High-Precision Measurement of $\mu_p G_E^p / G_M^p$ at $Q^2 = 3.7$ GeV^2 Using Polarization Transfer (PR12-24-010)

Andrew Puckett, University of Connecticut
(spokespersons A. Puckett, J. Bernauer, A. Schmidt)

PAC52

July 10, 2024

UCONN

Motivation—Positrons @JLab and the Proton Form Factor Ratio Puzzle

- https://inspirehep.net/literature/1809448

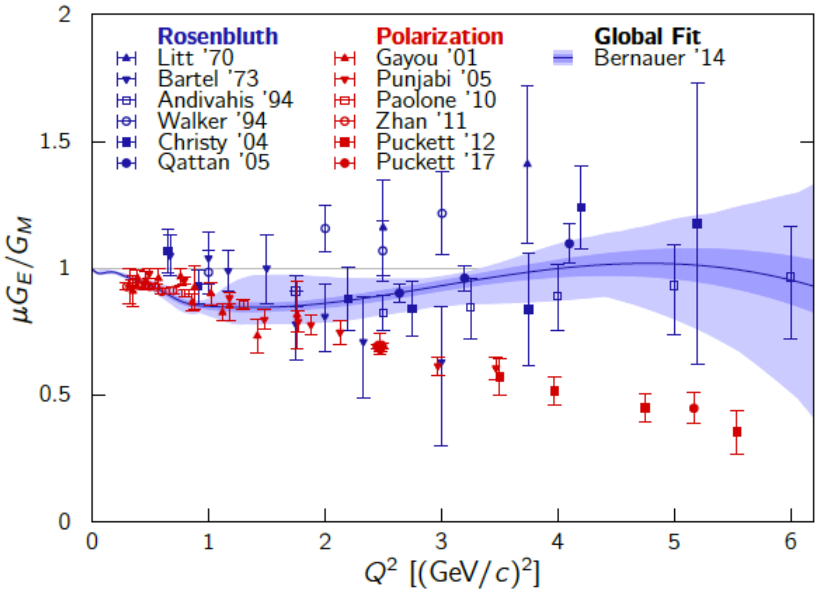


Fig. 1 A representative sample of the world data on the proton's form factor ratio, $\mu_p G_E/G_M$ shown as a function of squared four-momentum transfer, Q^2. Rosenbluth separations of unpolarized cross sections are shown in blue [48, 49, 50, 51, 52, 53]. Polarized measurements are shown in red [35, 36, 37, 38, 39, 40]. A global fit to unpolarized cross sections [59] is shown, along with statistical and systematic uncertainties, by a blue curve with light blue bands.

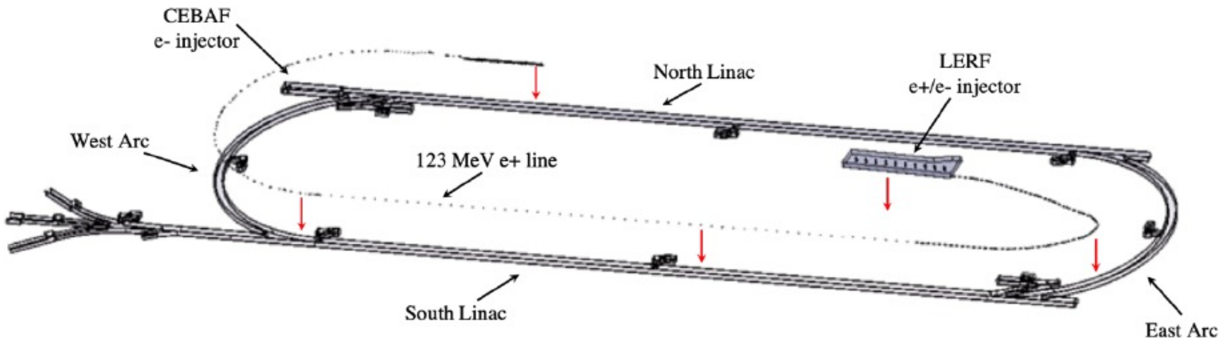


Figure 44: A new tunnel and beam line (shown raised) connects the LERF to CEBAF and transports the 123 MeV e^+ beam for injection and acceleration into CEBAF 12 GeV.

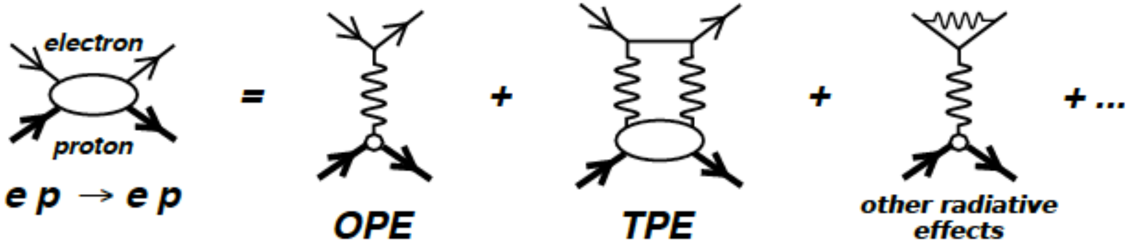


Fig. 2 Feynman diagram series for elastic electron-proton scattering. The two-photon exchange amplitude contributes at the same order as several other radiative processes.

