Status of GEp-III/GEp-2γ Archival Results/Publication

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On behalf of the GEp-III Collaboration

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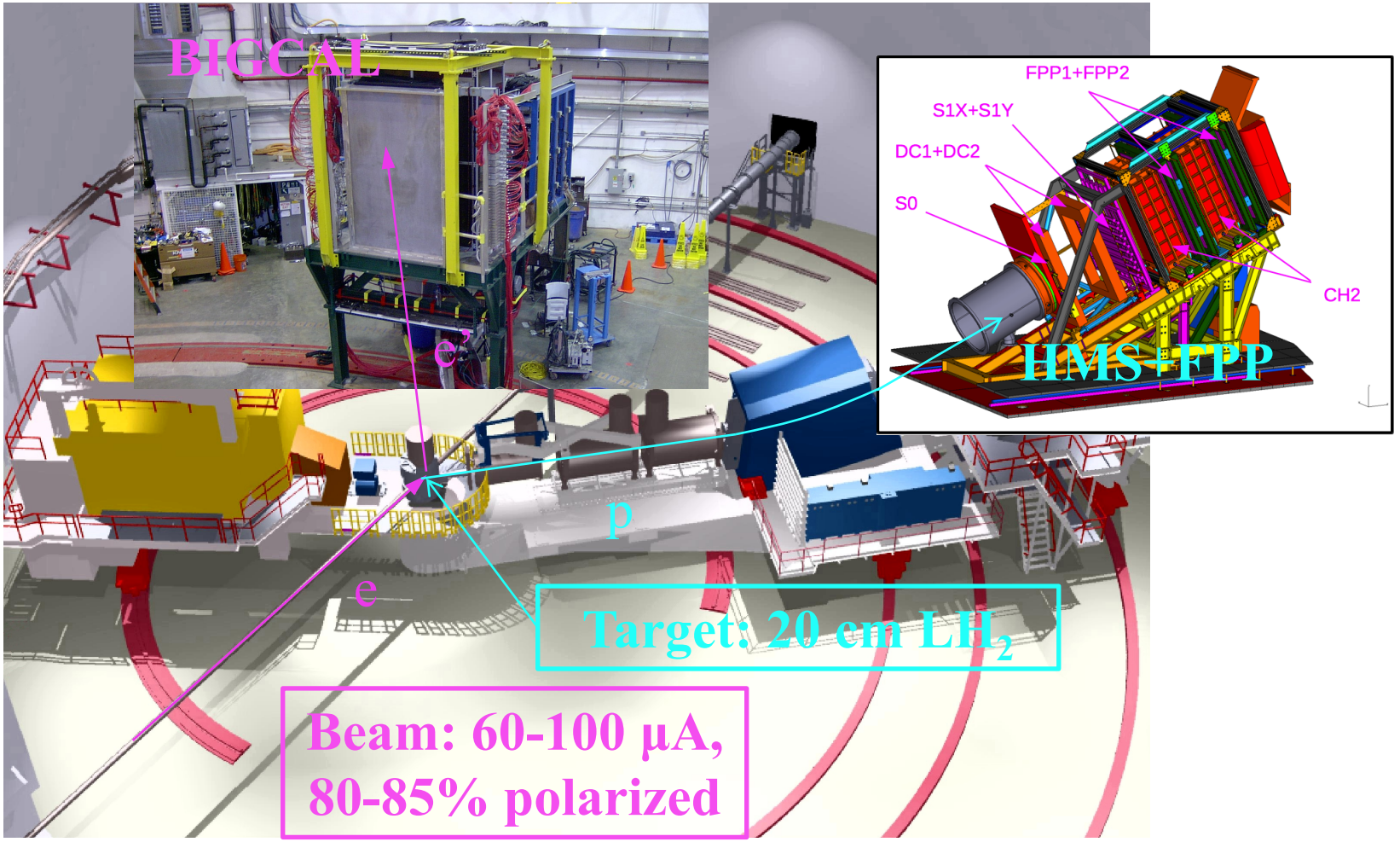
Outline

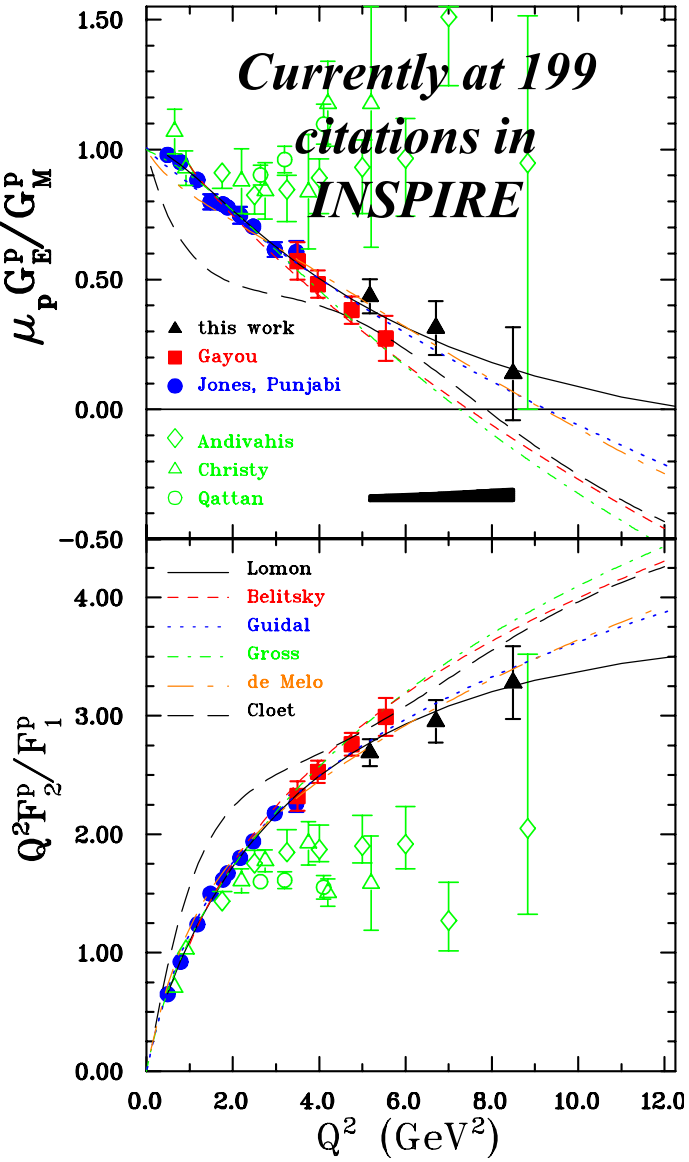
- Review of GEp-III/GEp-2γ experiments in Hall C at JLab
- Existing publications from Hall C polarization transfer experiments
- Re-analysis of the Hall C data
- *New results from GEp-2γ data including unpublished full-acceptance data*
- PRELIMINARY (not for public distribution/discussion/consumption) results of final analysis
- Status of draft PRC publication on combined Hall C GEP measurements

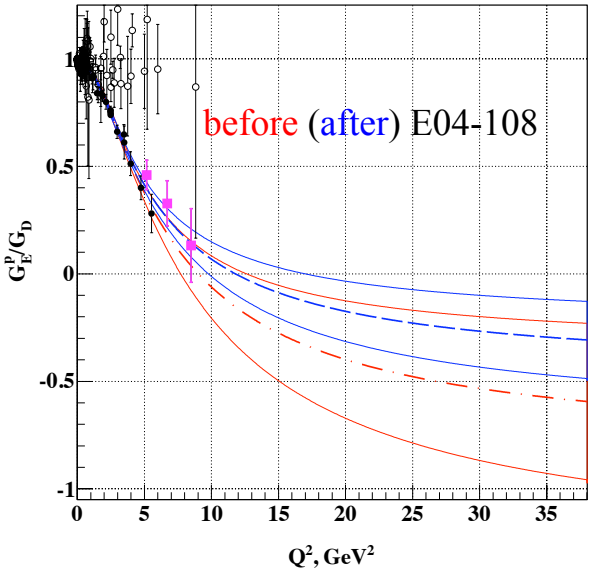
The GEp-III and GEp-2γ Experiments in Hall C

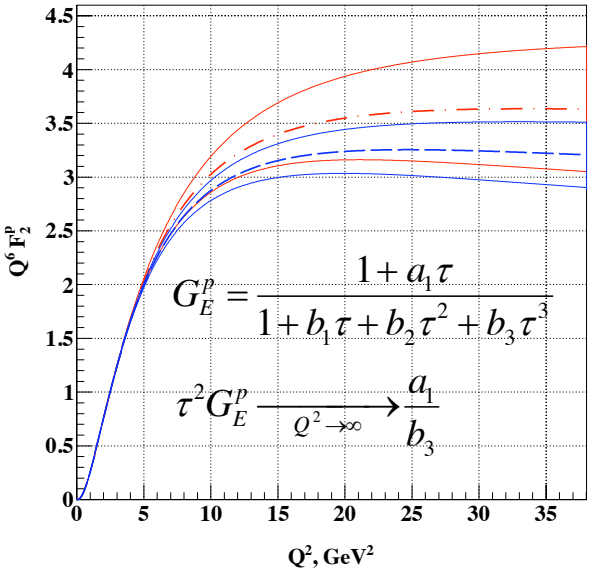


Polarization transfer in ^{1}H(**e**,e'**p**). Nominal luminosity ~ 4×10^{38} Hz/cm^2

GEp-III Results: PRL 104, 242301 (2010)

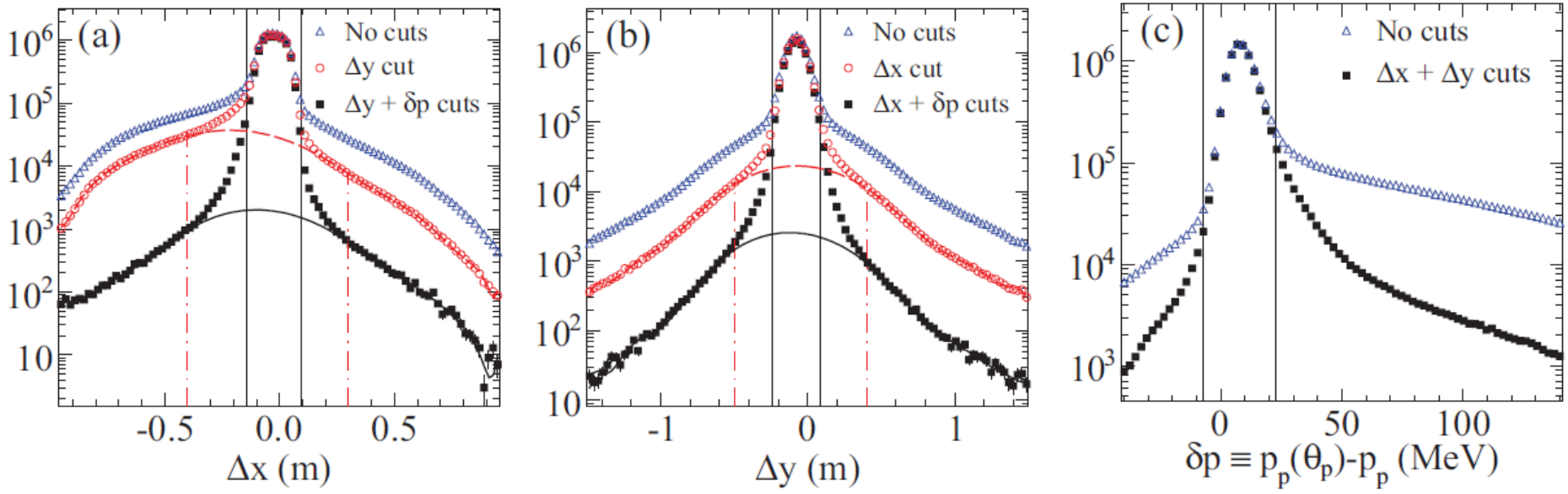






- Increased Q^2 coverage of the data by ~50%
- All three points at least 1.5σ above Gayou linear fit to GEp-I/II data:
  - ***Possible consistency issue between Halls A/C?***
- Rate of decrease of G_{Ep}/G_{Mp} slowing down
- Error bars in high-Q^2/asymptotic G_{Ep}/F_{2p} reduced by ~factor of 2 in a global analysis using the Kelly fit.

