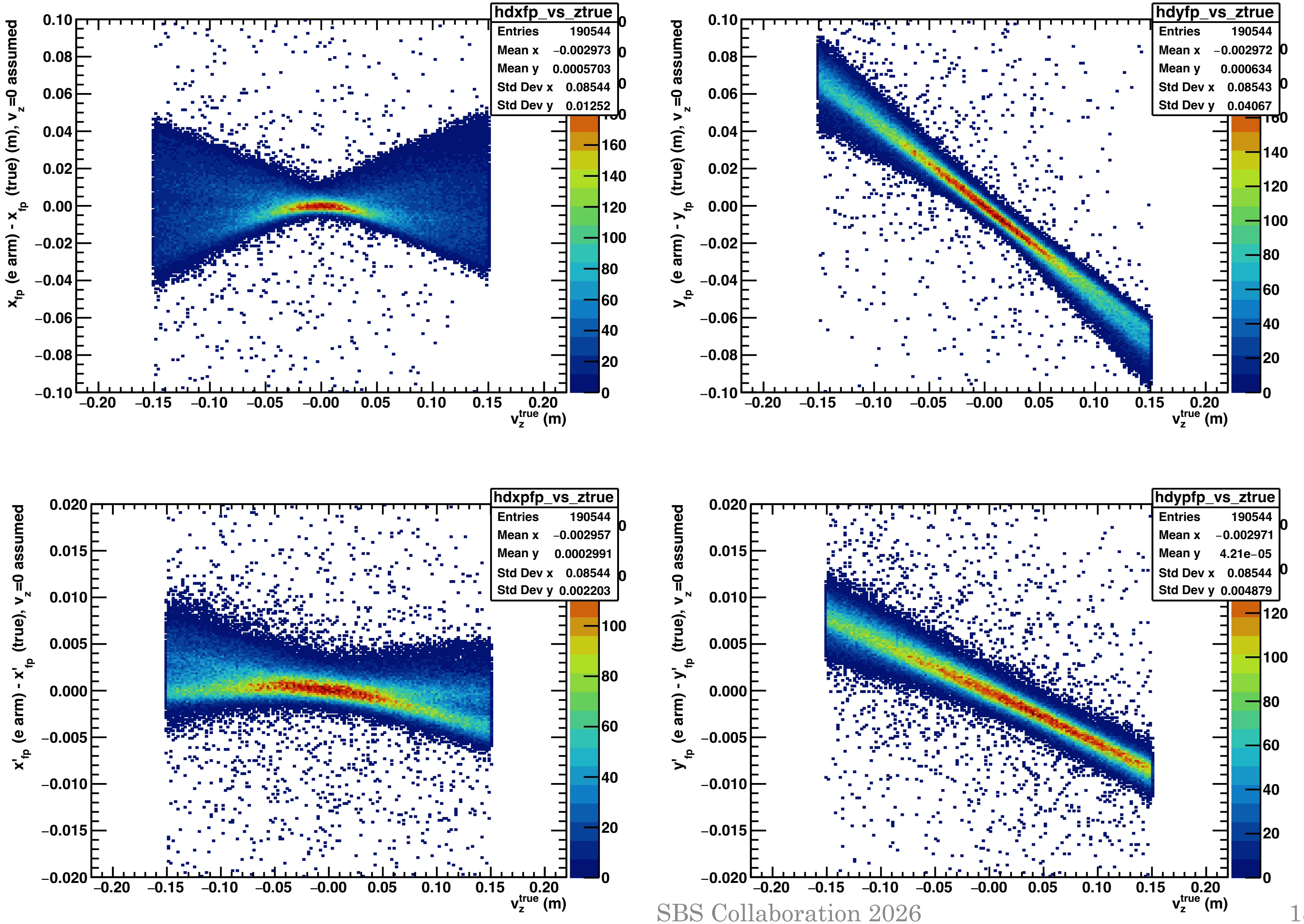
From ”straight-through” data at the beginning of Kin. 1, before CH_2 install, on single C foil target with magnet OFF. This was a “golden” alignment (internal+global+front-to-back), which we sadly couldn’t actually use ☹!

How to calibrate GEP reconstruction?

- No sieve slit in GEP (we couldn't really use one if we had it due to no PID capability and punch-through of high-energy hadrons)
- No "traditional" straight-through data
- We have single C foil and multi-foil optics targets, with full-field and zero-field data obtained at low current
- We also have H(e,e'p) scattering; however, it is all but impossible in the current formalism to calibrate SBS optics using this channel due to overconstrained kinematics, correlations, and "overfitting" issues.
- Also, how well do we know ECAL geometry?
- →Optics models are generated from simulation using randomized proton trajectories in angles, vertex, and momentum.
- SBS GEMs are globally aligned wrt magnet and Hall using zero-field data on thin foil targets→ significant fringe field effect on SBS track curvature seen (see Vidura's talk tomorrow)

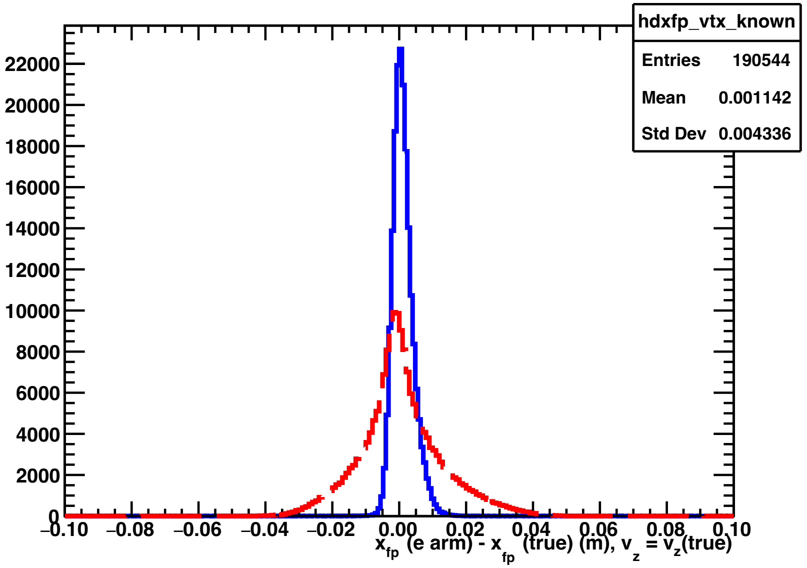
Logic of Electron Arm Reconstruction and Front Tracking Constraint

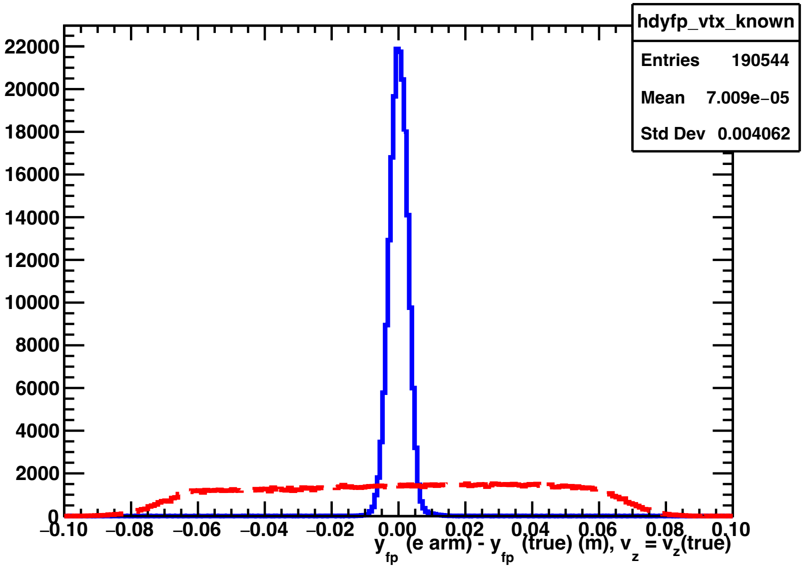
- At right, we show the correlation of the "true" vertex z position (x axis) and the difference between the "true" proton track parameters in the SBS front tracker and the "predicted" ones from ECAL+CDET for the point-target assumption.
- From top left to bottom right: (x,y,dx/dz,dy/dz), where x (y) is dispersive-plane (non-dispersive plane) coordinate

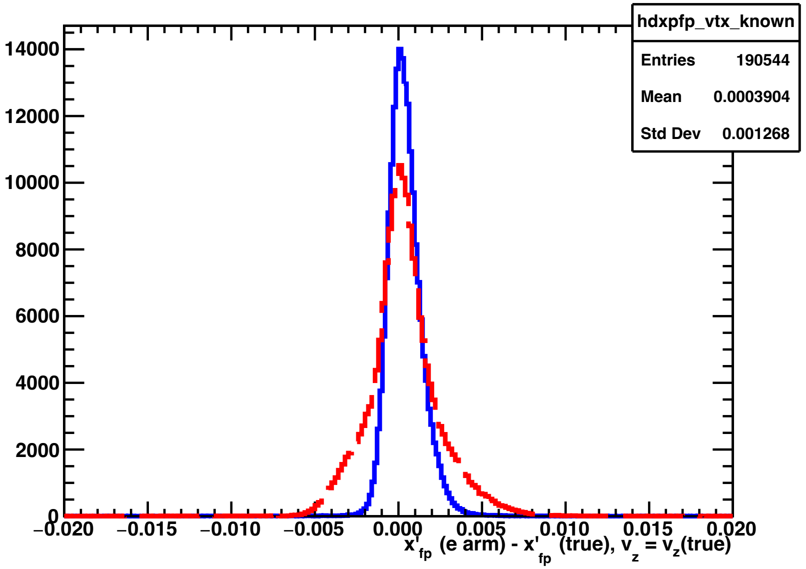


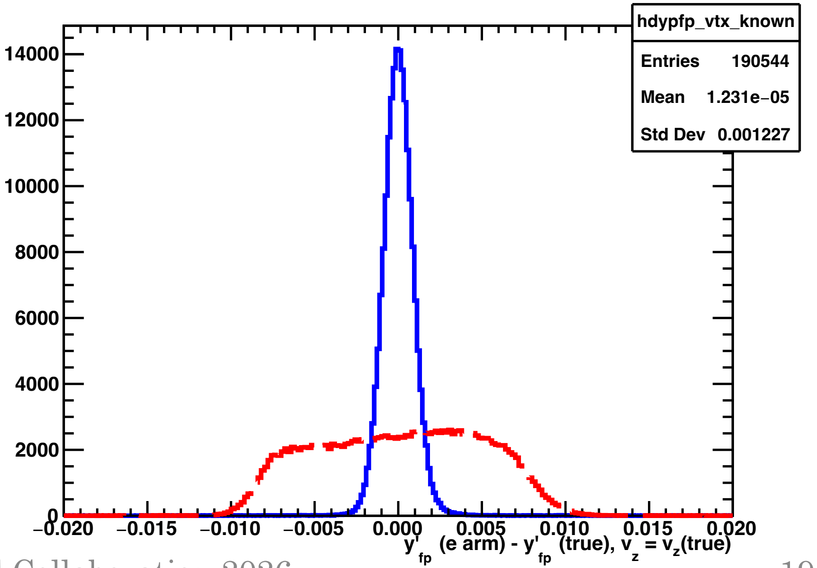
Logic of Electron Arm Reconstruction and Front Tracking Constraint