- Differences in scattering observables between e^+p and e^-p scattering are considered "direct" signatures of hard TPE, as the $1\gamma - 2\gamma$ interference changes sign with the lepton charge

Polarization Results for $\mu_p G_E^p / G_M^p$ and the 2017 Bonner Prize

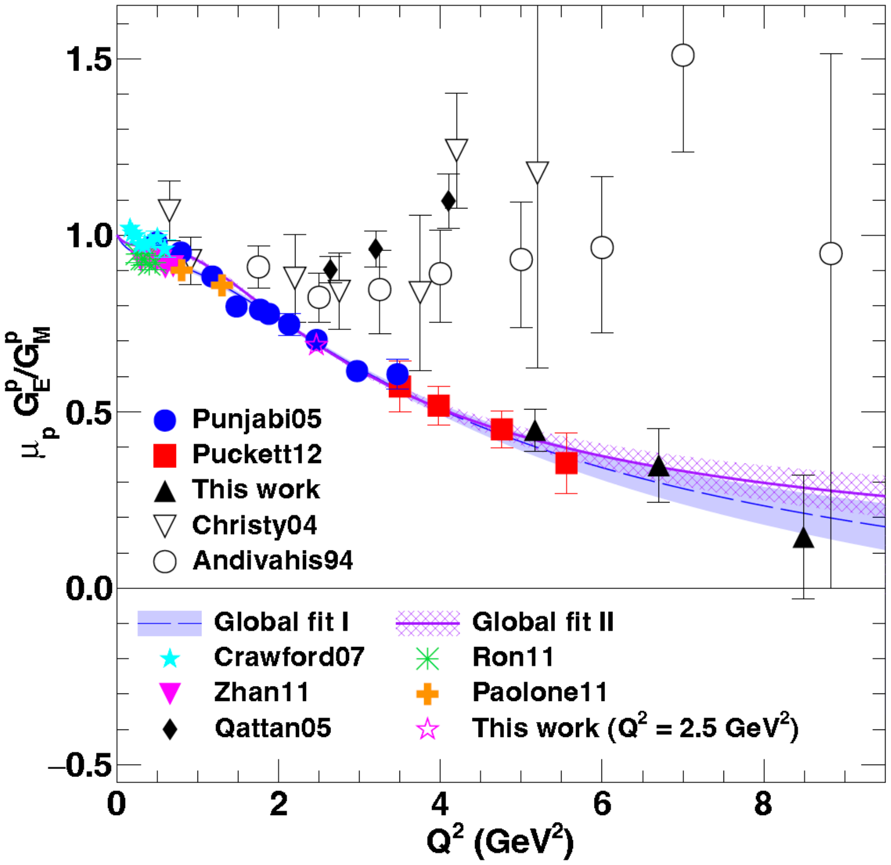


Figure from PRC 96, 055203 (2017)

References:

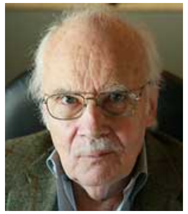
- GEp-I (E93-027):
  - Jones, PRL 84, 1398 (2000)
  - Punjabi, PRC 71, 055202 (2005)
- GEp-II (E99-007):
  - Gayou, PRL 88, 092301 (2002)
  - Puckett, PRC 85, 045203 (2012)
- GEp-III/GEp-2γ (E04-108/E04-019):
  - Puckett, PRL 104, 242301 (2010)
  - Meziane, PRL 106, 132501 (2011)
  - Puckett, PRC 96, 055203 (2017)

- (Arguably) most famous results in the history of JLab, inarguably among the most cited

APS physics

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

Experimental Status of TPE

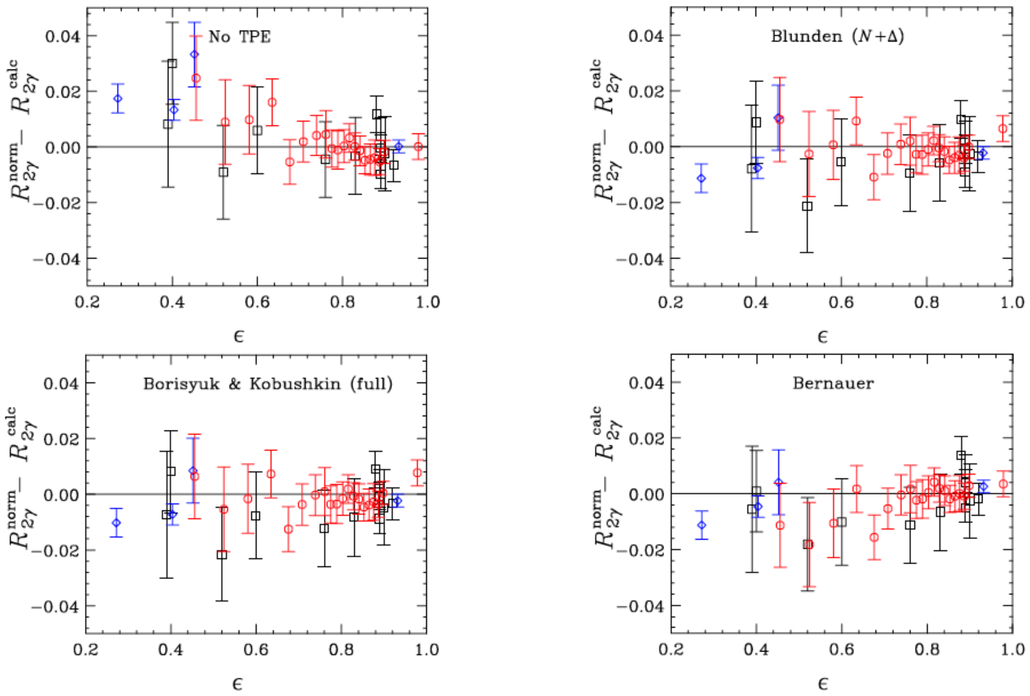


Figure 3.17: Difference between *normalized* $R_{2\gamma}$ and model predictions as a function of ε. Data symbols are the same as in Fig. 3.15.