GEp-II reanalysis—Elastic event selection

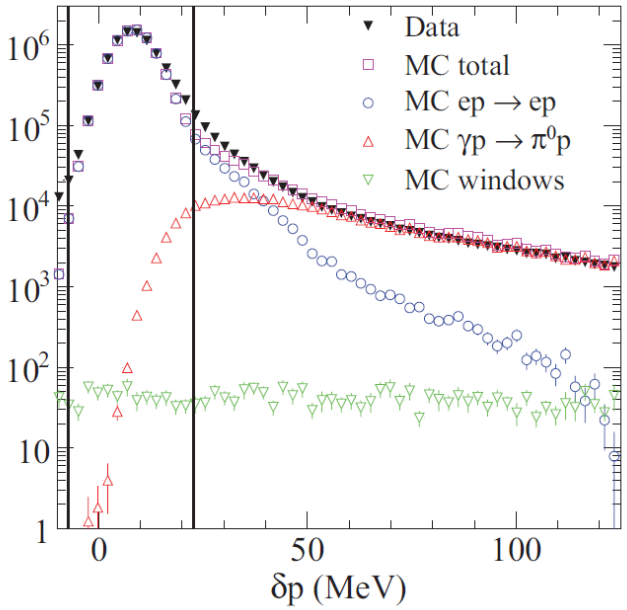


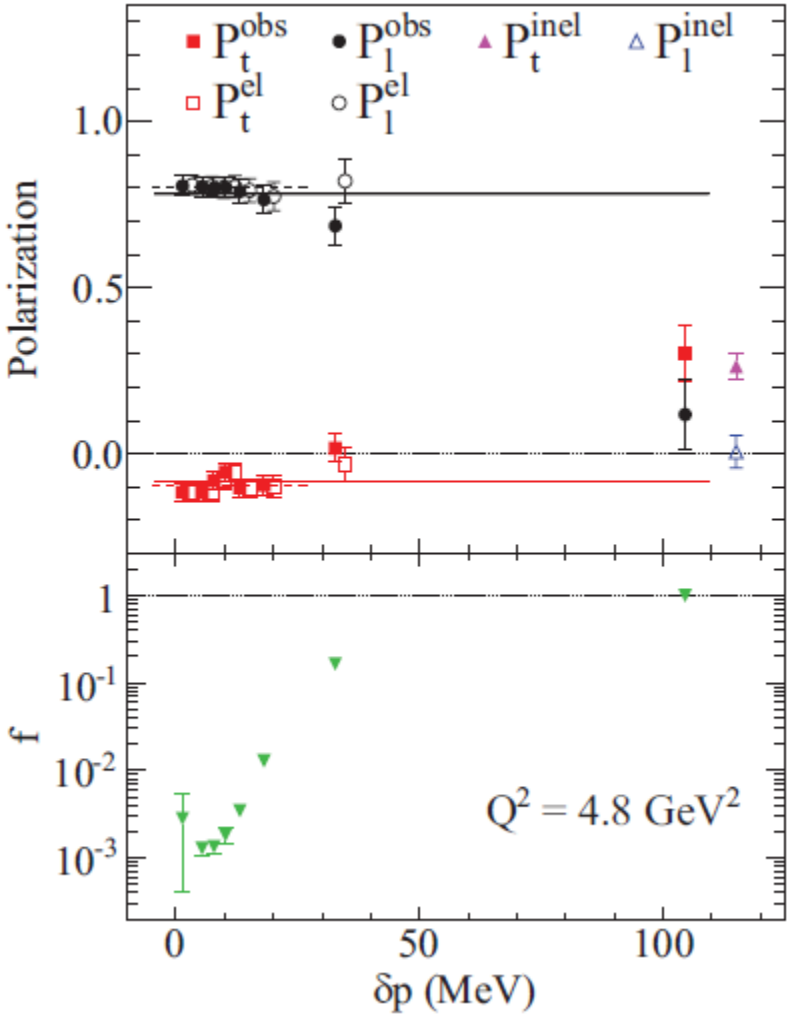
Elastic event selection in GEp-II, $Q^2 = 4.8$ GeV^2

- Elastic event selection in GEp-II: similar to GEp-III but with different dominant sources of resolution
- $\gamma p \rightarrow \pi^0 p$ background led to significant **positive** corrections to R in GEp-III at 8.5 GeV^2; proton p(θ) – p cut found crucial, but *no such cut* was applied in original GEp-II analysis
- Even a small contamination can have a large effect on asymmetries!
- Motivated a new analysis of the GEp-II data at $Q^2 = 4.0, 4.8, 5.6$ GeV^2, for which electrons were also detected by a lead-glass calorimeter as in GEp-III

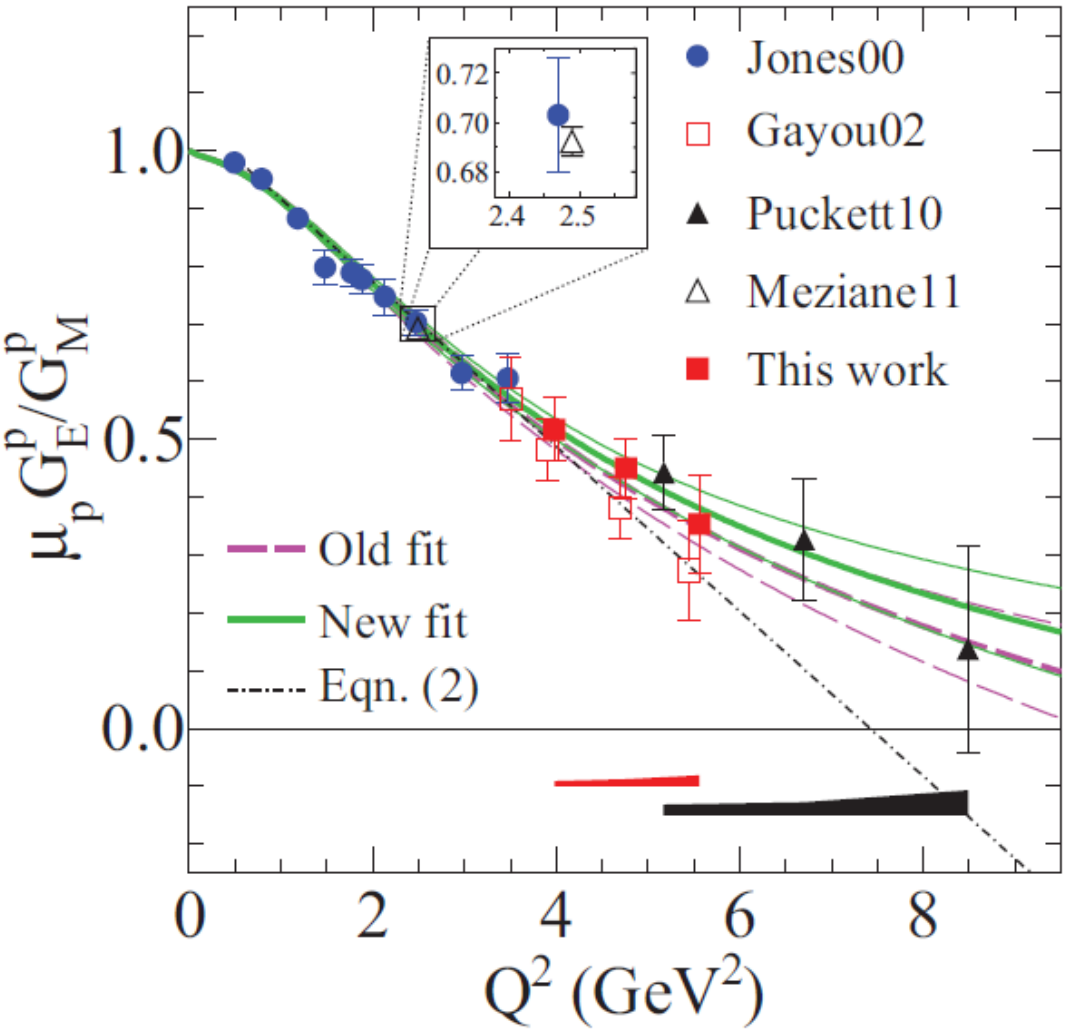
Effect of the underestimated background

- Most events outside the elastic peak of δp = p(θ) – p are background-dominated.
- The observed polarization components evolve from those of the signal to those of the background as δp increases
- Net systematic effect is ~15% in P_T, 2% in P_L
- Conclusions borne out by Monte Carlo:





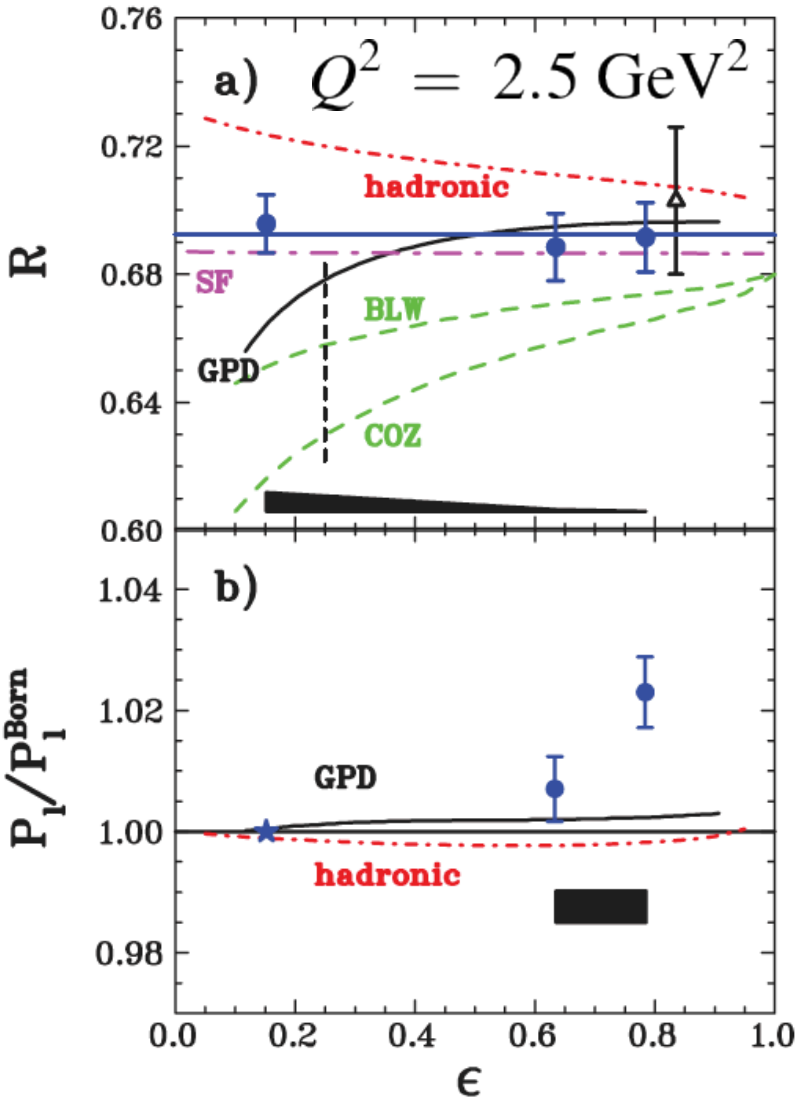
Final Results of GEp-II

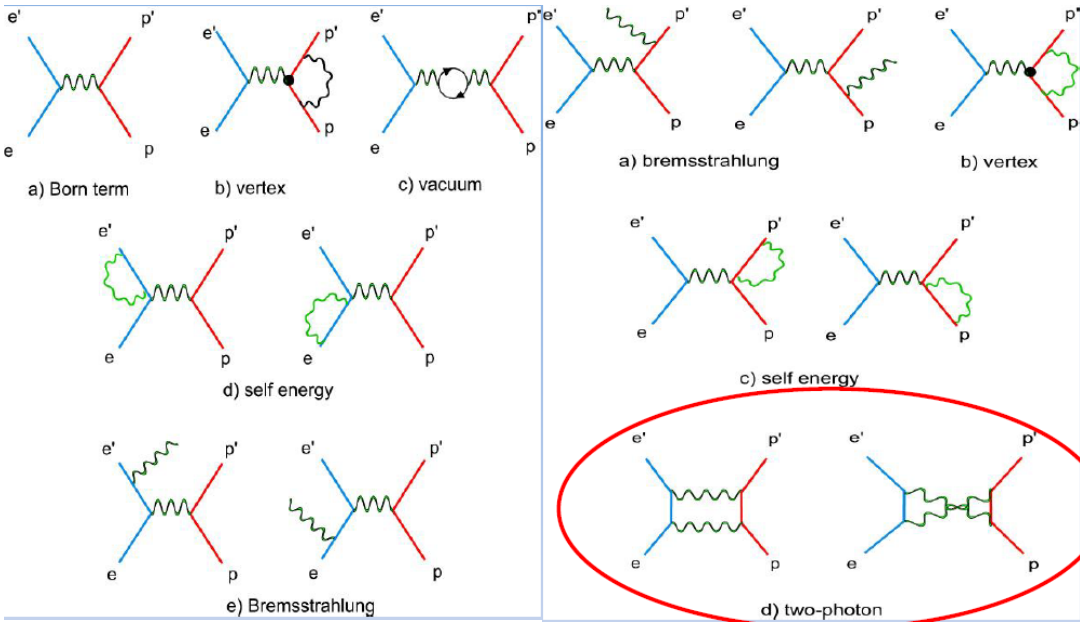


Summary of results

- Reanalyzed three highest-Q^2 points (electron detected in calorimeter)
- Lowest Q^2 = 3.5 GeV^2 not reanalyzed (electron detected in HRSR).
- Three highest-Q^2 R values systematically increase, by several times the originally quoted systematics.
- ***Increase mainly due to previously underestimated background***
- Addition of p(θ) – p cut suppresses background to <0.4%, remaining correction and uncertainty small
- Consistency of GEp-I/II/III/2γ data (Hall A vs. Hall C) is now excellent in a wide Q^2 range
- ***Updated analysis and results now published in Phys. Rev. C, PRC 85, 085, 045203***