- Here we compare the "region of interest" constraints for the "point target" assumption (**red-dashed**) to what we would get if the "true" vertex z position was known (**blue solid**).
- Thus we see that the "ROI" starts out at a size of roughly $\pm 5\ (9)\ cm$ in x (y) and roughly $\pm 8\ (10)\ mrad$ in dx/dz (dy/dz) due to target thickness, and shrinks to (conservatively) $\pm 2 \times 2\ cm^2$ in area and $\pm 5\ mrad$ in angles along both x and y.
- **These plots are from simulation and use MC truth info! We need improved GEM alignments and optics calibrations before we can shrink the ROI to the size indicated by the blue histograms**









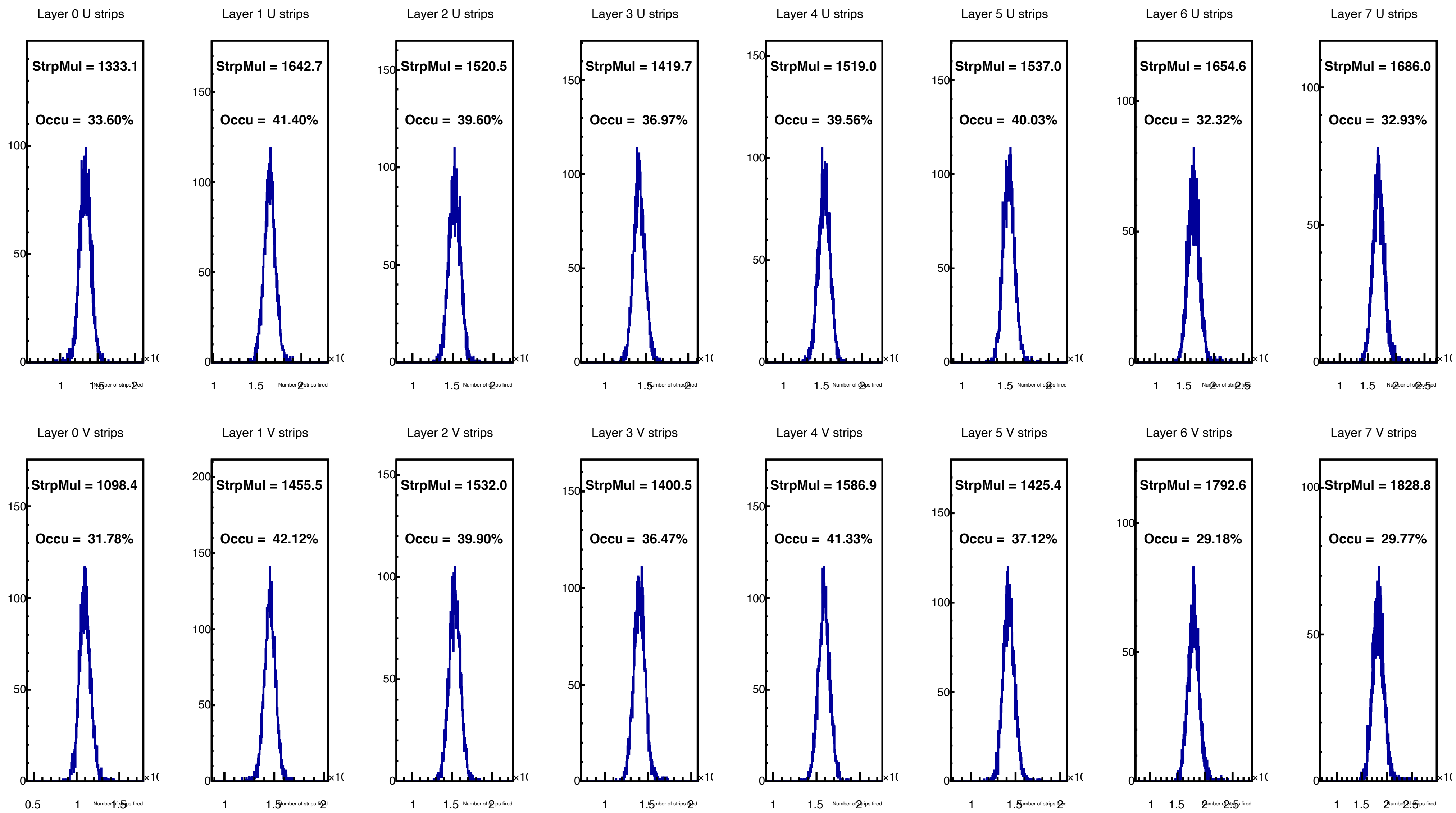
GEP reconstruction: "front to back" approach

- SBS track-finding algorithm is what I call "constrained brute force" approach—all possible combinations of one 2D hit candidate per GEM layer are considered (within region-of-interest defined by external detectors)!
- ECAL clustering, energy and position reconstruction use well-established algorithms from GEp-III BigCal analysis, described in, e.g., https://inspirehep.net/literature/1611577
- ECAL(+CDET?) do not provide vertexing information, but do precisely determine azimuthal angle of reaction plane→ however, long target plus momentum dispersion within large SBS Q^2 acceptance limits the utility of this information!
- Following ECAL(+CDET?) reconstruction, we use the SBS forward optics model and measured electron angles and energy assuming a point target at the origin to project "expected" elastically scattered proton track to SBS front tracker and define "region of interest (ROI)" for tracking
  - But we can do even better!
- We divide the target length into 24 bins of 1.5 cm each and calculate a proton trajectory through the front tracker using the SBS forward optics model assuming the vertex is at the center of each bin.
- This gives 24 "constraint point pairs" defining track search regions where elastically scattered protons might be found. Each pair defines a search region at each front GEM layer of roughly 6x6 cm^2
- This drastically reduces combinatorics of GEM hits that need to be considered!
- If front track is found, use it with HCAL to define ROI for back tracker, then analyze back tracker
- **Experience has shown that the "front-to-back" approach is too slow for "educated brute force" algorithm with 8 layers at ~40% raw occupancy, when ONLY ECAL information is used to constrain the front tracker**
- **→ Need to bring in reinforcements from the back tracker and HCAL! (next slide)**

GEP reconstruction: “back to front” approach

- Exploits the fact that the back tracker (”FPP”) has much lower occupancy, and we are only really interested in events where we have a good FPP track anyway.
- We use ECAL(+CDET?) and HCAL to define ROI for back tracker.
- As in “front-to-back” algorithm, we define 24 constraint point pairs, only this time the ”front” constraint point is the projection of the expected proton trajectory to the midpoint of the CH_2 analyzer for a given vertex assumption, and the “back” constraint point is the position of the highest-energy cluster in HCAL
- ROI widths are informed by simulation.
- Back tracker occupancy is manageable even using 24 constraint point pairs
- Back tracker results are used to choose ONE ”constraint point pair” for the front tracker analysis… typically based on distance and point of closest approach and angle between actual FPP track and *expected* FT track.
- Using the back tracker results to further shrink/constrain the front tracker ROI makes the FT analysis computationally manageable (barely)

GEP GEM Front Tracker (raw) occupancy at 15 uA on 30-cm LH_2



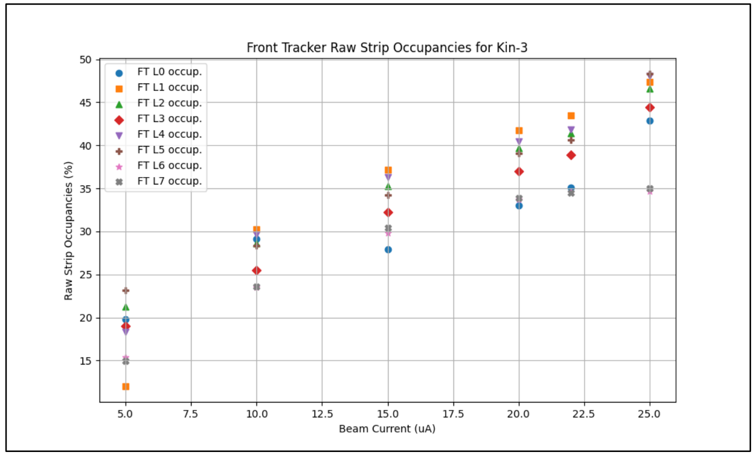
A few lessons from the SBS FF program for future intensity-frontier experiments (e.g., SOLID)

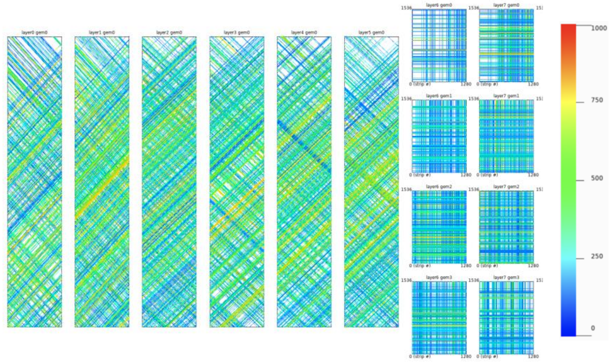
- More commissioning/calibration time with new/custom equipment operating in extreme high-rate/high-background regimes
- High-rate GEM tracking is more challenged for MIP-like particles (e.g., 7-GeV protons) than for ultra-relativistic electrons (signal/noise ratio!)
- APV25 front-end seems inadequate for the most extreme conditions (e.g., GEP)—need faster pulse shaping, better stability of baseline/gain/etc
- APV25 would have worked significantly better in SBS with 9 time samples instead of 6
- Pay VERY close attention to trigger threshold calibrations and efficiencies for both electron and hadron calorimeters—need clear plans to validate trigger efficiencies and TIME to collect the data—even (especially) for asymmetry measurements

Front tracker occupancies and elastic yields vs beam current

GEP Experiment Event Reconstruction Challenges

- Main challenge by far is *GEM tracking* under high occupancy (space and time signal pileup) and low signal to background ratios
- The hit comes from the large number of combinatorics → high computational times + (fake hits + fake tracks)
- 1D cluster formation and 2D hit reconstruction is especially affected by high occupancy → lots of *fake hit* reconstruction
- Tracking portion itself is done in field-free regions → straight lines; hence not the most complicated part *if* the hits fed in are mostly *true/real* proton hits

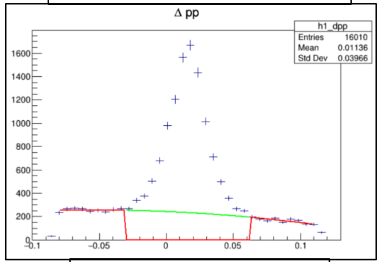




Plot: V. Vishvanath

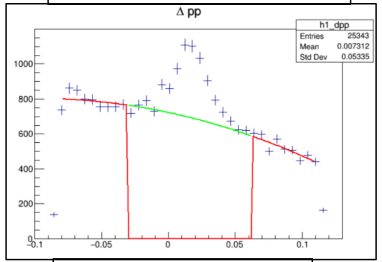
Front Tracker strips fired in an event color coded in ADC strength.
22 uA on LH2 target; one of the highest background cases in SBS.