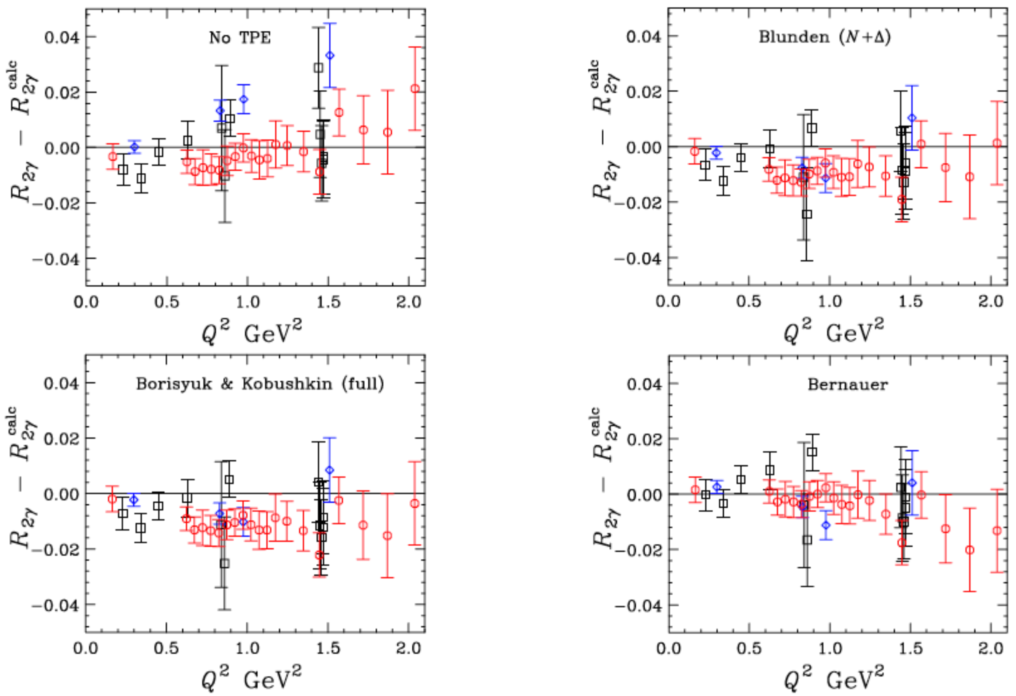


Figure 3.16: Difference between $R_{2\gamma}$ and model predictions as a function of Q^2. Data symbols are the same as in Fig. 3.15.

- Afanasev *et al.*, Prog. Part. Nucl. Phys. 95 (2017) 245-278
- CLAS-TPE, VEPP-3, and OLYMPUS exclude the "no-TPE" hypothesis at ~98% confidence, and are largely consistent with existing calculations that partially account for the discrepancy for $Q^2 < 2$ GeV^2.
- However, these experiments do not reach high-enough Q^2 and/or low-enough ϵ with sufficient precision to conclusively resolve the discrepancy in favor of the TPE hypothesis in the region where it is large ($Q^2 \geq 2\ GeV^2$).

Theoretical formalism for TPE corrections to polarization observables

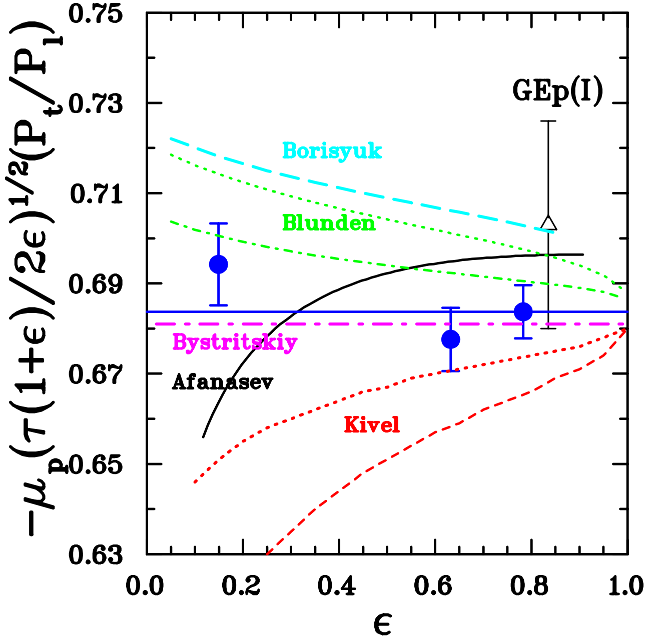
- TPE corrections to elastic lepton-nucleon scattering observables can be parametrized in terms of "generalized" form factors that depend on both Q^2, ϵ:
  - See, e.g., Carlson and Vanderhaeghen, Ann. Rev. Nucl. Part. Sci. 57, 171 (2007)
- Polarization transfer provides complementary information to cross sections (and beam/target/recoil SSA)

$$\frac{P_t}{P_\ell} = -\sqrt{\frac{2\epsilon}{\tau(1+\epsilon)}}\frac{G_E}{G_M} \times \left[1 \pm \mathrm{Re}\left(\frac{\delta\widetilde{G}_M}{G_M}\right) \pm \frac{1}{G_E}\mathrm{Re}\left(\delta\widetilde{G}_E + \frac{\nu}{M^2}\widetilde{F}_3\right) \mp \frac{2}{G_M}\mathrm{Re}\left(\delta\widetilde{G}_M + \frac{\epsilon\nu}{(1+\epsilon)M^2}\widetilde{F}_3\right) + \mathcal{O}(\alpha^2)\right]$$

$$\frac{\sigma_{e^+p}}{\sigma_{e^-p}} = 1 + 4G_M\mathrm{Re}\left(\delta\widetilde{G}_M + \frac{\epsilon\nu}{M^2}\widetilde{F}_3\right) - \frac{4\epsilon}{\tau}G_E\mathrm{Re}\left(\delta\widetilde{G}_E + \frac{\nu}{M^2}\widetilde{F}_3\right) + \mathcal{O}(\alpha^2).$$

- Polarization transfer never measured before in positron-proton scattering!
- Different and complementary sensitivity to TPE amplitudes as compared to cross section ratio
- Theoretical predictions are model-dependent→ latest estimates for LOI kinematics are not yet in hand, ***but predictions and impact studies will be ready in time for the full proposal for the positron measurements,(targeting PAC53 if PR12-24-010 is approved).***

Hard TPE effects in Polarization Transfer?