GEp-2γ Results: PRL 106, 132501 (2011)





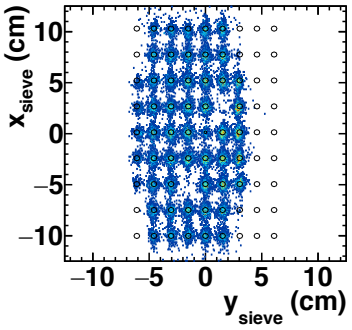
- Results show no ε-dependence of the ratio R (= $\mu G_E/G_M$ in Born approximation) at the 1% level at $Q^2 = 2.5\ \mathrm{GeV}^2$
- Relative variation of $P_L/P_L(\mathrm{Born})$ with ε shows a ~2% enhancement at large ε relative to small ε—not predicted by any model calculations of TPEX (available at the time of publication)

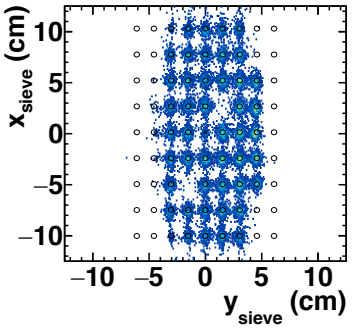
$$P_\ell^{Born} = \frac{\sqrt{1-\varepsilon^2}}{1+\frac{\varepsilon}{\tau}\left(\frac{G_E}{G_M}\right)^2} \quad R \equiv -\mu_p\sqrt{\frac{\tau(1+\epsilon)}{2\epsilon}}\frac{P_t}{P_\ell}$$

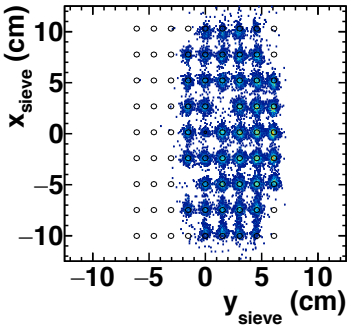
New/Final analysis of the Hall C data

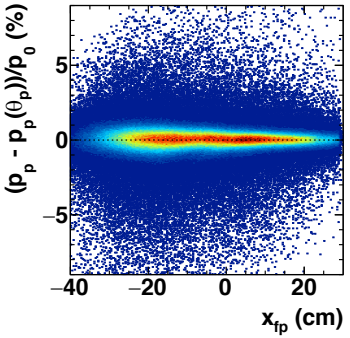
- Goal: Improve understanding of systematic uncertainties in order to publish full-acceptance results from GEp-2g and final archival results from GEp-2g/GEp-III.
- Major aspects of event reconstruction/calibration revisited:
  - **HMS optics calibration: angle and vertex reconstruction**
  - **HMS and FPP time-to-distance calibration performed run-by-run (and card-by-card for FPP drift chambers)**
  - **Improved FPP-HMS drift chamber alignment from straight-through data**
  - Minor improvements/bug fixes to HMS/FPP tracking algorithms
  - Recalibration of BigCal energy reconstruction for some run ranges with room for improvement
  - Minor improvements to BigCal shower coordinate reconstruction
  - Updated beam position/energy database from EPICS (beam position + raster corrections important for momentum/out-of-plane angle reconstruction)
  - More thorough run-by-run data quality checks; exclusion of runs with significant FPP data quality issues from GEp-2gamma analysis (minimize false asymmetries)
- Major aspects of physics analysis revisited:
  - Use of more efficient variable-width exclusivity cuts to account for variations of the widths of several exclusivity cut variables within the HMS acceptance (compared to fixed-width cuts used in the analysis for PRL publications)
  - Improved "fully differential" description of the analyzing power
  - Understanding of finite-acceptance/bin-centering effects on P_T, P_L, R