15 uA run elastic yield



Heep yield/C = **24K**

22 uA run elastic yield



Heep yield/C = **11K**

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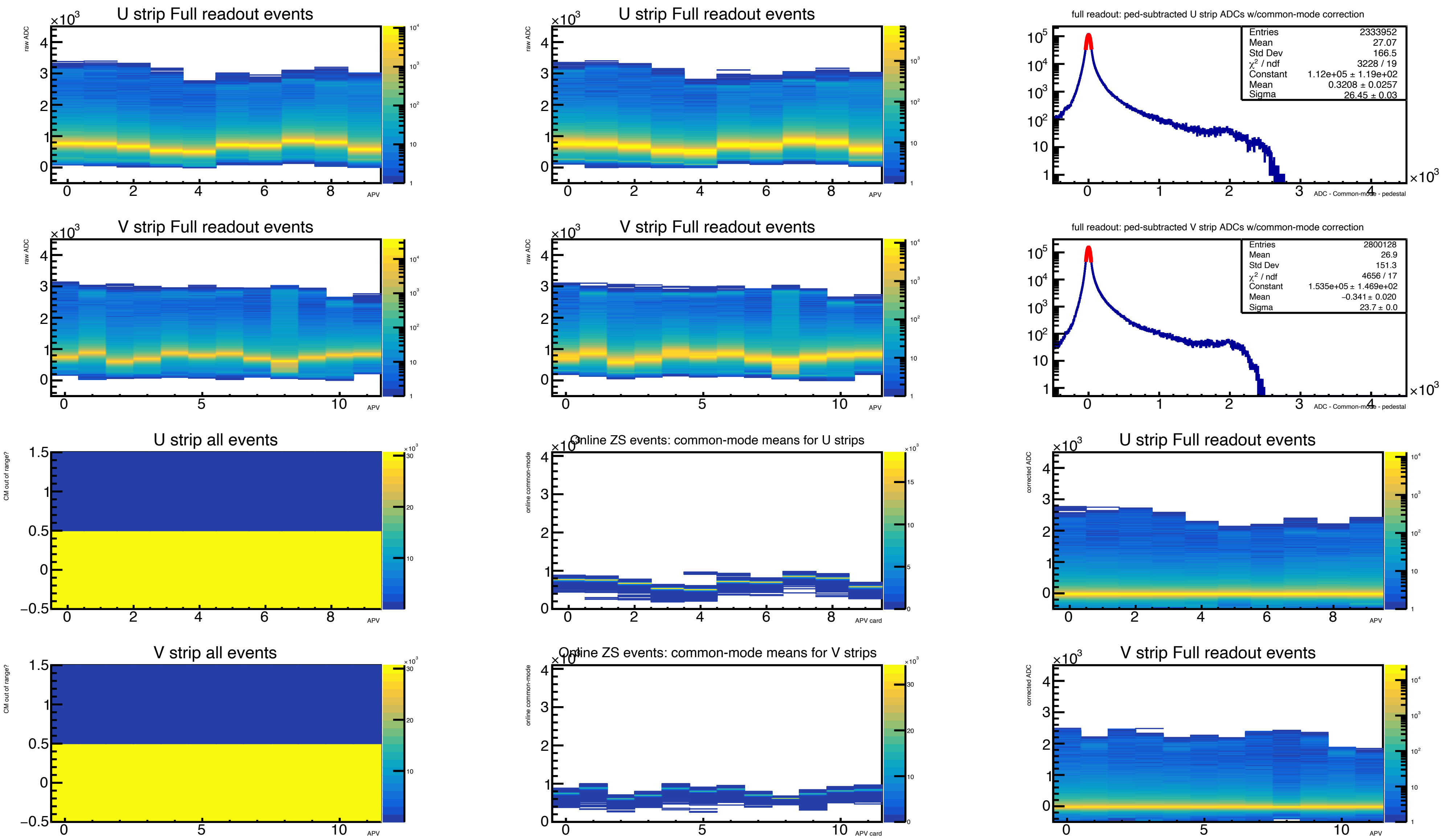
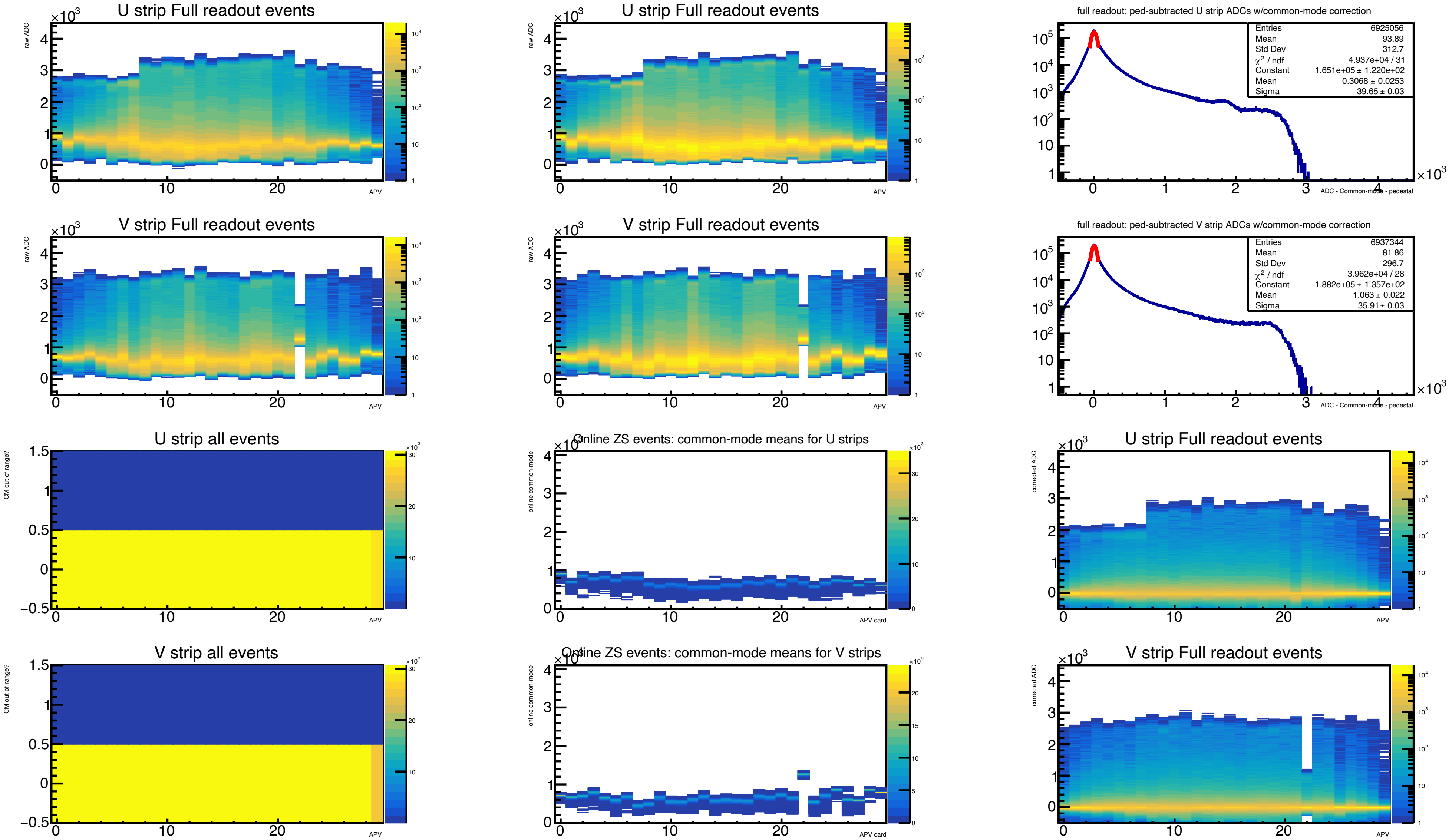
Slide credit: Anuruddha Rathnayake @Fall 2025 DNP Chicago

APV25 baseline sagging/broadening—FPP module 6 @20 uA



APV25 baseline sagging/broadening—FT layer 5 @20 μA



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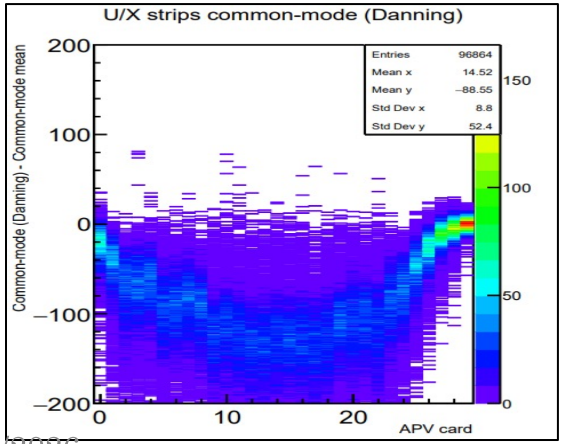
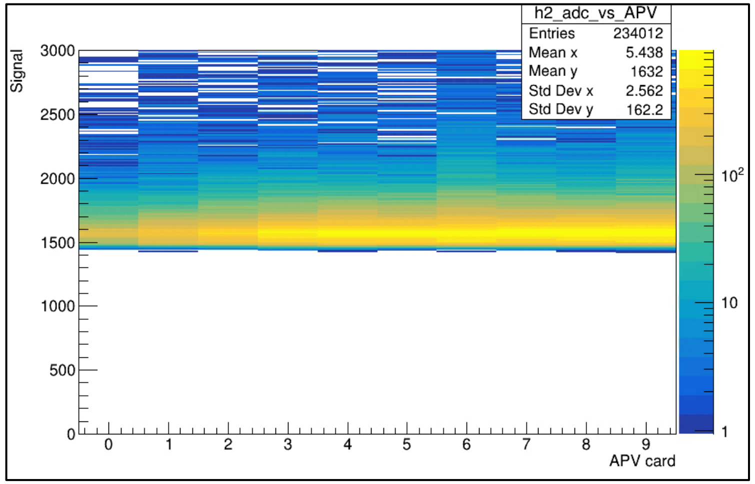
Producing MC data to train ML models for GEM tracking

- An attempt to enhance the reconstruction speed and efficiency through ML.
- Both hit finding (1D clustering and 2D hit formation) and track reconstruction under the overwhelming GEM occupancy/background is very challenging.
- After some discussions with experts, we decided to go in the route of using MC data to train a ML model to help with this.
- However, our existing MC GEM data is much less noisy and have an unrealistically better signal/noise ratio that REAL GEP data. Some of the missing features in MC:
  - GEM pulses seems to be shorter in time.
  - APV25 (front-end r/o) have baseline fluctuations (common-mode, CM) in real data which is not simulated in MC data.
  - In real data taking we did online CM correction and ZS. This will introduce some error into the GEM signal strengths.
  - "Sagging" of the CM under high-rate will also cause
- More realistic MC GEM data is better for ML training and to benchmark any new algorithmic developments.

Data – CM sagged and broadened at the mid-acceptance.