- Left: GEp-2γ results compared to theoretical predictions available at the time: Puckett *et al.* PRC 96, 055203 (2017)
- Right: phenomenological extraction of TPE amplitudes from cross section and polarization data: Guttmann *et al.,* EPJA, 47, 77 (2011)

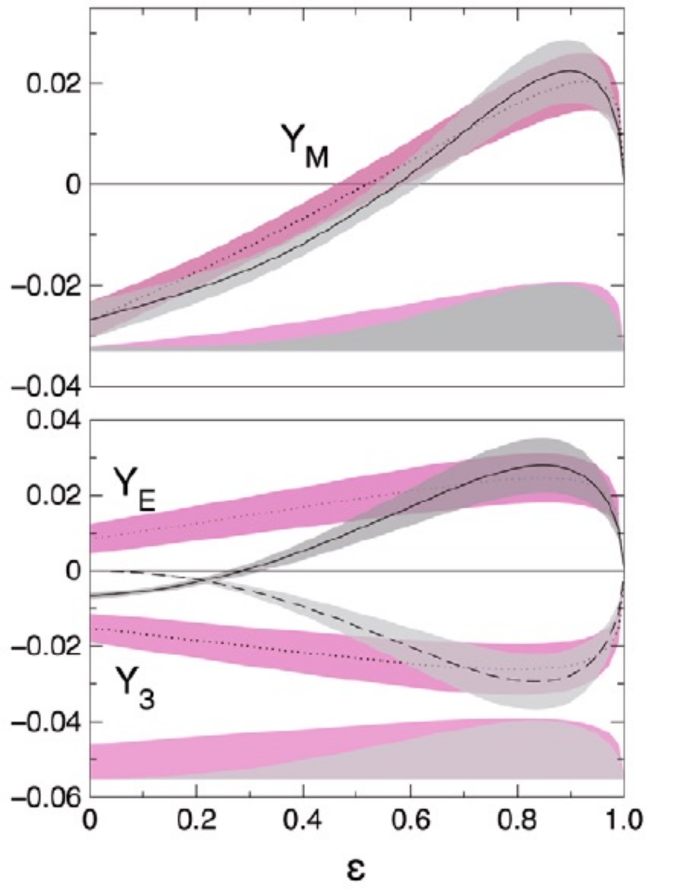


Fig. 4. (Color online) The extracted 2γ-amplitudes as a function of ε for $Q^2 = 2.64\,\mathrm{GeV}^2$ for the two fits of P_l in eq. (10), with their 1σ statistical error bands. Fit 1: grey bands; Fit 2: red bands. The horizontal bands at the bottom of the plots indicate the systematic errors.

- $G_E^p - 2\gamma$ experiment saw no significant ϵ dependence in the P_T/P_L ratio at 2.5 GeV^2
- Hint of a nonzero effect in $\frac{P_L}{P_L^{Born}}$, but with only ~2σ significance—drives equal magnitude and opposite sign of Y_E, Y_3 TPE amplitudes
- **Positron PT observables never measured before!**
- Polarization observables are thought to be less sensitive to TPE as compared to cross sections, but not immune!
- Not just ϵ dependence, but difference between e^+p/e^-p
- Wide range of theoretical predictions for ϵ dependence.

Prospects for polarization transfer using positrons

Regular Article - Experimental Physics | Published: 09 June 2021

Polarization transfer in $e^+p \to e^+p$ scattering using the Super BigBite Spectrometer

A. J. R. Puckett, J. C. Bernauer & A. Schmidt

The European Physical Journal A **57**, Article number: 188 (2021) | Cite this article