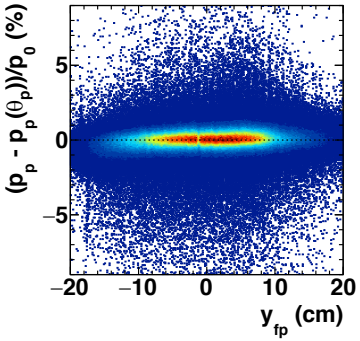
HMS Optics Calibrations

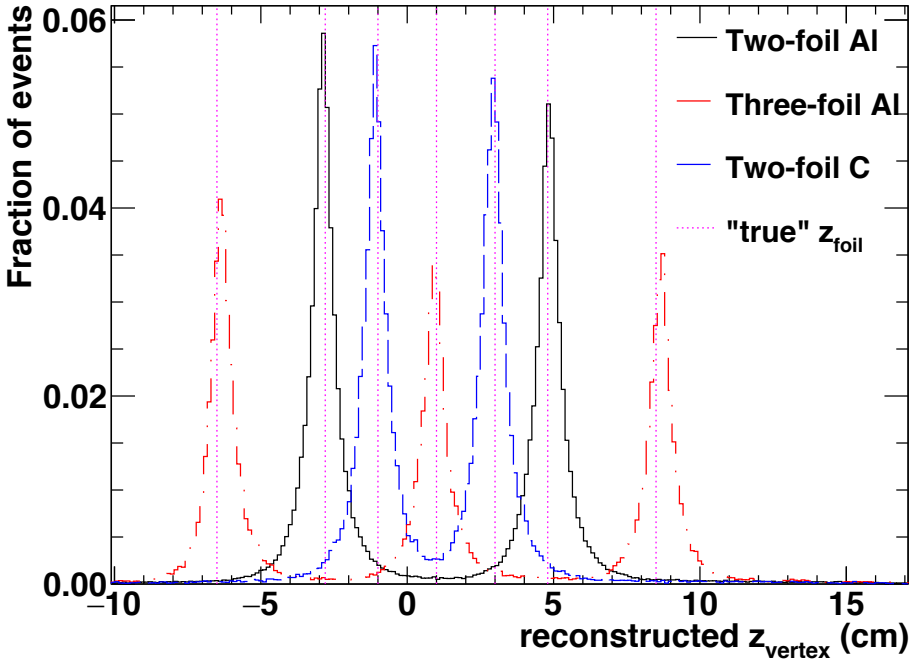


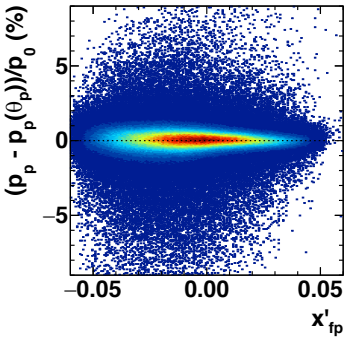


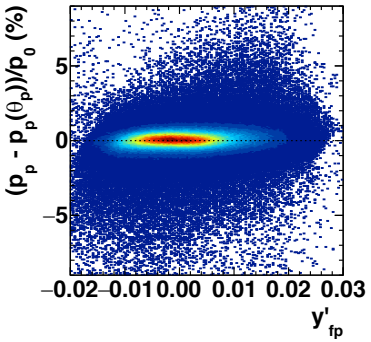


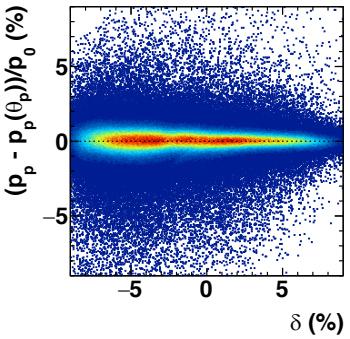


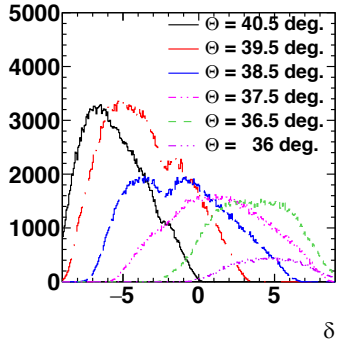




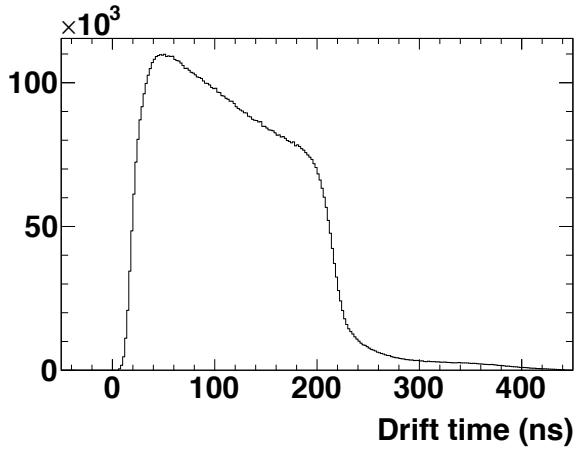


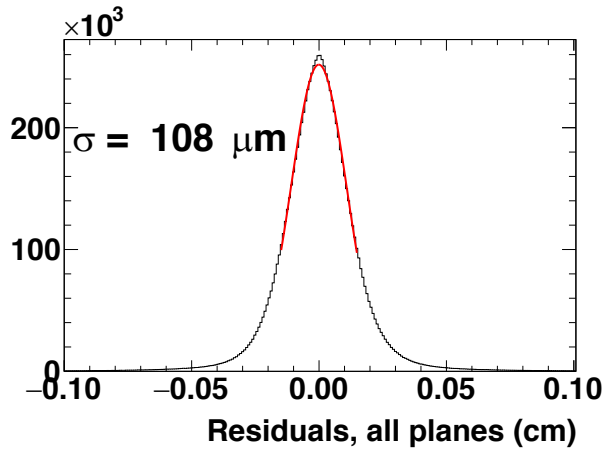


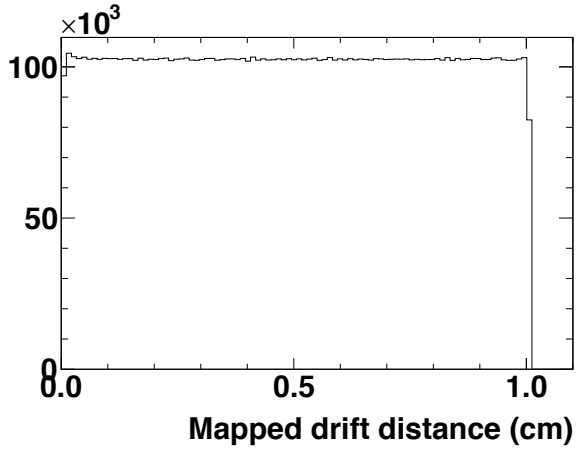


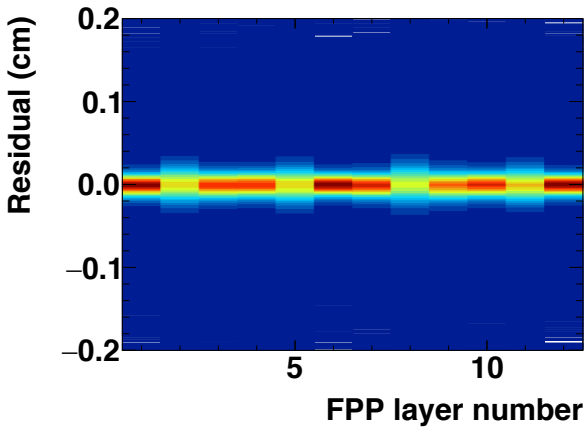


HMS and FPP drift-map database



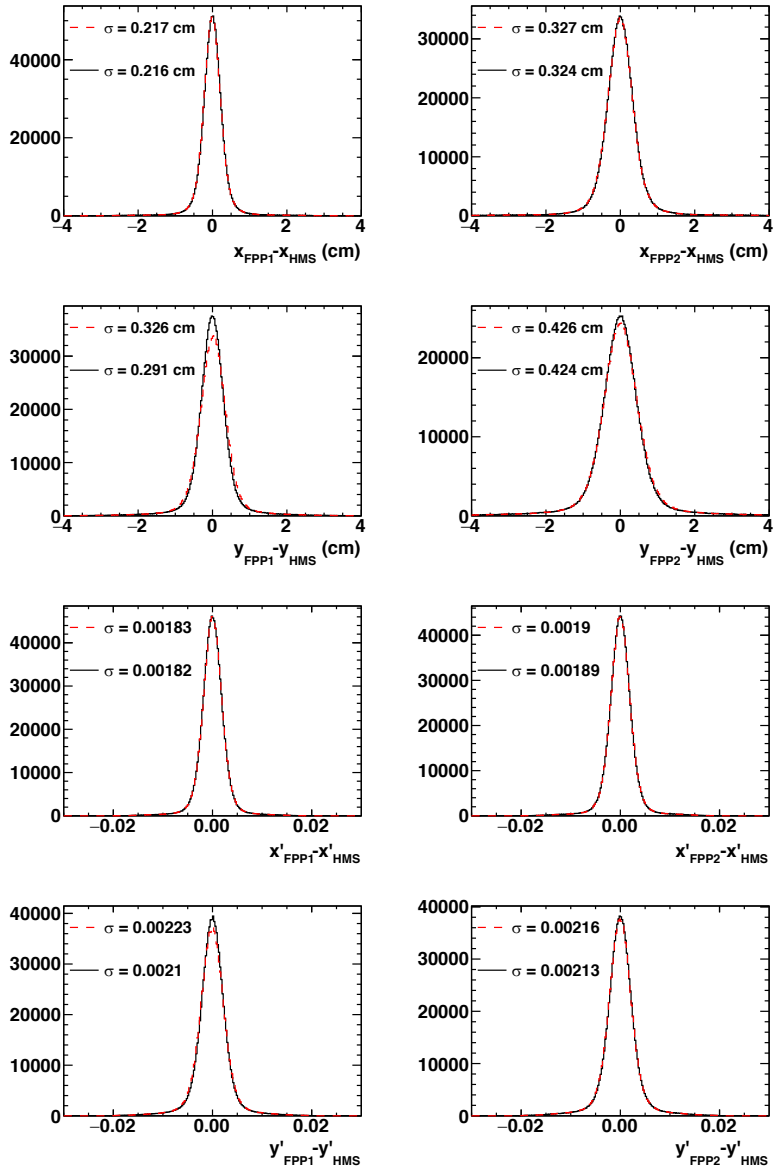




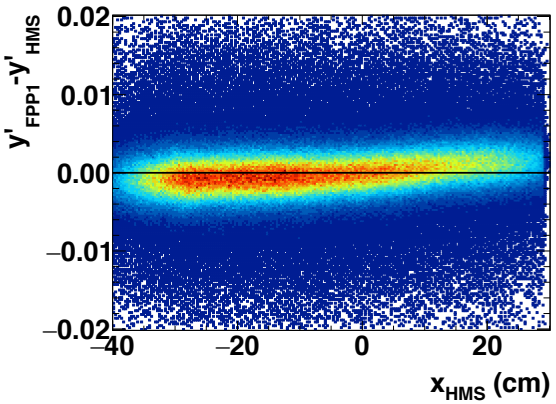


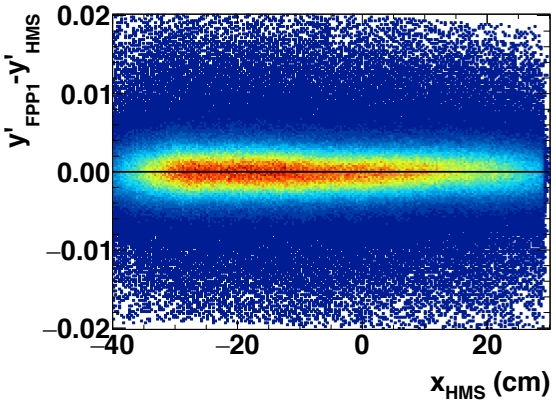
- Left: Example FPP drift time spectrum and mapped uniform drift distance distribution within a cell
- Right: FPP tracking residuals, averaged and by plane number

FPP alignment



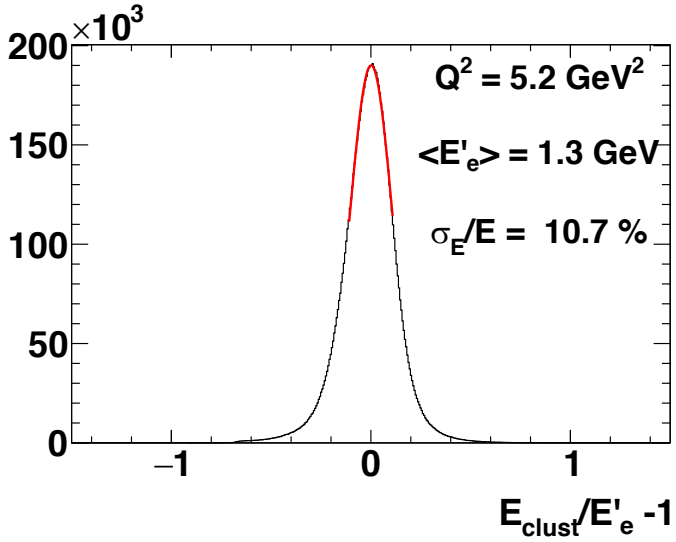
- Alignment strategy: determine best geometric alignment parameters (position, orientation)
- Remove residual spurious correlations via *ad hoc* corrections to FPP track expanded up to 2nd order in *HMS* track parameters
- Left: FPP-HMS track parameter differences from straight-through data, before (red-dashed) and after (black solid) applying *ad hoc* alignment corrections
- Right: residual correlation between **Δ**y' and x_{HMS} removed by *ad hoc* corrections

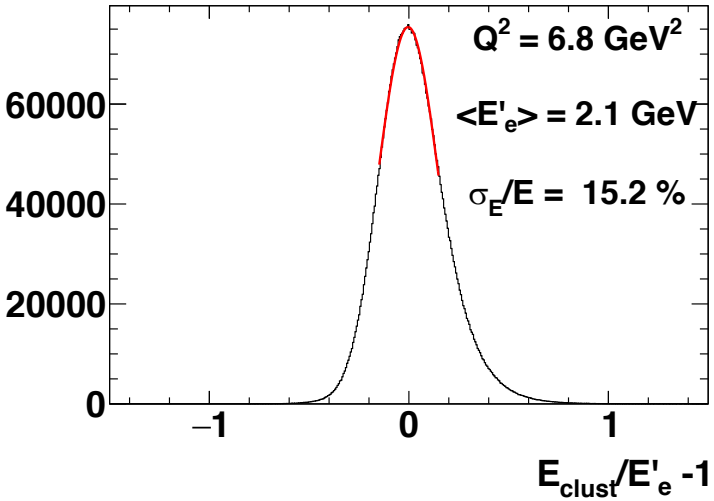


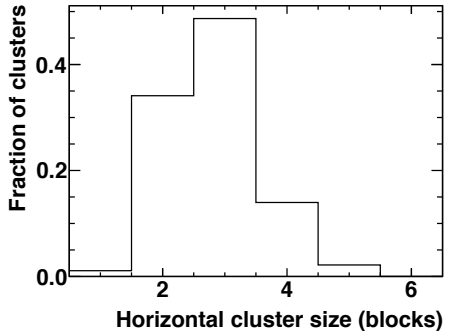


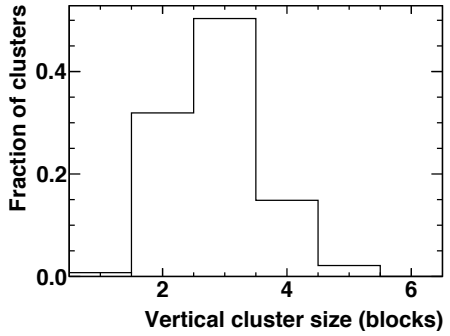
$$\Delta u = C_0^{(u)} + C_x^{(u)} x + C_y^{(u)} y + C_{x'}^{(u)} x' + C_{y'}^{(u)} y' + C_{xx}^{(u)} x^2 + C_{xy}^{(u)} xy + C_{xx'}^{(u)} xx' + C_{xy'}^{(u)} xy' + C_{yy}^{(u)} y^2 + C_{yx'}^{(u)} yx' + C_{yy'}^{(u)} yy' + C_{x'x'}^{(u)} x'^2 + C_{x'y'}^{(u)} x'y', \quad (20)$$