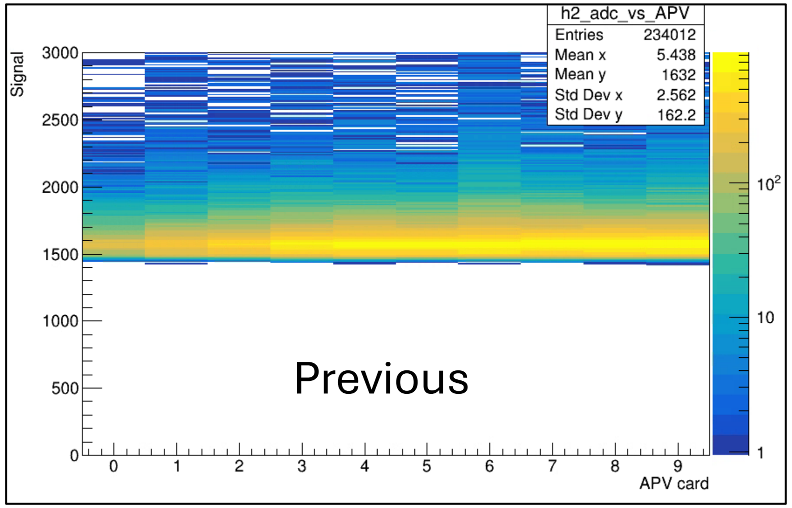


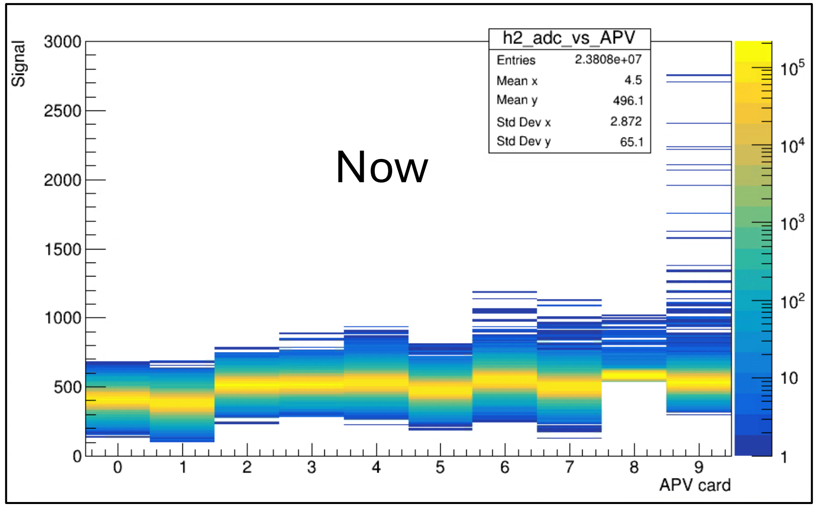


Current MC – signals added to a const. CM of 1500.

Improvements/additions to the GEM digitization

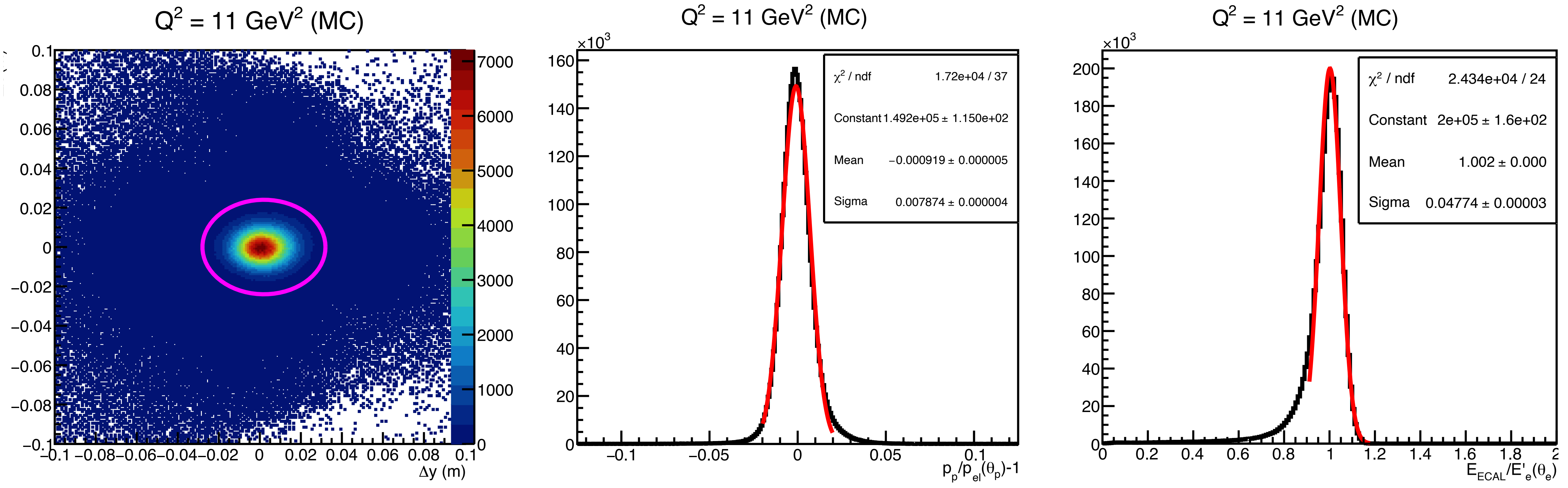
- Now we add CM random fluctuations to simulation 'APVs'.





- Also, now "online" Danning CM calculation and ZS is implemented in digitization.
- CM sagging effect yet to be implemented. But now the machinery is setup for that.
- Replay of MC data with new CM/pedestal effects works to an extent but still not 100% figured out. On progress…
- Added the "*adc_good*" branch to the GEM digitization output that tells you what number of ADCs are from the "mother particle" avalanche. This will be used as our 'MC truth info help train a ML model. Eric. F working on getting this integrated to SBS_OFFLINE.

Elastic Event Selection (ideal)



- Left to right:
  - $(\Delta y, \Delta x)\ (\sigma_{\Delta y}, \sigma_{\Delta x}) = (1\ cm, 8\ mm)$
  - $\frac{\sigma_p}{p} \approx 0.8\%$
  - $\frac{\sigma_{Ecalo}}{E'_e} \approx 4.8\%$

Expected elastic event selection performance in the "ideal" scenario from MC: no background, no alignment uncertainty, no magnetic field and/or optics modeling uncertainty

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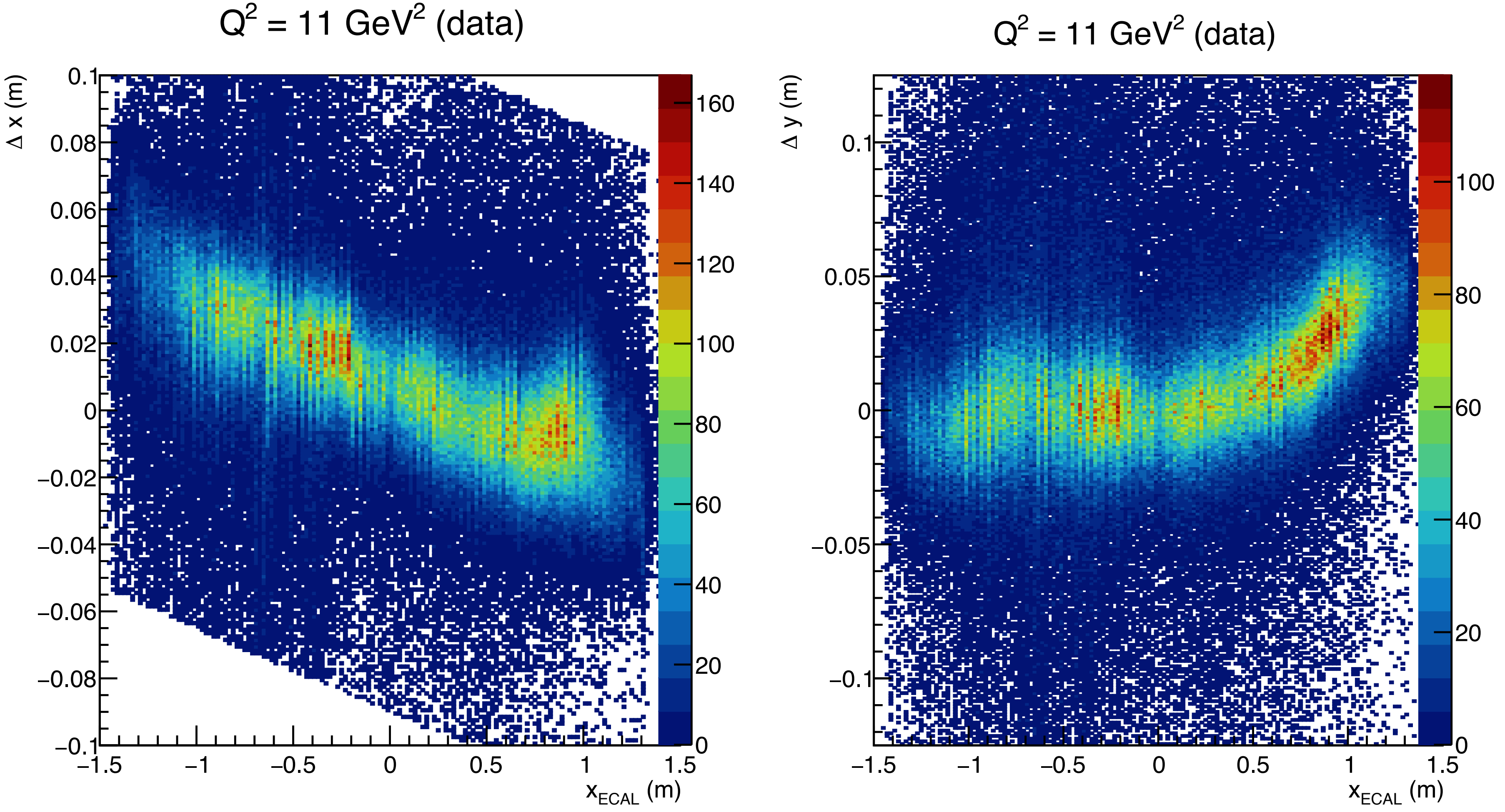
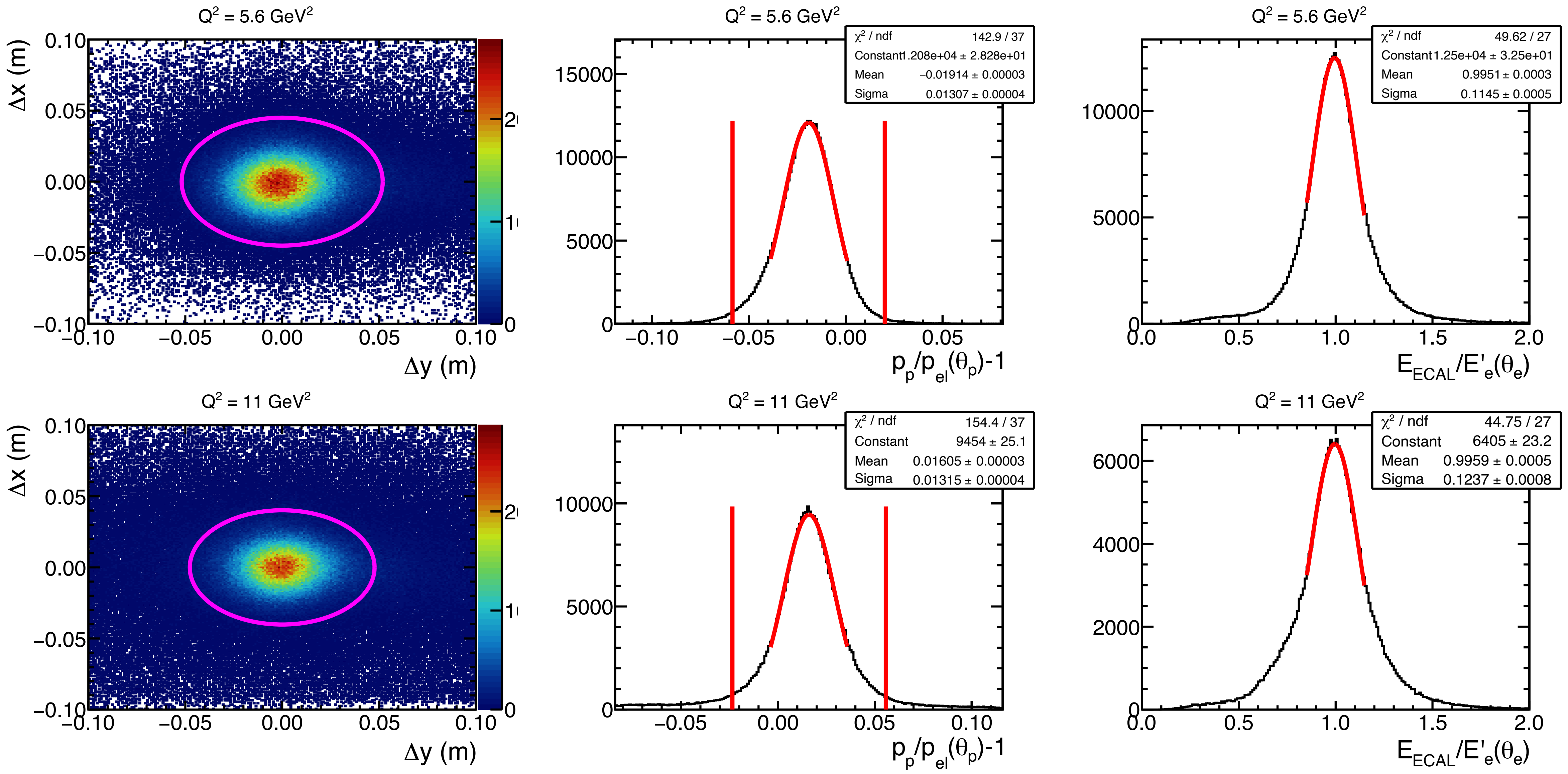
Elastic Event Selection (real), I: Spurious Correlations