Abstract

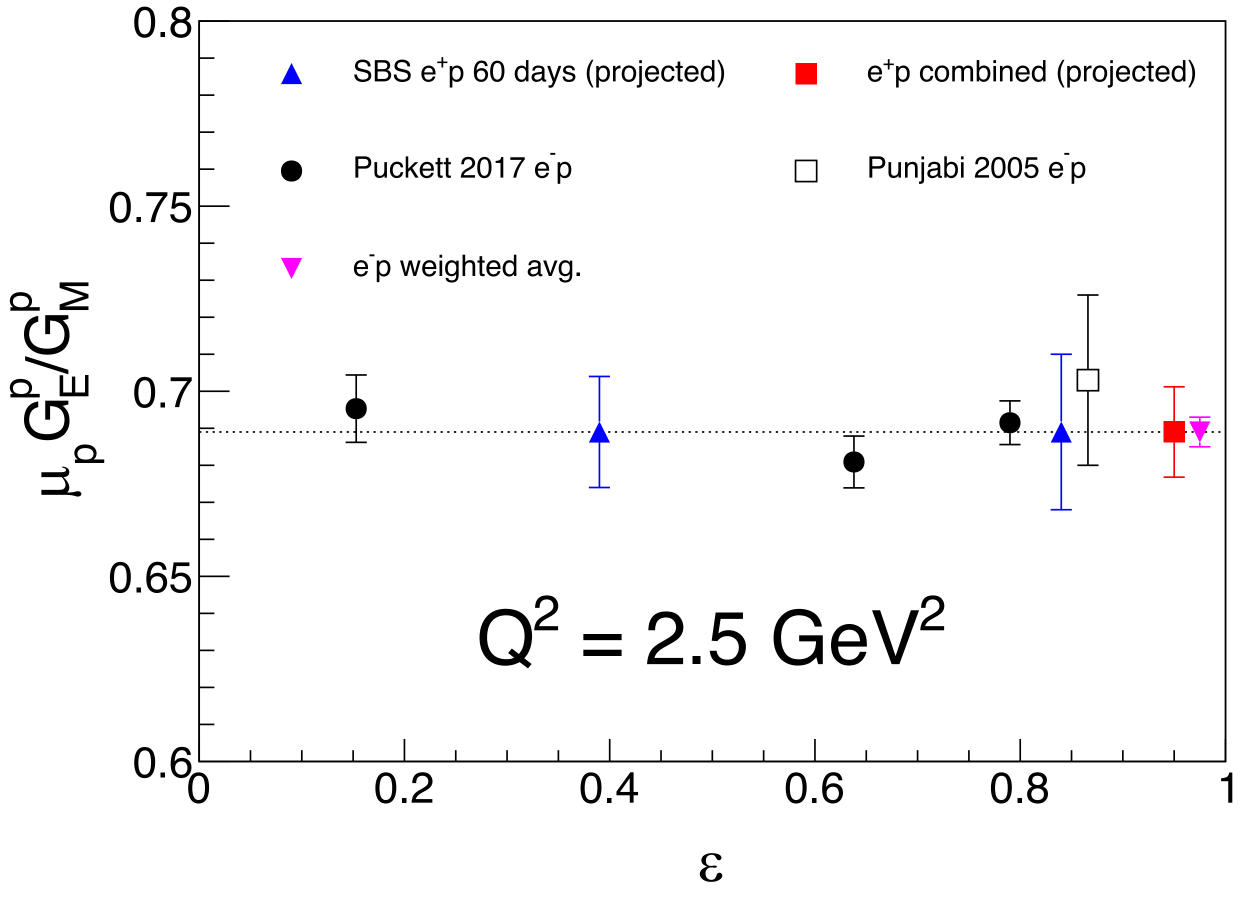
The effects of multi-photon-exchange and other higher-order QED corrections on elastic electron-proton scattering have been a subject of high experimental and theoretical interest since the polarization transfer measurements of the proton electromagnetic form factor ratio G_E^p/G_M^p at large momentum transfer Q^2 conclusively established the strong decrease of this ratio with Q^2 for $Q^2 > 1$ GeV^2. This result is incompatible with previous extractions of this

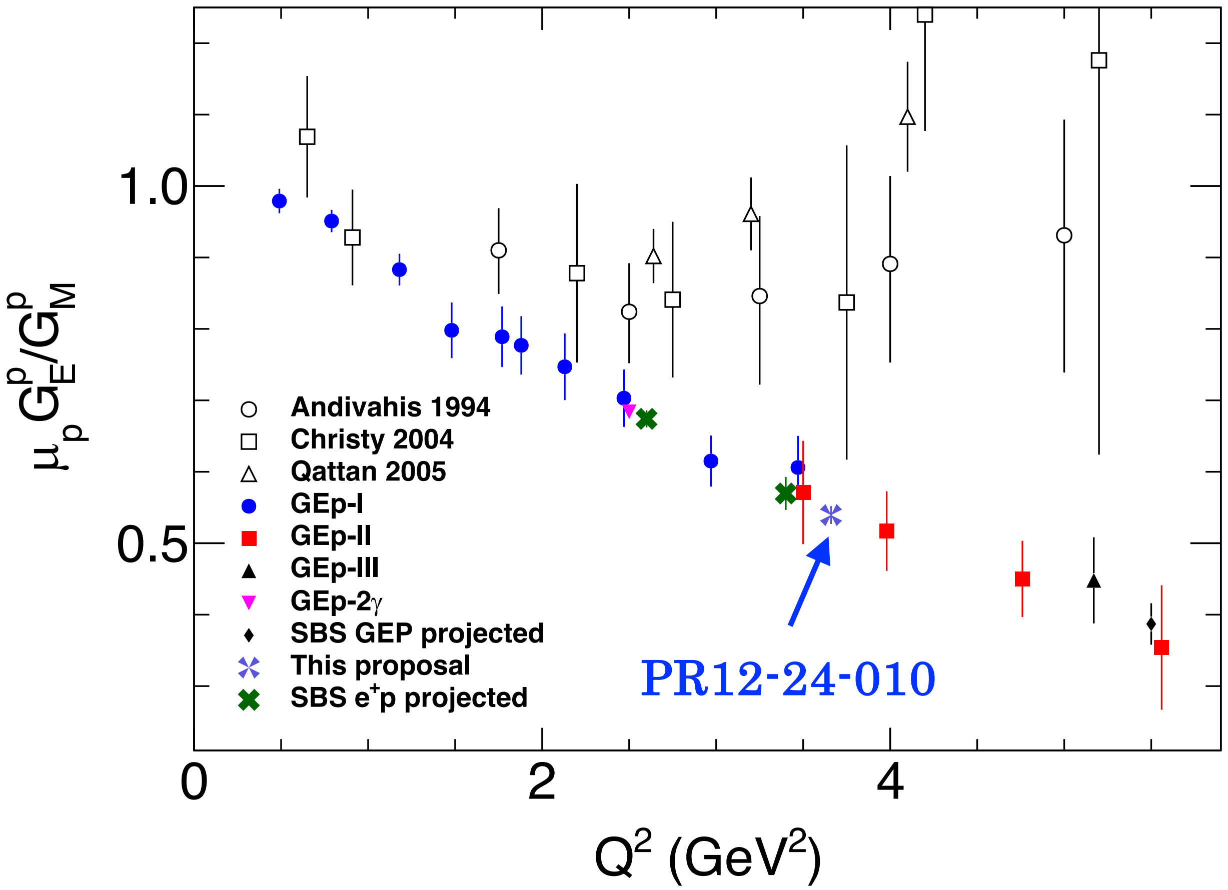
A. J. R. Puckett *et al.*, Eur.Phys.J.A 57 (2021) 6, 188