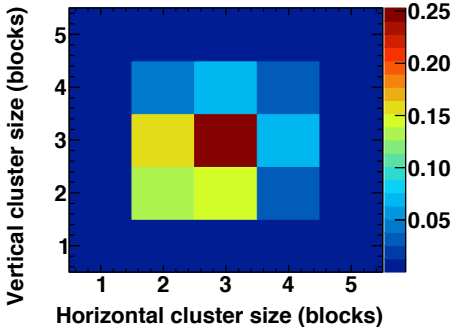
BigCal Reconstruction

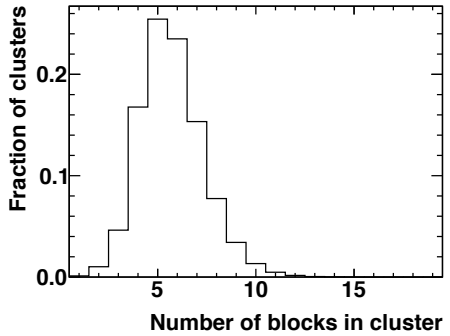






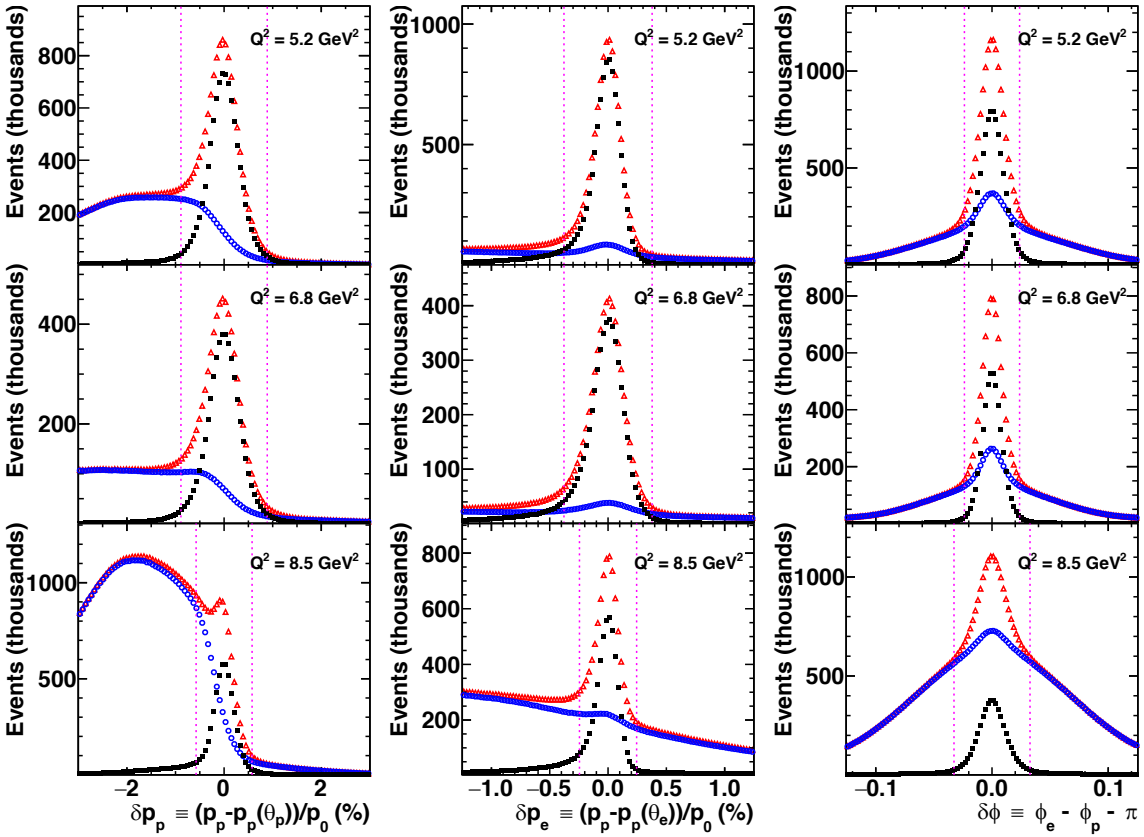


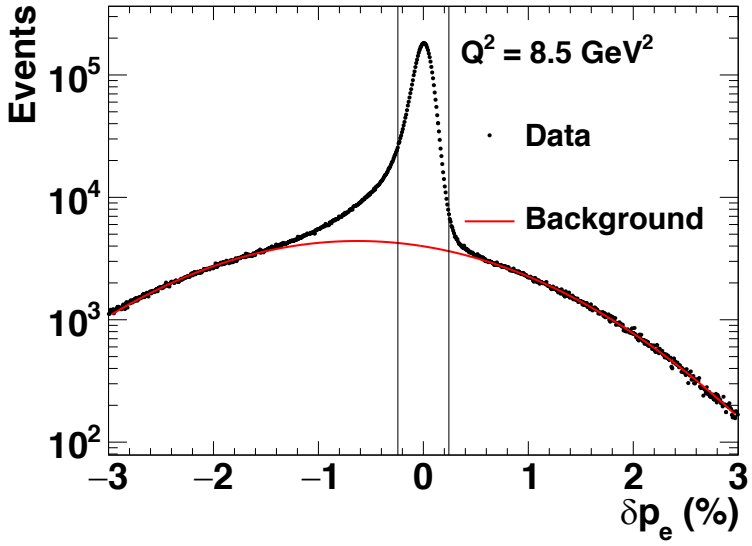


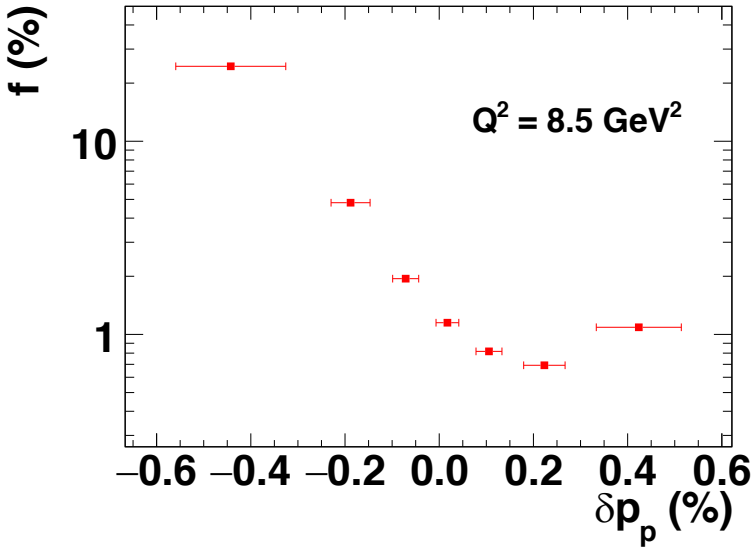


- Left: Energy resolution near beginning of experiment ($Q^2 = 5.2$ GeV^2) and end of experiment ($Q^2 = 6.8$ GeV^2). Scaled energy resolution at 1 GeV increased from 12% → 22% as a result of radiation damage
- Above: BigCal cluster size distribution at E' ~1.5 GeV

Elastic Event Selection, I

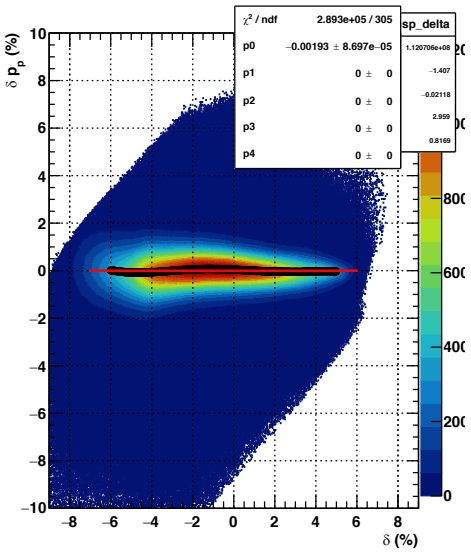


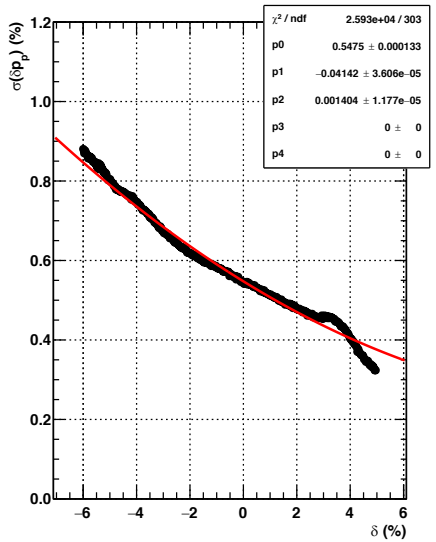


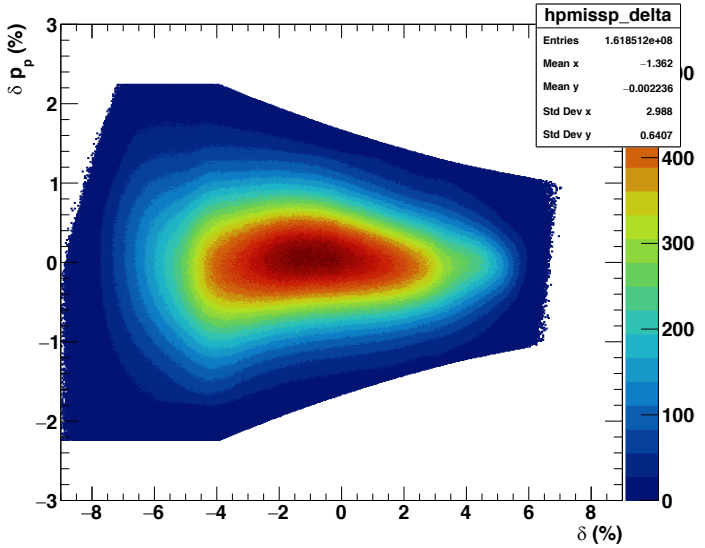


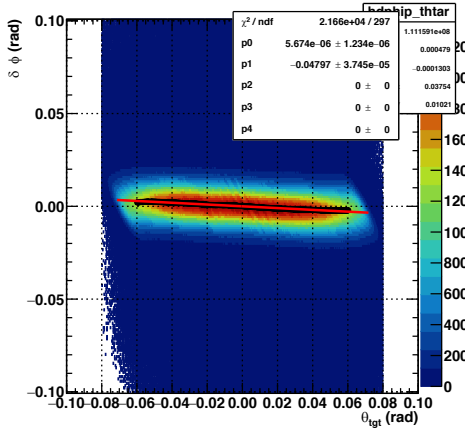
- Above: simplified picture of elastic event selection with fixed-width cuts for GEP-III kinematics
- Right, top: background estimation from sideband analysis of dp_e spectrum
- Right, bottom: estimated fractional background contamination vs. dp_p at $Q^2 = 8.5$ GeV^2

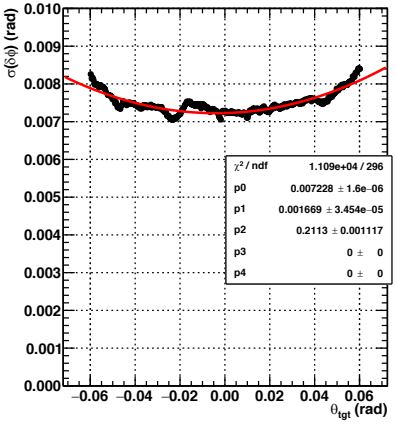
Elastic Event Selection, II

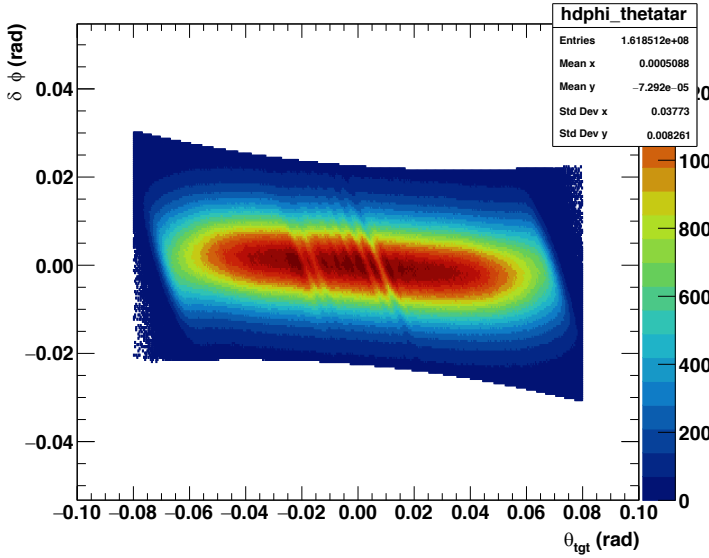






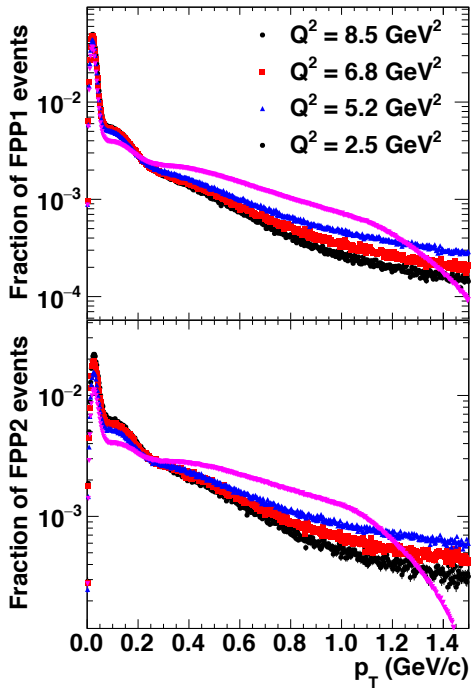


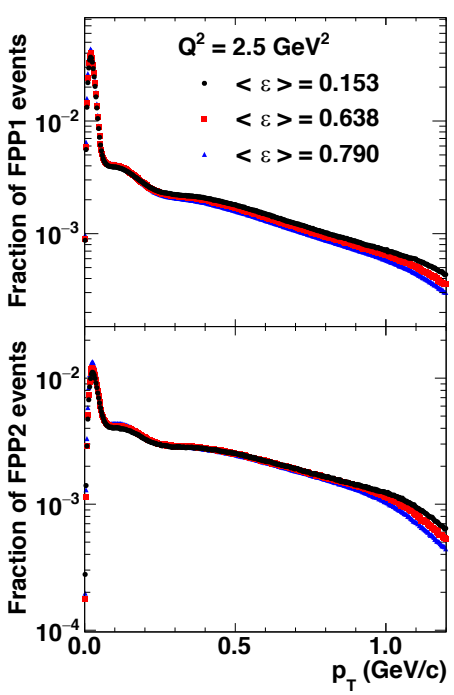


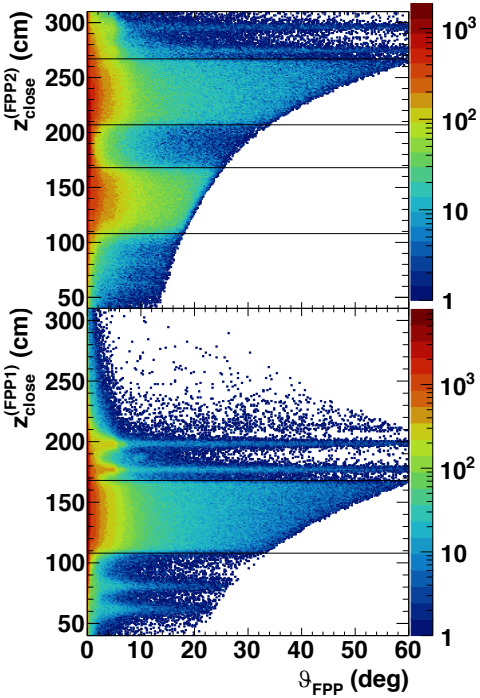


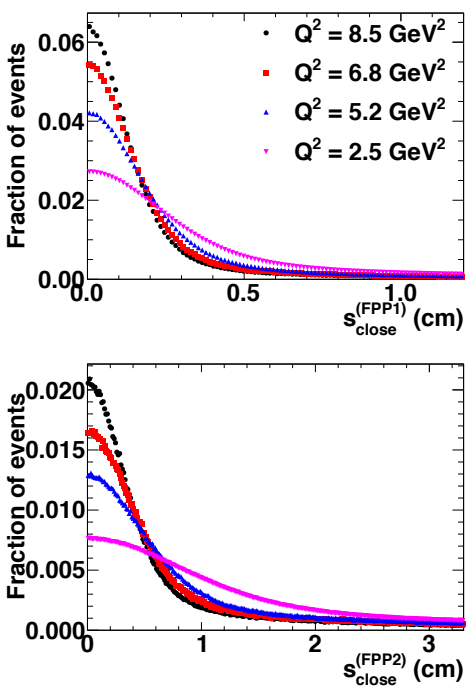
- Variable-width exclusivity cuts in δp_p and $\delta\phi$ improve efficiency and signal/background ratio of elastic event selection; and minimize cut-induced bias in the spin transport calculation