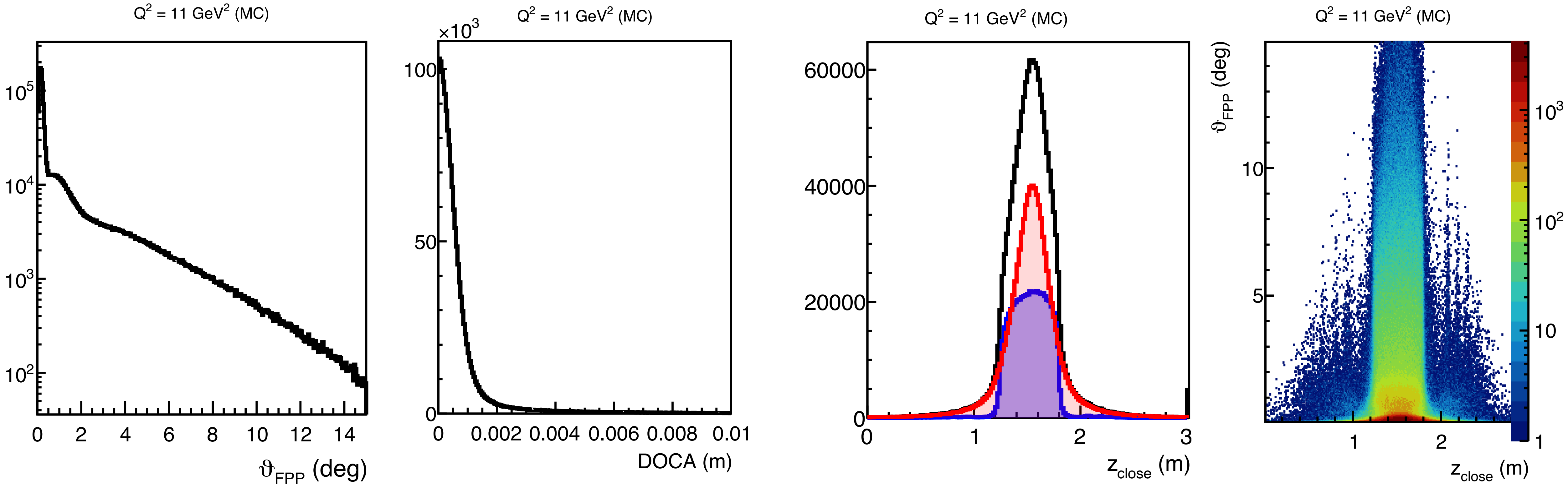
- For now, we apply *ad hoc* corrections to $\Delta x, \Delta y$ to remove this spurious correlation
- Momentum reconstruction is also significantly off; by about -2% (5.6 GeV^2) and +1.6% (11 GeV^2), with worse-than-expected resolution

- Significant spurious correlation seen between $\Delta y, \Delta x$ and vertical position at ECAL
- Cause not fully understood: ECAL geometry description, GEM alignment, SBS optics modeling, all of the above?

Elastic Event Selection (real), II (w/ *ad hoc* corrections on $\Delta x, \Delta y$)

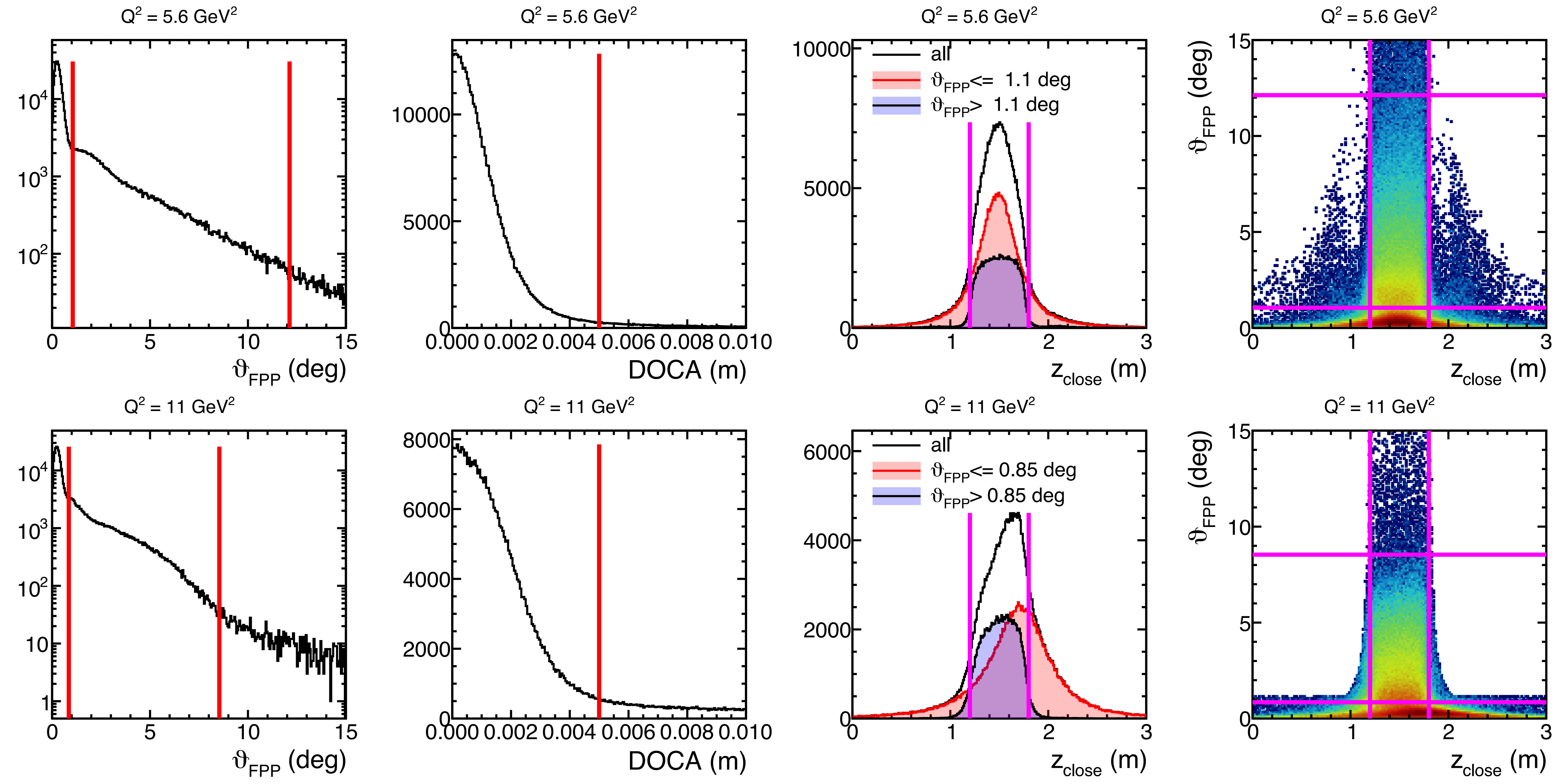


Polarimeter Reconstruction (ideal)