- Kinematics and projections for an exploratory program of PT measurements in $e^+p \to e^+p$ were laid out in LOI12-23-008 (and 2021 EPJA paper)

- PEPPO experiment demonstrated concept of polarized positron source driven by high-intensity polarized electron beams.
- *PT has never been measured in positron scattering at any Q^2 (to my knowledge)*
- PT/LT discrepancy is still by far the most significant (albeit indirect) evidence for the importance of hard TPE effects in elastic *ep*.
- Cross section ratios and L/T separations with positrons will be pursued in the Q^2 regime where the discrepancy is most significant
- Comparison of PT between e^+/e^- and comparison of LT/PT results for e^+p scattering (independent of electron scattering data) will be extremely interesting, and essential in the eventual conclusive resolution of the discrepancy
- **SBS GEP apparatus enables competitive precision in a reasonable amount of beam time!**

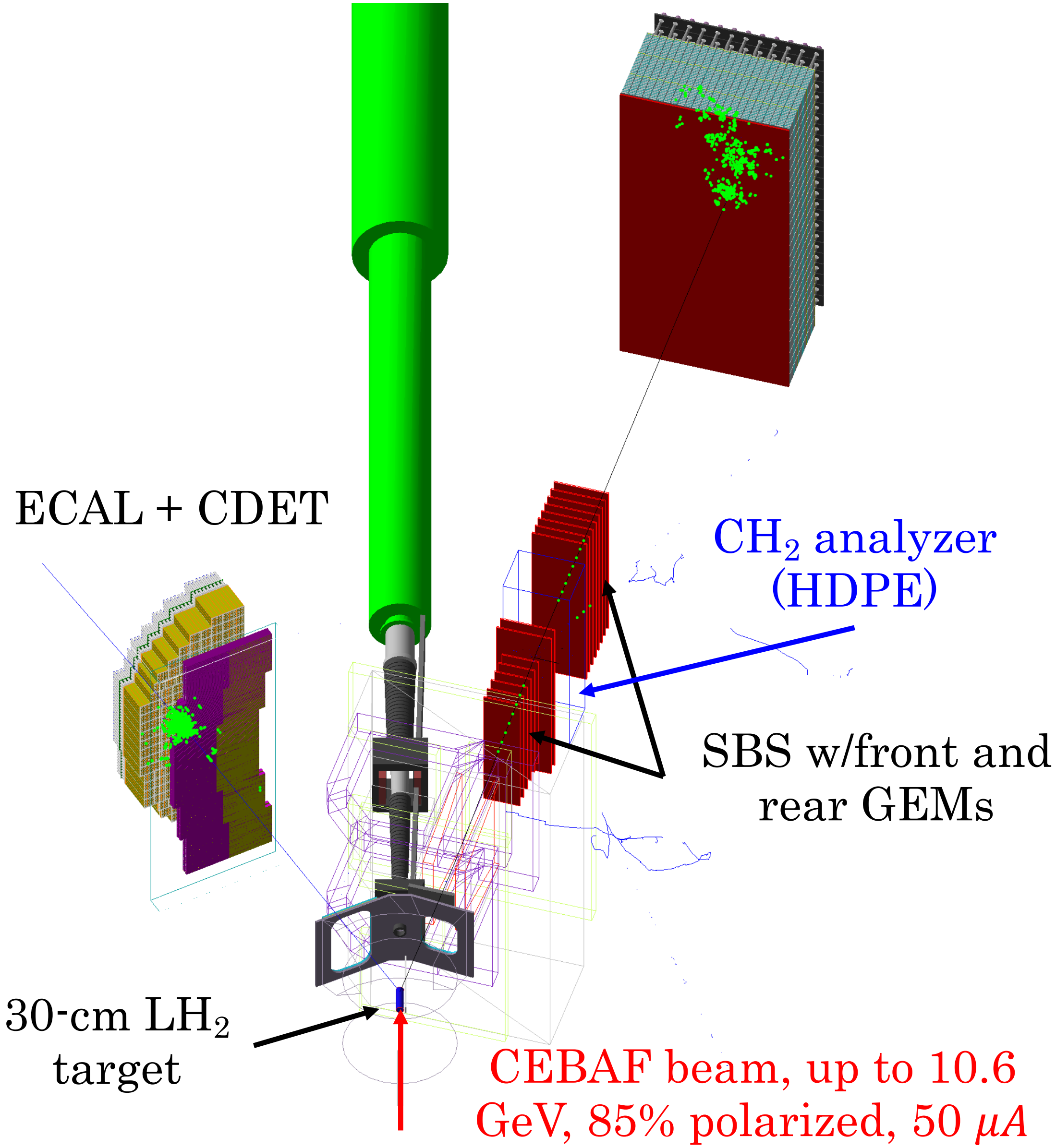
A program of polarized positron-proton scattering using SBS (LOI12-23-008)