FPP angular distributions, I



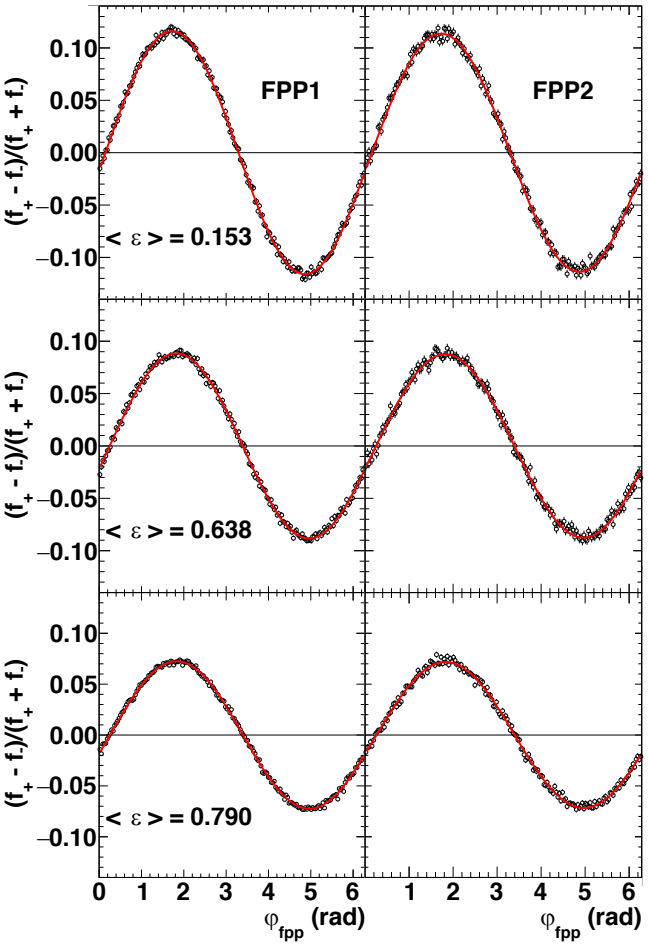


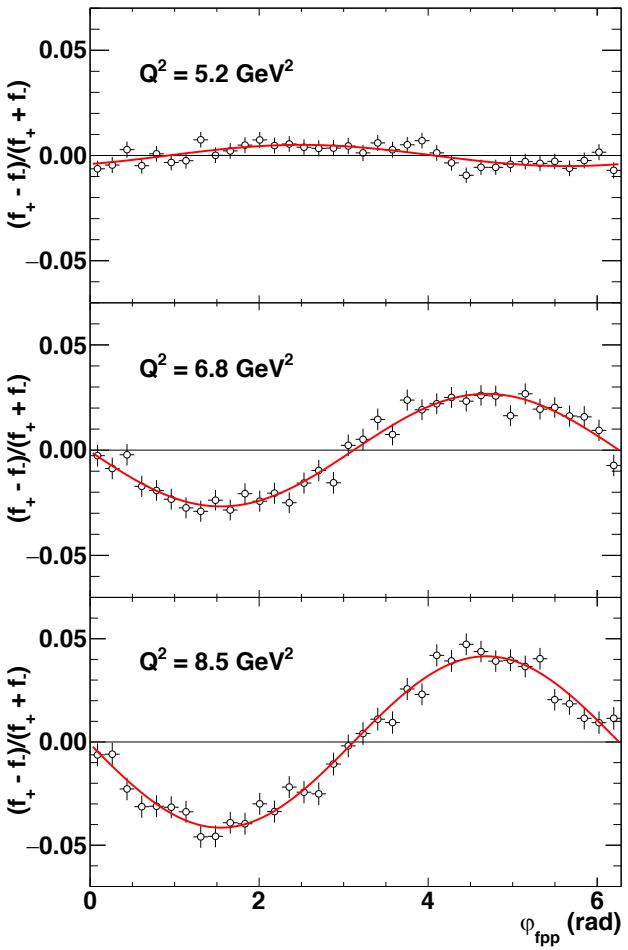




- Far left: $p_T = p \sin(\vartheta)$ for different Q^2, single-track events passing s_{close}, z_{close} cuts (closest-approach parameters) and cone test
- Mid left: $p_T = p \sin(\vartheta)$ for different ε, $Q^2 = 2.5$ GeV^2, single-track events passing s_{close}, z_{close} cuts (closest-approach parameters) and cone test
- Mid right: z_{close} vs. ϑ for FPP1 and FPP2, $Q^2 = 8.5$ GeV^2, single-track events passing s_{close} cut and cone test
- Far right: s_{close} (distance of closest approach) vs Q^2

FPP angular distributions, II





$$f^+ - f^- \equiv \frac{\pi}{\Delta\varphi}\left[\frac{N^+(\varphi)}{N_0^+} - \frac{N^-(\varphi)}{N_0^-}\right] = \bar{A}_y\left[P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right]\times \left[1+\mu_0(\varphi)\right] \quad (24)$$

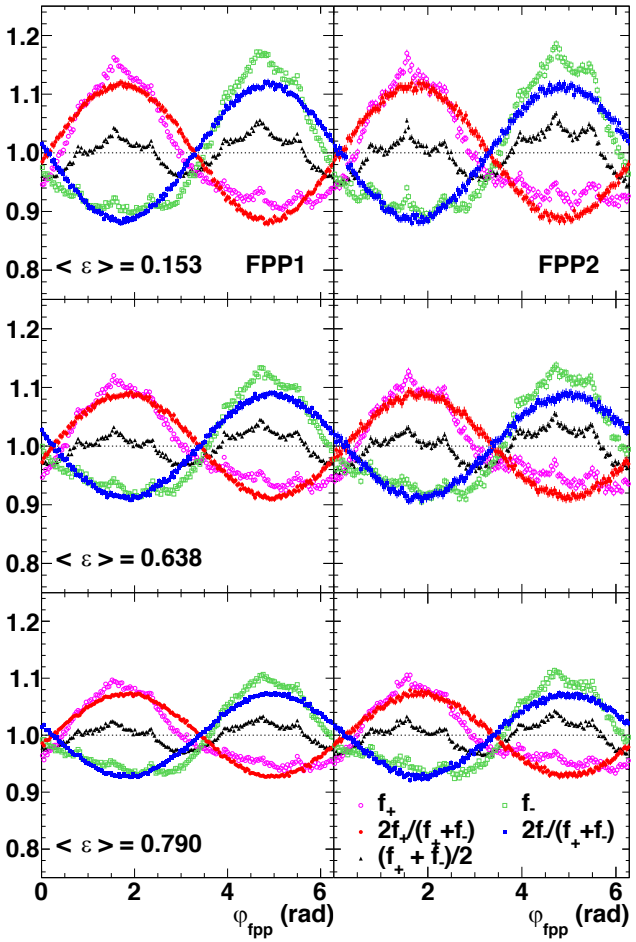
$$f^+ + f^- \equiv \frac{\pi}{\Delta\varphi}\left[\frac{N^+(\varphi)}{N_0^+} + \frac{N^-(\varphi)}{N_0^-}\right] = \left[1+\mu_0(\varphi)\right]\times \left[1+\bar{A}_y(P_{y,ind}^{FPP}\cos\varphi - P_{x,ind}^{FPP}\sin\varphi)\right] \approx 1+\mu_0(\varphi) \quad (25)$$

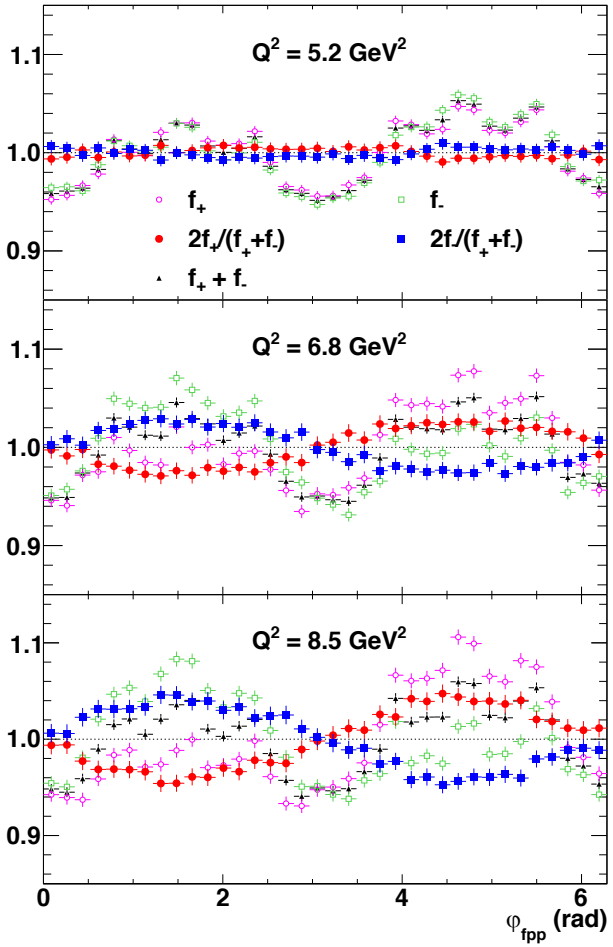
$$\frac{f_+ - f_-}{f_+ + f_-} = \frac{\bar{A}_y\left(P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right)}{1+\bar{A}_y\left(P_{y,ind}^{FPP}\cos\varphi - P_{x,ind}^{FPP}\sin\varphi\right)} \approx \bar{A}_y\left(P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right) \quad (26)$$

$$\frac{2f_\pm}{f_+ + f_-} = 1 \pm \frac{\bar{A}_y\left(P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right)}{1+\bar{A}_y\left(P_{y,ind}^{FPP}\cos\varphi - P_{x,ind}^{FPP}\sin\varphi\right)} \approx 1 \pm \bar{A}_y\left(P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right) \quad (27)$$

- Left: azimuthal helicity-difference/sum ratio asymmetry for FPP1 and FPP2 for GEp-2gamma kinematics
- Middle: Same for GEp-III kinematics
- Right: Equations for angular distributions in terms of transferred/induced polarizations and false asymmetries

FPP angular distributions, III





$$f^+ - f^- \equiv \frac{\pi}{\Delta\varphi}\left[\frac{N^+(\varphi)}{N_0^+} - \frac{N^-(\varphi)}{N_0^-}\right] = \bar{A}_y\left[P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right]\times\left[1+\mu_0(\varphi)\right] \quad (24)$$

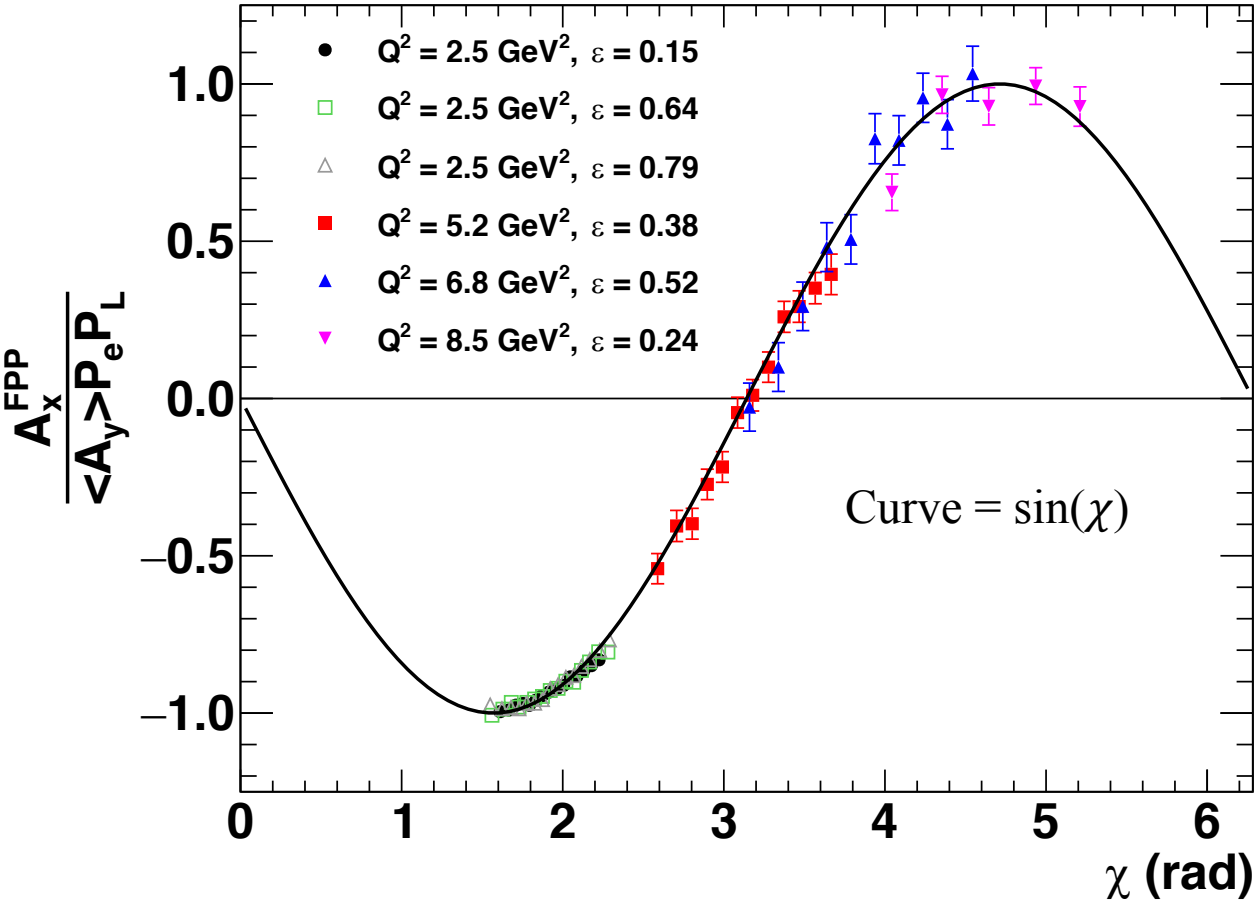
$$f^+ + f^- \equiv \frac{\pi}{\Delta\varphi}\left[\frac{N^+(\varphi)}{N_0^+} + \frac{N^-(\varphi)}{N_0^-}\right] = \left[1+\mu_0(\varphi)\right]\times\left[1+\bar{A}_y(P_{y,ind}^{FPP}\cos\varphi - P_{x,ind}^{FPP}\sin\varphi)\right] \approx 1+\mu_0(\varphi) \quad (25)$$