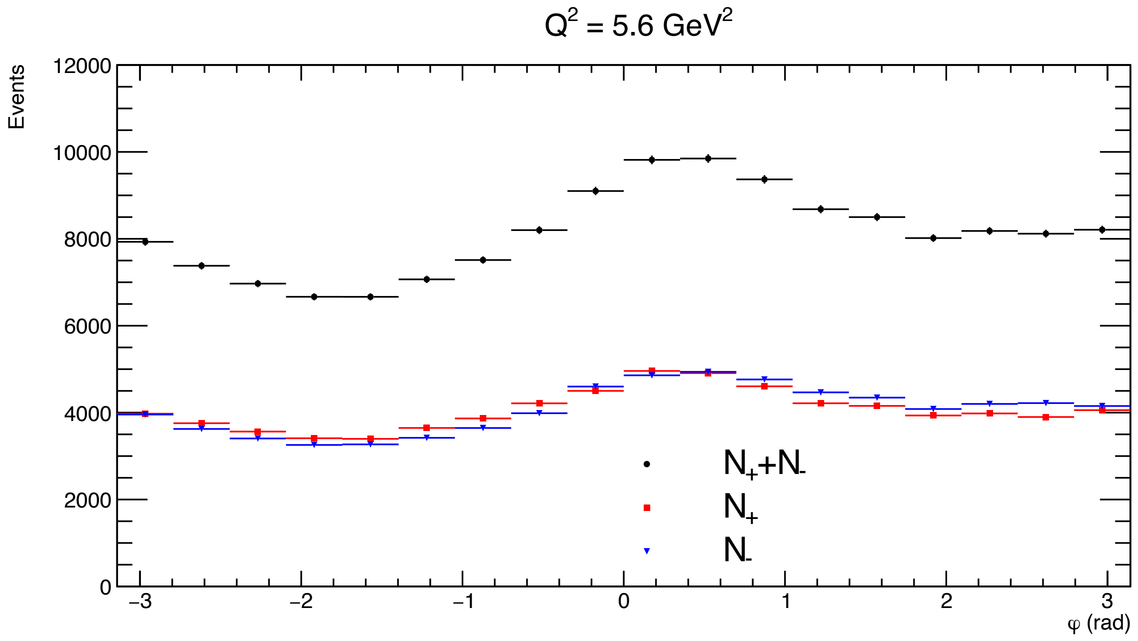


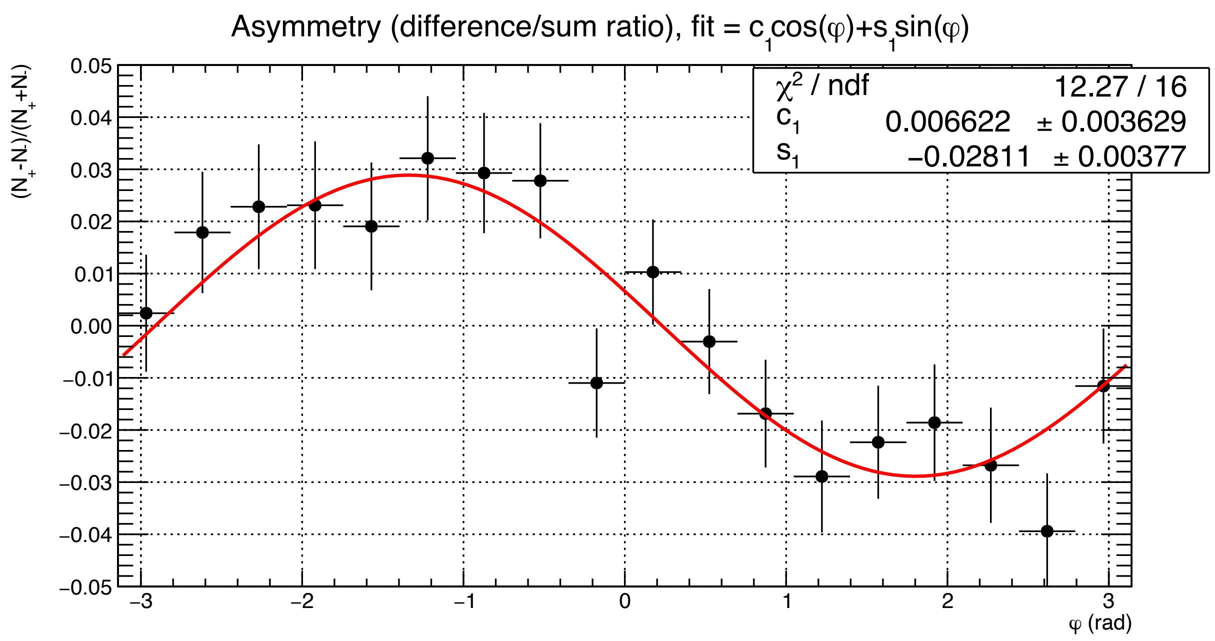
- Left to right: polar scattering angle, distance-of-closest-approach, z coordinate of closest approach, correlation between ϑ, z_{close}

Polarimeter Reconstruction, real



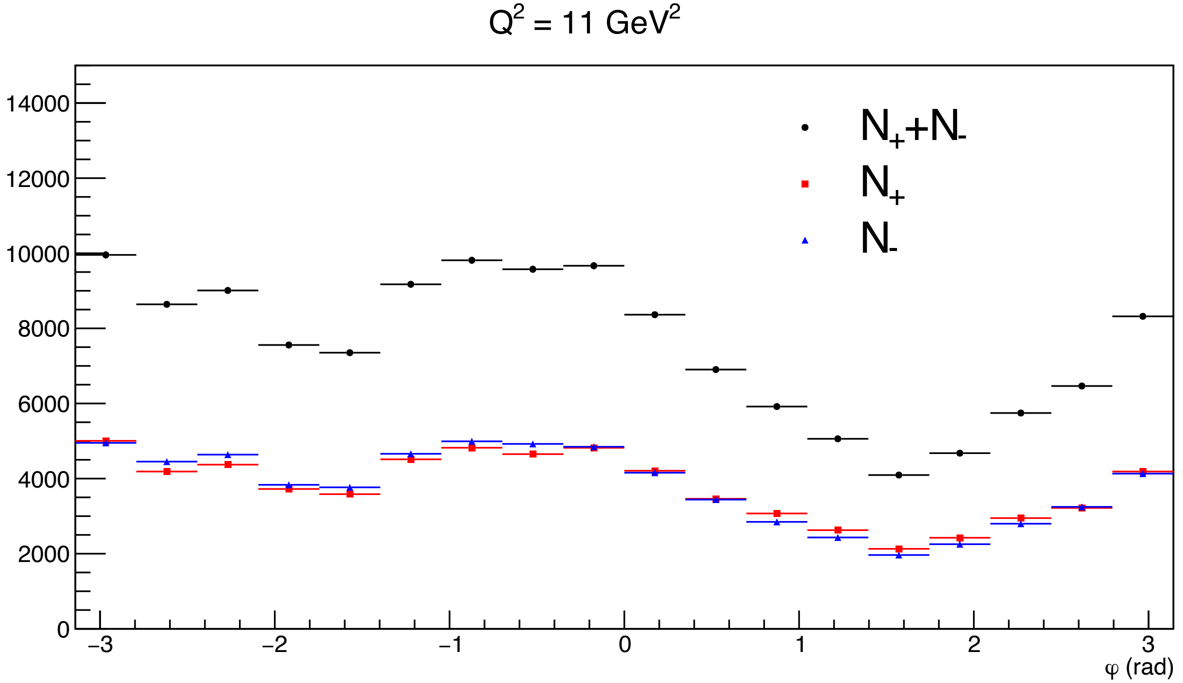
FPP Kin. 1 azimuthal distribution and asymmetry

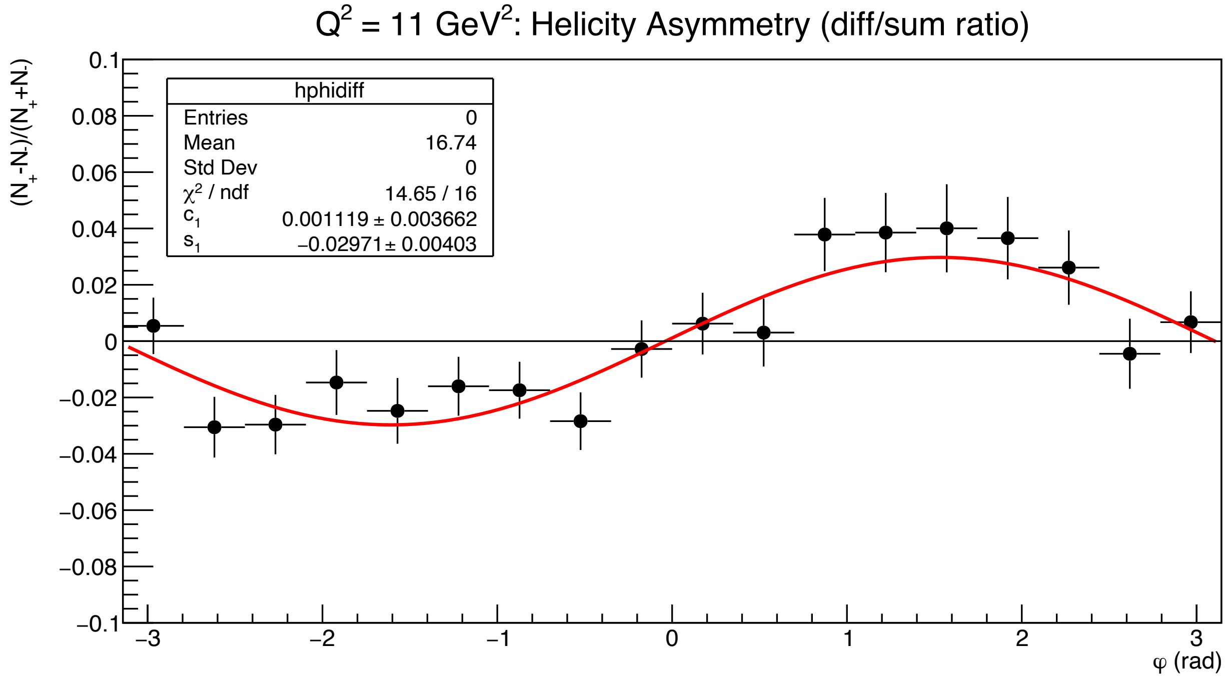




- Left: FPP azimuthal angle distribution passing all exclusivity and other cuts; for helicity sum and individual helicity states—large instrumental asymmetry due to nonuniform acceptance/efficiency
- Right: Helicity asymmetry: difference/sum ratio and cancellation of false asymmetry
- Asymmetry amplitude and relative sign/magnitude of sine and cosine asymmetries are consistent with expectations, with low statistical significance
- NOTE: both asymmetry signs are reversed for this Q^2 due to not accounting for correlation between IHWP state and absolute beam polarization sign as determined by Moller measurement.
- No evidence (yet) for analyzing power increase due to HCAL energy sensitivity—result is consistent with GEp-III

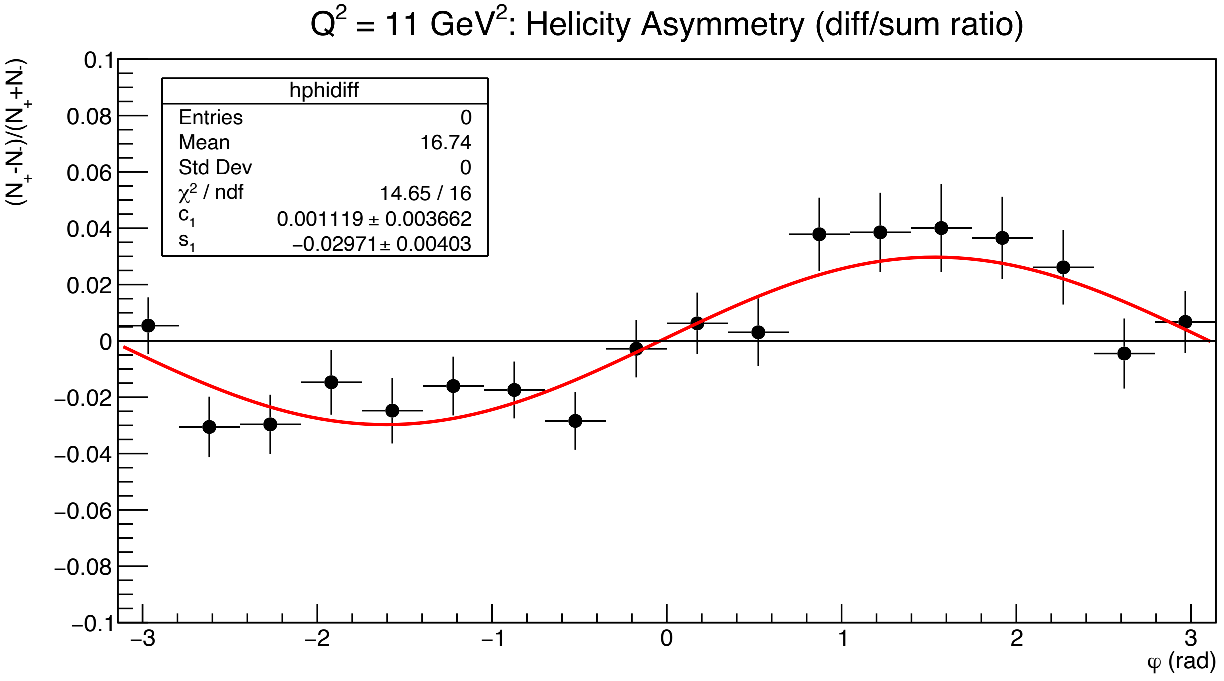
FPP Kin. 3 azimuthal distribution and asymmetry