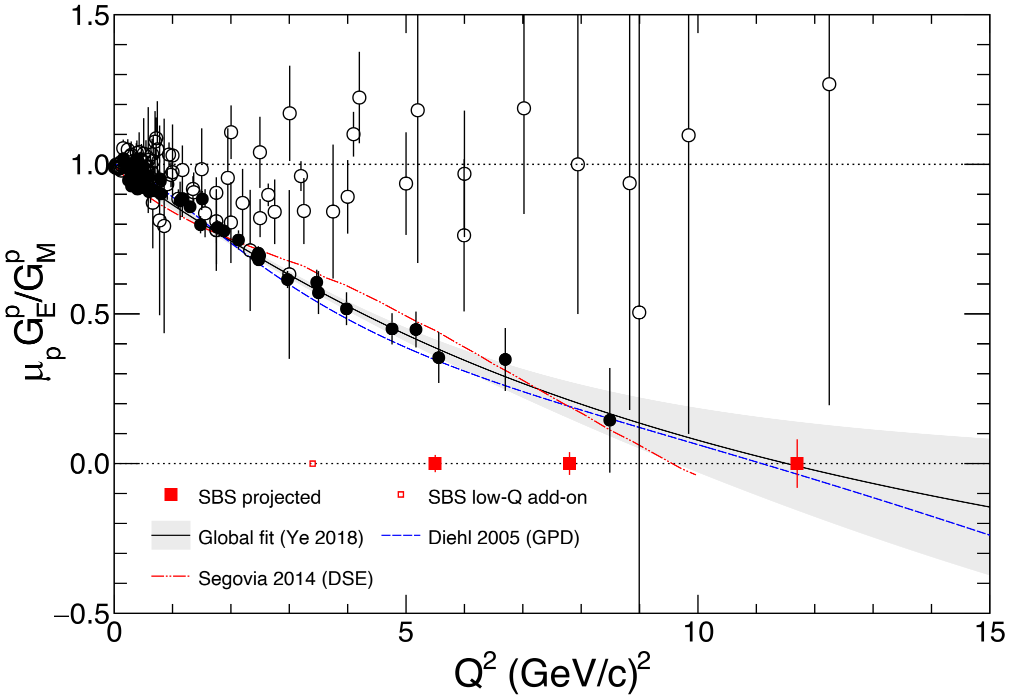




- Left: ϵ dependence at $Q^2 = 2.5\ GeV^2$ (compare to GEp-2γ)
- Right: Q^2 dependence in the region where the discrepancy is largest and most statistically significant. **Improved precision of e^-p data is needed for the higher Q^2 (this proposal)**

The SBS G_E^p Experiment (E12-07-109): Scheduled 2024-2025





- **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

PR12-24-010 in the context of E12-07-109

TABLE III. Kinematics, projected accuracy and beam time allocations for "GEP+". The projected statistical uncertainties in the form factor ratio include the assumption of 70% overall event reconstruction efficiency due to the combined efficiencies of the individual detectors, including DAQ dead-time.

Status	E_{beam}, GeV	Q^2 range, GeV^2	$\langle Q^2 \rangle$ GeV^2	θ_{ECAL} degrees	$\langle E'_e \rangle$, GeV	θ_{SBS} degrees	$\langle P_p \rangle$ GeV	$\langle \sin\chi \rangle$	Event rate Hz	Days (PAC)	$\Delta(\mu G_E/G_M)$ (statistical)
Proposed	4.3	3.1-4.4	3.7	35.0	2.35	28.5	2.73	0.55	882	2	0.011
Approved/scheduled	6.4	4.5-7.0	5.5	29.8	3.66	25.7	3.77	0.72	291	2	0.029
Approved/scheduled	8.5	6.5-10.0	7.8	27.5	4.64	22.1	5.01	0.84	72	11	0.038
Approved/scheduled	10.6	10.0-14.5	11.7	30.0	4.79	16.9	7.08	0.99	13	32	0.081

- We postponed a full proposal for the positron measurements to a future PAC, in order to optimize the experiment design and obtain the latest theoretical predictions/perform impact studies
- Achievable, well-motivated kinematics and precision goals for an initial positron PT program are already well-defined, science motivation endorsed by PAC51
- **We propose this measurement now because the upcoming SBS GEP run presents a one-time opportunity to obtain the needed electron beam measurement at the higher Q^2 (~3.7 GeV^2) at a low cost in beam time—measurement will be *done* before PAC53, if PAC52 approves the requested two PAC days (at 50 uA, 2nd-pass, 85% polarized beam)**
- Ancillary benefit: addition of a fourth, high-precision Q^2 point will provide improved control of systematics for SBS GEP, and aid rapid commissioning of the apparatus