$$\frac{f_+ - f_-}{f_+ + f_-} = \frac{\bar{A}_y\left(P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right)}{1+\bar{A}_y\left(P_{y,ind}^{FPP}\cos\varphi - P_{x,ind}^{FPP}\sin\varphi\right)} \approx \bar{A}_y\left(P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right) \quad (26)$$

$$\frac{2f_\pm}{f_+ + f_-} = 1 \pm \frac{\bar{A}_y\left(P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right)}{1+\bar{A}_y\left(P_{y,ind}^{FPP}\cos\varphi - P_{x,ind}^{FPP}\sin\varphi\right)} \approx 1 \pm \bar{A}_y\left(P_{y,tr}^{FPP}\cos\varphi - P_{x,tr}^{FPP}\sin\varphi\right) \quad (27)$$

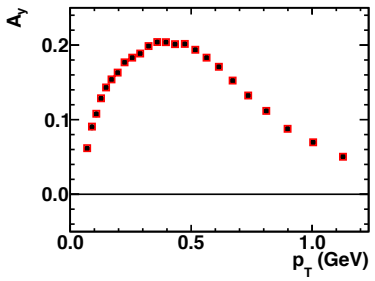
- Left: azimuthal angle distributions for +,- helicities, their sum and their ratio to the sum, vs ***ε*** at $Q^2 = 2.5$ GeV^2
- Mid: Same for GEp-III kinematics
- Right: Equations for angular distributions in terms of transferred/induced polarizations and false asymmetries

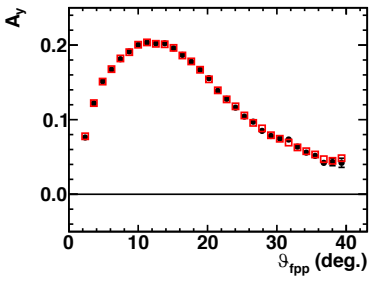
Spin Precession

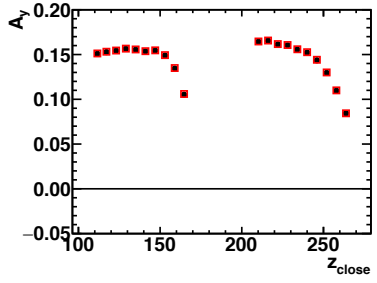


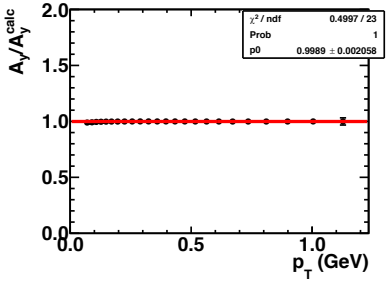
- Large acceptance of the HMS in the main "dipole" precession angle χ and generally large values of P_L means that even with a central precession angle near 180 deg., the uncertainty in R is dominated by the determination of P_T; even at $Q^2 = 5.2$, $\Delta P_T/P_T \sim 4\Delta P_L/P_L$

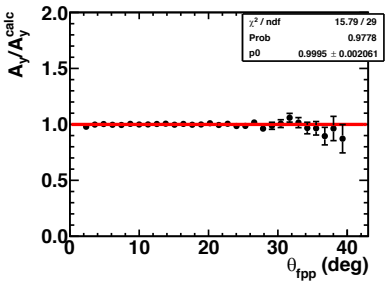
Analyzing Power Calibration

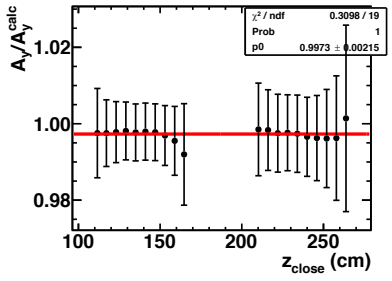












$$\hat{P}_t^{(A_y=1)} = \bar{A}_y P_t$$

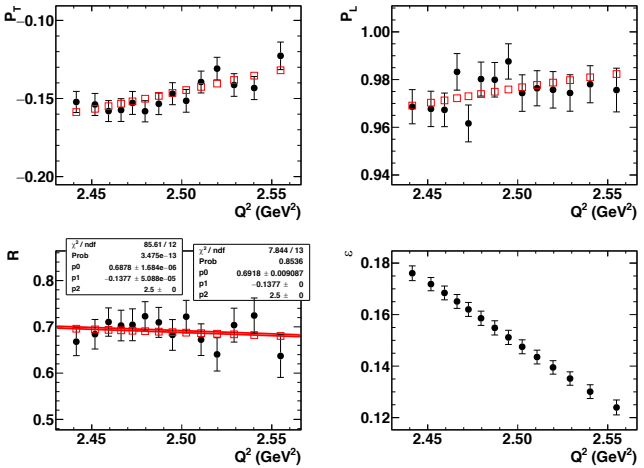
$$\hat{P}_\ell^{(Ay=1)} = \bar{A}_y P_\ell$$

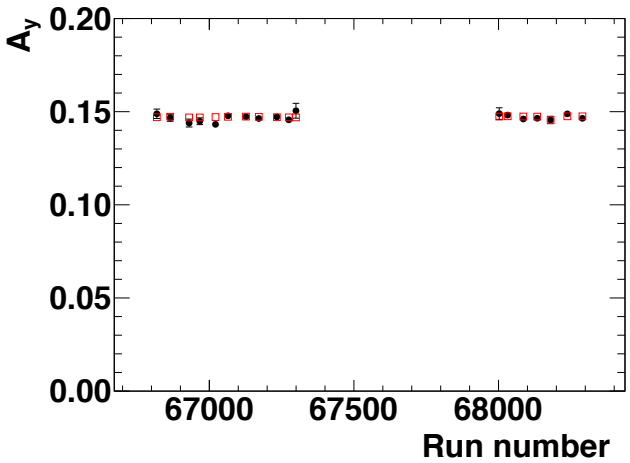
$$\bar{A}_y = \frac{\hat{P}_t^{(A_y=1)}}{P_t^{Born}} = \frac{\hat{P}_\ell^{(A_y=1)}}{P_\ell^{Born}}$$

$$P_t^{Born} = -\sqrt{\frac{2\epsilon(1-\epsilon)}{\tau}}\frac{r}{1+\frac{\epsilon}{\tau}r^2}$$

$$P_\ell^{Born} = \frac{\sqrt{1-\epsilon^2}}{1+\frac{\epsilon}{\tau}r^2}$$

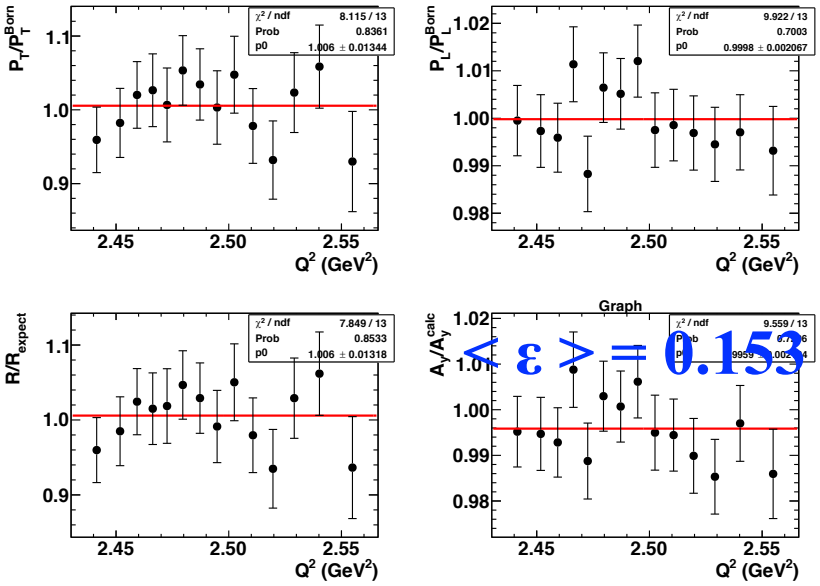
- Analyzing power for $Q^2 = 2.5$ GeV^2 is calibrated using the low-ε point:
  - P_L^{Born} is very insensitive to the FF ratio at this (ε, Q2)
- 2D binning in $p_T = p \sin(\vartheta)$ and z_{close}
- Momentum dependence accounted for using an overall 1/p scaling event-by-event

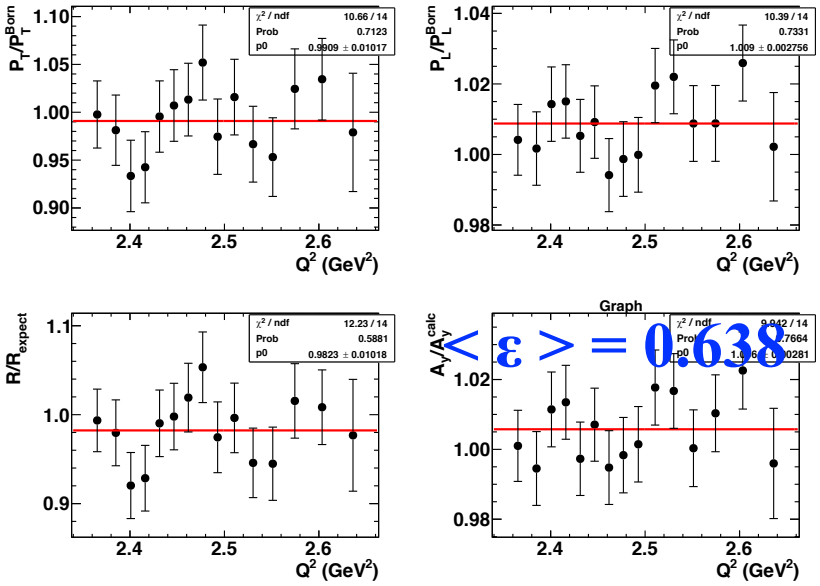




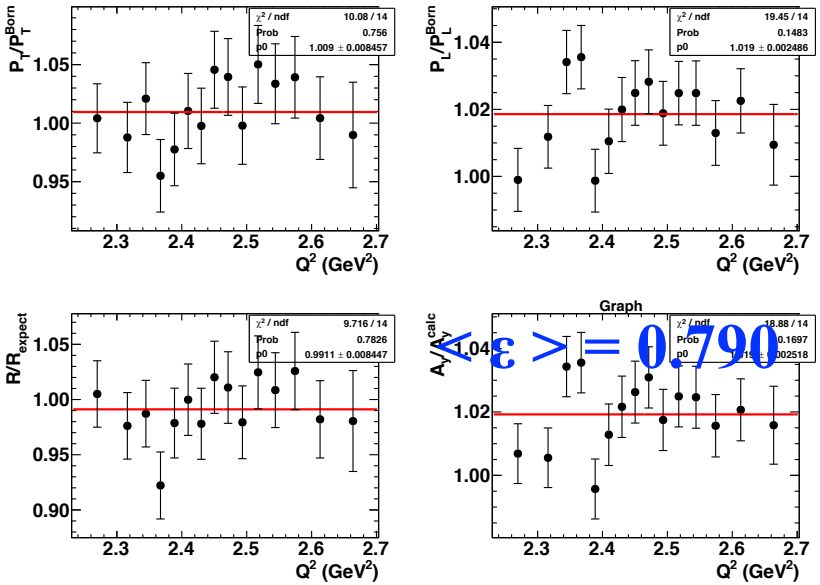
- **Key assumption for full acceptance extraction of P_L/P_L^{Born}: p_T dependence of A_y factorizes from p_p dependence: $A_y = A_y^0(p_T)/p$**