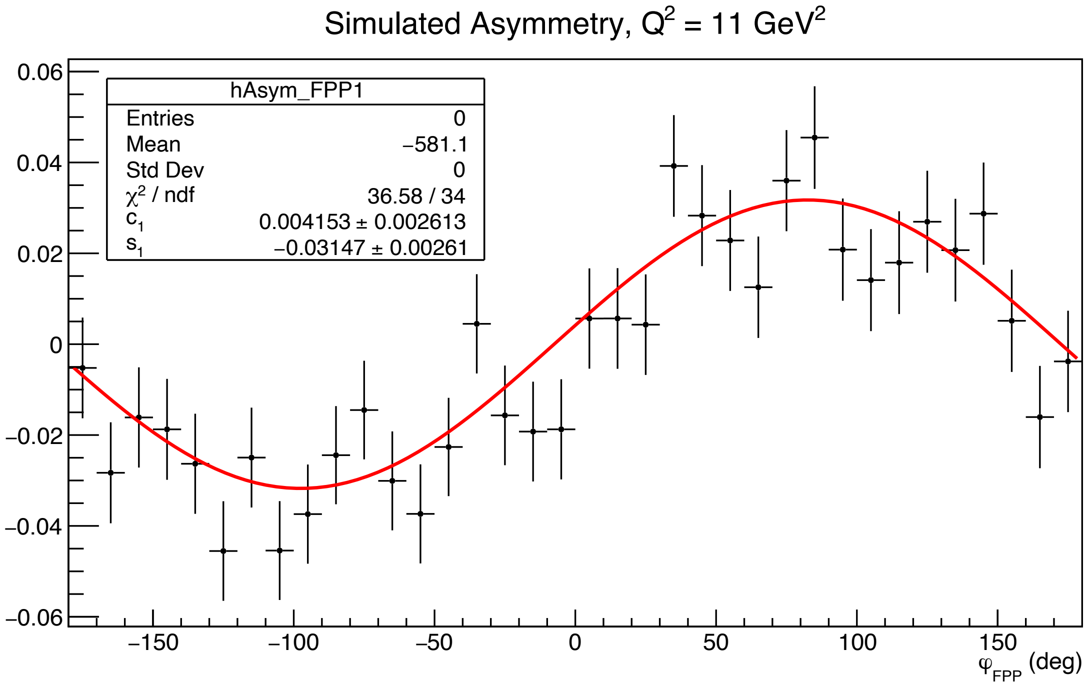




- I’ve aggregated many different Kin. 3 replays done over the summer here.
- False asymmetry distribution is still quite ugly due to front/back misalignment and acceptance/efficiency nonuniformity
- Helicity asymmetry (diff/sum ratio) shows expected sinusoidal behavior, consistent sign/magnitude with expectation (I’m not 100% sure the error calculations here are correct, didn’t check in detail)
- $(3 \pm 0.4)\% \sin(\varphi)$ asymmetry indicates analyzing power is good, roughly in line with expectation
- $\cos(\varphi)$ asymmetry consistent with zero (also as expected given small P_T component)
- Lots of work to do but this result is super-encouraging

Kin. 3 asymmetry: measured vs. projected





- Left: Real data asymmetry from ~140k elastic ep events with scattering angles in the useful range $0.07 \leq p_T(GeV) \leq 1.0$ (this represents approximately 1/4th of "worst case" statistics accounting for polarimeter efficiency
- Right: Asymmetry from ~440k simulated events with scattering angles in the useful range (note this is not supposed to represent full proposal stats!)
- Consistency of measured and simulated asymmetries suggests analyzing power is good and consistent with (extrapolated) GEp-III parametrization

For more details, see student talks tomorrow:

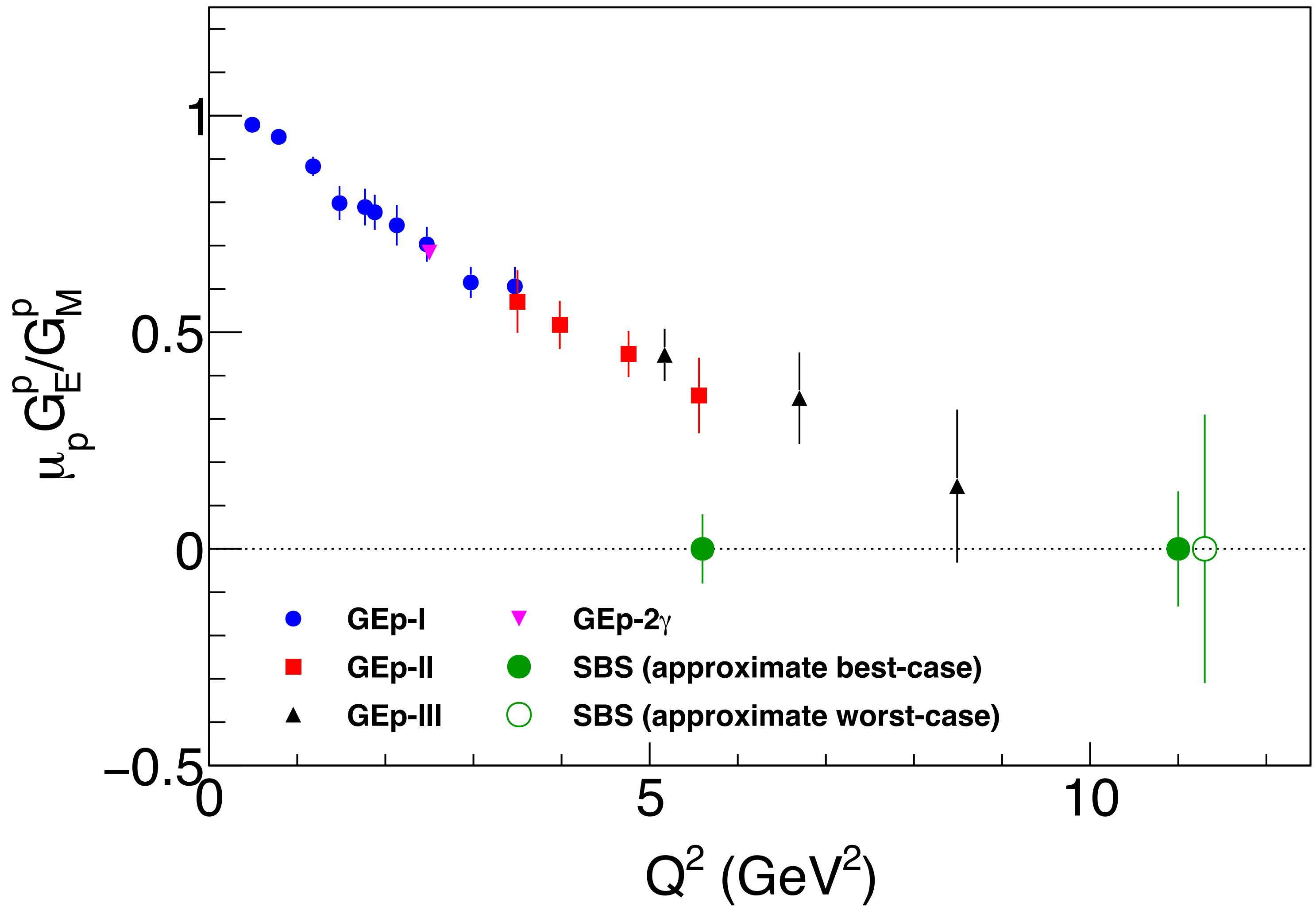
Schedule

Student	Topic	Time of Talk
Kate Evans	Neutron Polarization in 3He	T 13:00
Vimukthi Gamage	Hadron arm tracking data analysis in GEnII	T 13:12
Jacob Koneman	Timing Calibration	T 13:24
Briain Mederos	Waveform/FADC signal analysis for HCAL	T 13:36
Jack Jackson	GRINCH in GEn	T 13:48
Bhasitha Dharmasena	Timing Calibrations and Spin Precession for GEn-RP	T 16:00
Saru Dhital	Analysis of PR Detector Data From GEn-RP Experiment	T 16:12
Faraz Chahili	SBS Moller polarimetry update	W 13:00
Vidura Vishvanath	Internal Alignment of GEM detectors in GEp-V	W 13:12
Jacob McMurtry	GEp high rate tracking	W 13:24
Jhih-ying Su	ECal Calibration	W 13:36
Mahmoud Gomina	HCal Timing Calibration for GEp V	W 13:48
Ben Spaude	CDET analysis update	W 16:00
Kip Hunt	Updated Pulse Finding of the GEp Calorimeters	W 16:12

Students: Talks are due to me this evening
tdaver@wm.edu

Summary and Conclusions

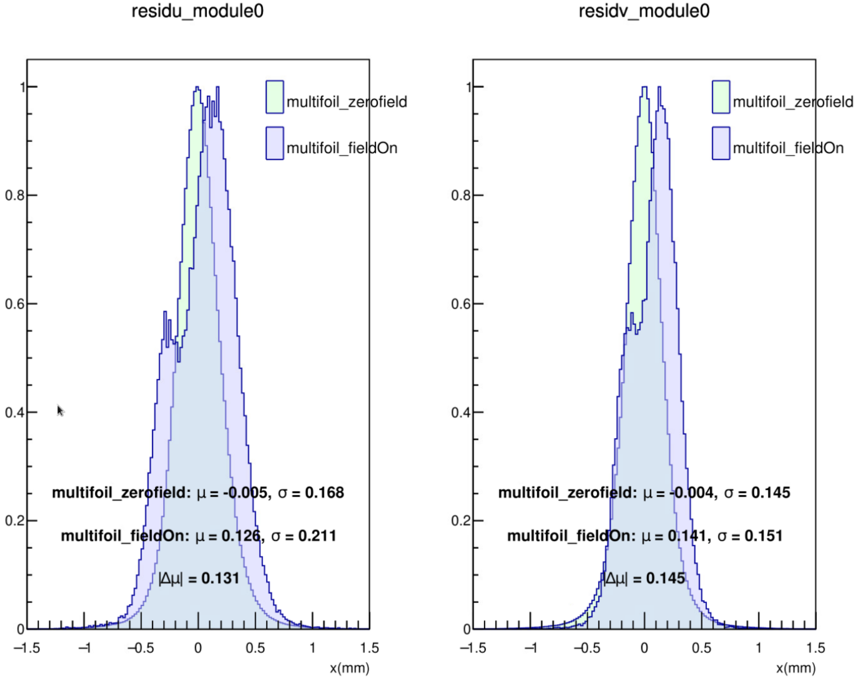
- Despite significant setbacks, SBS GEP has succeeded in expanding the frontier of Q^2 reach and precision for polarization transfer measurement of $\mu_p G_E^p / G_M^p$
- First FPP asymmetry extraction at $Q^2 = 11$ GeV^2 indicates good analyzing power in line with expectations at an unprecedented high energy
- Calibration and optimization work ongoing toward a first full reconstruction pass
- Data quality along with best-case and worst-case scenarios for physics results now largely understood
- THANKS FOR YOUR ATTENTION!



Backups

Progress on Internal GEM Alignment

- Performed a study to assess the differences in GEM tracking residuals between field-on and field-off data, in a common alignment obtained from field-off dataset.
- The study showed shifts in the mean of the residual distributions on the order of the intrinsic GEM resolution for field-on residuals.