Checking the momentum scaling of A_y

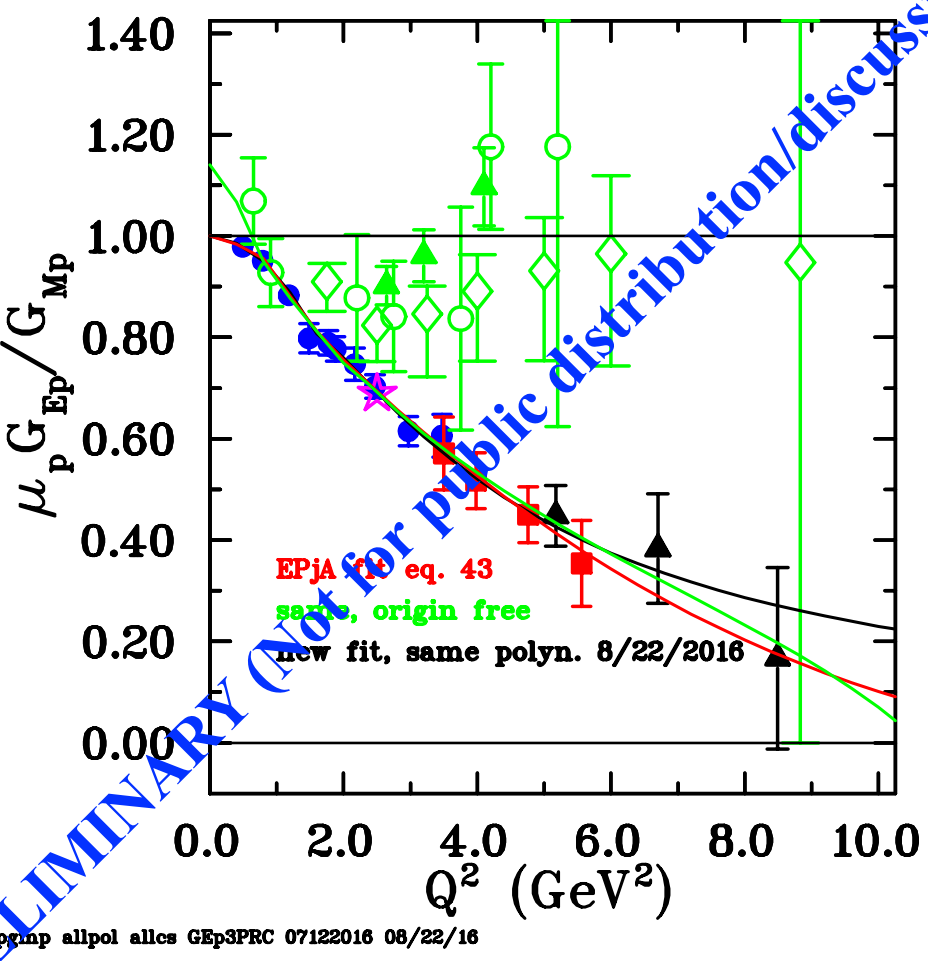


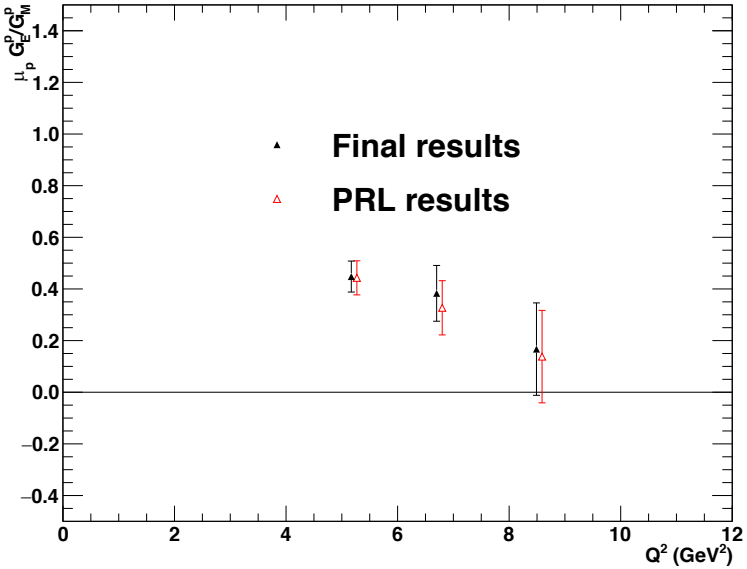


- Crucial for P_L/P_L^{Born} extraction is the application of the same cuts on all parameters of the secondary scattering (p_T, s_{close}, z_{close}) and the event topology (single-track events passing cone test); the effective average A_y should be the same up to the momentum dependence and the different Q^2/p_p ranges accepted by the HMS for different ε values
- Same central momentum setting also insures that the spin precession is the same and the associated p.t.p. systematics are very small.



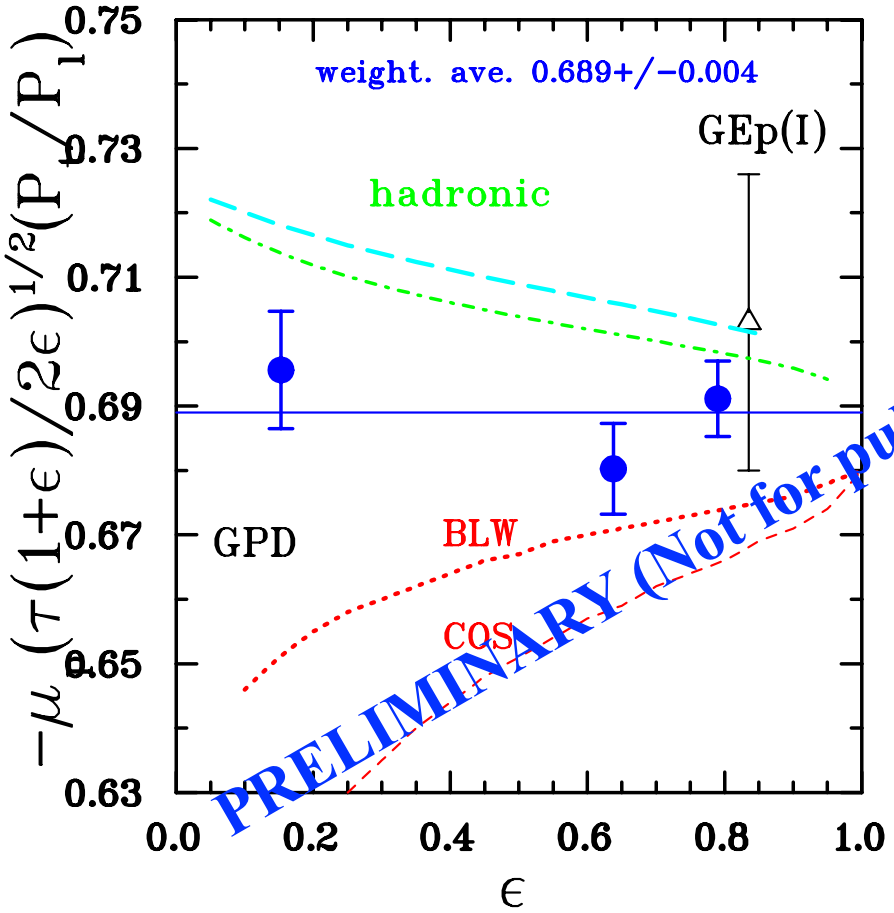
GEp-III Final Archival Results (PRELIMINARY)

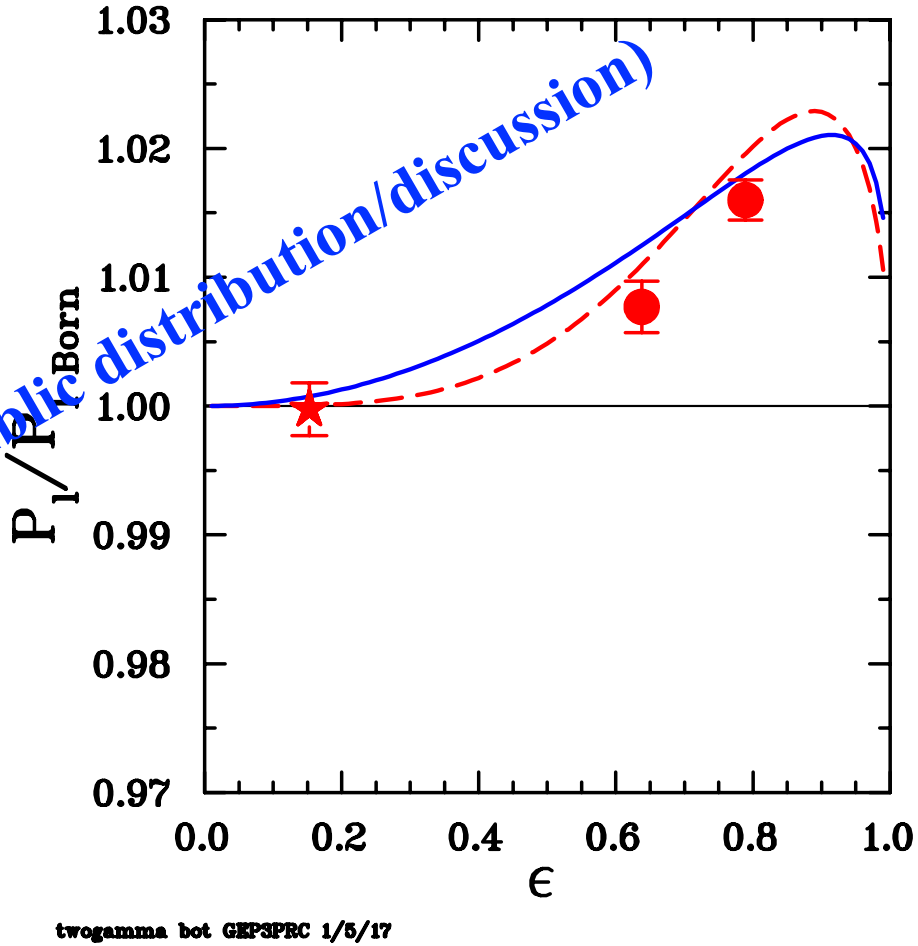




- GEp-III final results:
  - Statistically and systematically insignificant increases at $Q^2 = 6.8$, 8.5 GeV^2 relative to original publication. 5.2 GeV^2 result virtually identical
  - Statistical error reduced from 0.066 → 0.060 at 5.2 GeV^2, reflecting the (previously neglected) covariance term between P_T, P_L

GEp-2gamma Final Archival Results (PRELIMINARY)





PRELIMINARY (Not for public distribution/discussion)

- **Final analysis of GEp-2gamma with full-acceptance data more than doubles statistics at ε = 0.638, 0.790**
- Only stat. errors are shown here
- Our conclusions with respect to R and P_L/P_L^{Born} are basically unchanged, although the enhancement of P_L at large ε is somewhat smaller (but consistent to within stat. and syst. errors with original PRL publication, which only included data within an artificially restricted acceptance matched to the lowest ε)

Status, Summary and Conclusions

- A new and final analysis of GEp-III/GEp-2gamma data is complete, up to finalizing the systematic uncertainties, which is also very nearly complete pending some fine details of correlated vs. point-to-point systematic uncertainties in the precise 2.5 GeV^2 data
- This includes the previously unpublished data using the full HMS acceptance that was excluded from original PRL publication of GEp-2gamma
- A draft archival publication for both experiments combined is near completion; we expect to circulate to the collaboration for comment as soon as late Feb.-early March, hopefully publish by summer

Polarization Transfer Observables in Elastic Electron-Proton Scattering at $Q^2 = 2.5$, 5.2, 6.8 and 8.5 GeV^2

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This is the abstract of our paper.

I. INTRODUCTION

Scattering of electrons or of real photons is of great importance for the characterization of the structure of the nucleon as well as nuclei, because of the relative weakness of the electromagnetic interaction, compared to that of strongly interacting probes like nucleons or mesons. The field of elastic electron scattering received its initial start with the availability of electron beams of several hundreds of MeV (up to 550 MeV) at the High Energy Physics Laboratory (HEPL) in Stanford in the middle 1950's. One particularly outstanding result was the determination of a proton radius [1], which together with

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