- Conclusion: We will strictly use field-on data to improve the internal GEM alignment.
- Based on the repair work performed by the GEM team during the Kin1 and Kin3 run periods, Kin1 requires only a single internal GEM alignment for both the FT and FPP. The FT in Kin3 also requires one internal alignment, while the FPP requires two separate alignments due to the sliding out of layers for APV replacement during the May 21, 2025 repair work.

- Work on improving the internal GEM alignment is currently underway, with more details to be presented in Vidura's talk.
- Once the internal GEM alignment is done, the focus should shift toward improving the GEM back-to-front alignment and the overall global alignment.

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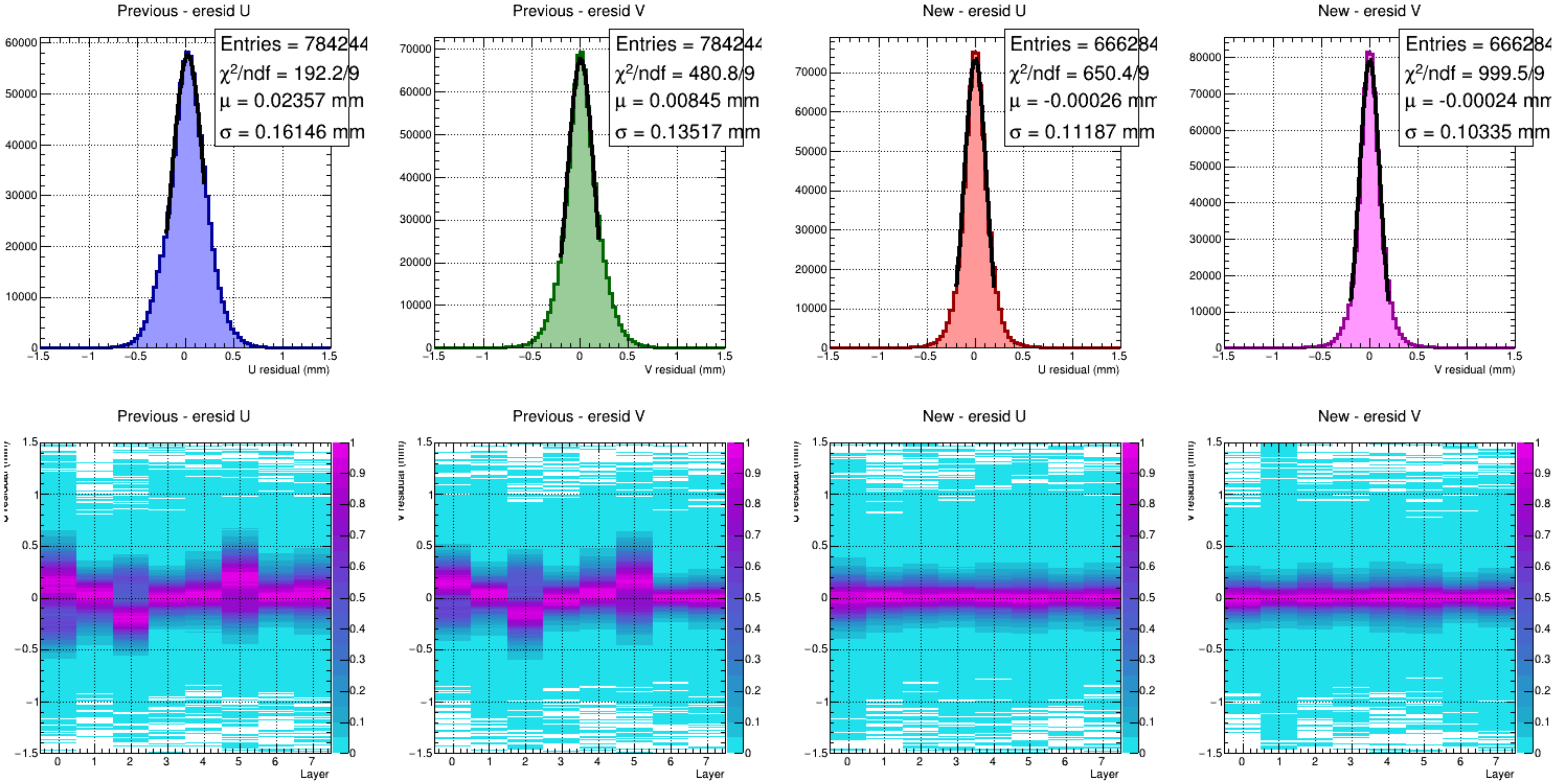
Internal GEM Alignment – Kin3 FT

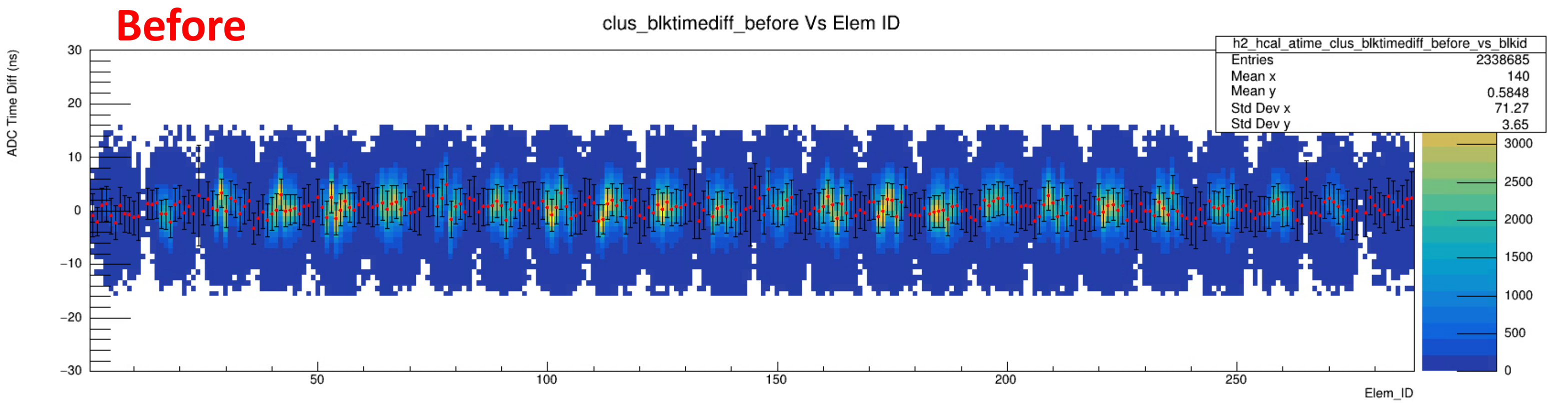


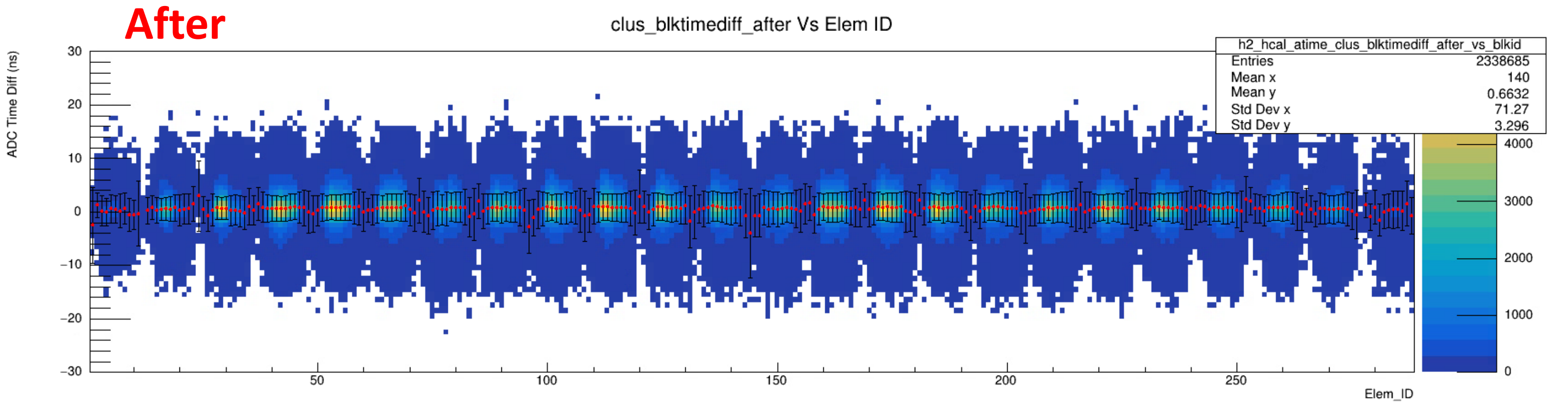
- Internal alignment of the FT for Kin3 before and after, performed using field-on optics data. We can observe residual shifts due to the effects of the SBS fringe field on the previous alignment.

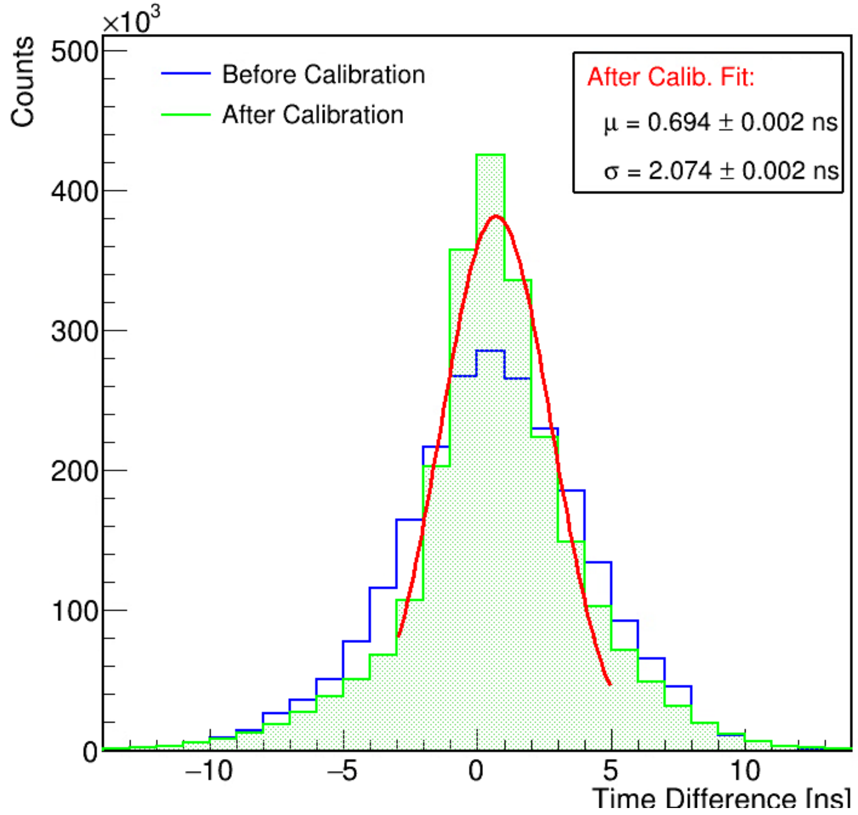
HCal Cluster Timing Difference

HCal cluster timing difference vs block ID:

- Broader timing response before calibration
- More zero-centered timing response and improved alignment







- Post calibration resolution improved to ~2.1 ns
- Further improvements are anticipated as calibration progresses.