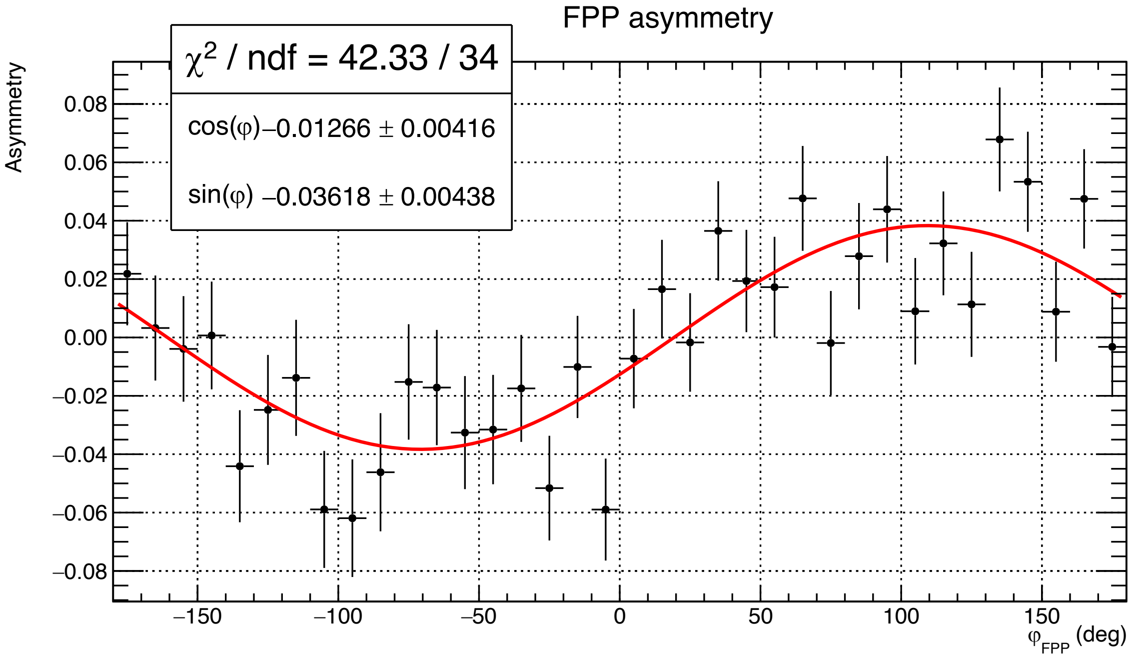
PR12-24-010: Statistical FOM summary

TABLE I. Summary of the Monte Carlo simulation results for the proposed measurement. Quantities enclosed by $\langle \ldots \rangle$ represent rate-weighted, acceptance-averaged values.

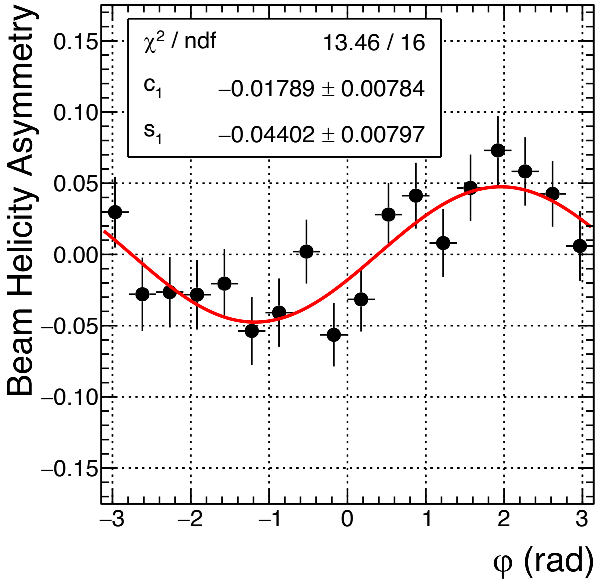
Beam energy E_e (GeV)	4.3
Electron scattering angle $\langle \theta_e \rangle$ (deg)	35.12
Proton scattering angle $\langle \theta_p \rangle$ (deg)	29.6
Scattered electron energy $\langle E'_e \rangle$ (GeV)	2.35
Scattered proton momentum $\langle p_p \rangle$ (GeV)	2.73
Squared four-momentum transfer $\langle Q^2 \rangle$ (GeV^2)	3.66
Virtual photon polarization $\langle \epsilon \rangle$	0.71
Spin precession: $\langle \sin(\chi) \rangle$	0.546
Analyzing power $\langle A_y \rangle$ (GEp-III parametrization)	0.114
Event rate at 50 μA (trigger cuts only, Hz)	882
Polarimeter "efficiency"[a]	0.26
Transverse polarization transfer $\langle P_t \rangle$	-0.115
Longitudinal polarization transfer $\langle P_\ell \rangle$	0.686
Kinematic factor (see Eq. (10)) $\left\langle \mu_p \sqrt{\frac{\tau(1+\epsilon)}{2\epsilon}} \right\rangle$	3.13
PAC Days at 50 μA	2
Absolute $\Delta_{stat} \left(\frac{\mu_p G_E^p}{G_M^p} \right)$	0.011

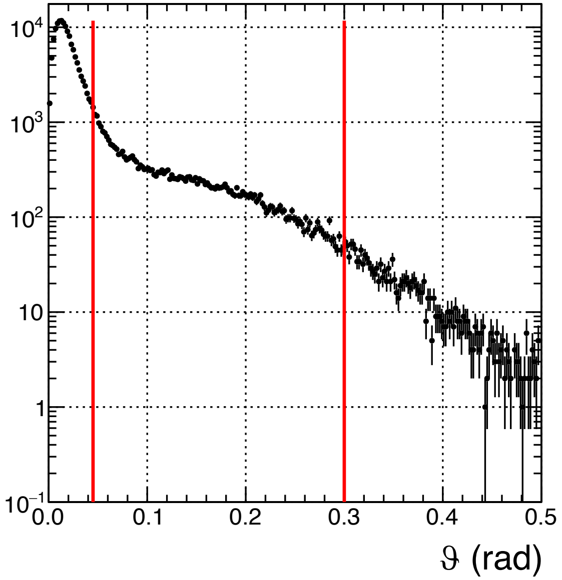
[a] Defined here as the fraction of all coincidence events that passed FPP event selection cuts.

Polarimeter Asymmetry—simulated and actual (from GEN-RP)



Simulated asymmetry in PR12-24-010 (equivalent to 8 minutes' beam time)





Measured LH2 elastic asymmetry (left) and polar angle distribution (right) from early GEN-RP data

$$\text{Asymmetry} \quad = \quad P_e \bar{A}_y \left[P_y^{FPP} \cos(\phi) - P_x^{FPP} \sin(\phi) \right]$$

- "Online" LH2 elastic asymmetry results from GEN-RP (with thin steel analyzer, not thick CH_2) consistent with expectations in both sign and magnitude at $Q^2 \approx 4.4$ GeV^2

PR12-24-010: (Estimated) Systematic Error Budget

TABLE II. Anticipated systematic uncertainty contributions to R_p and their estimated magnitudes. See text for details.

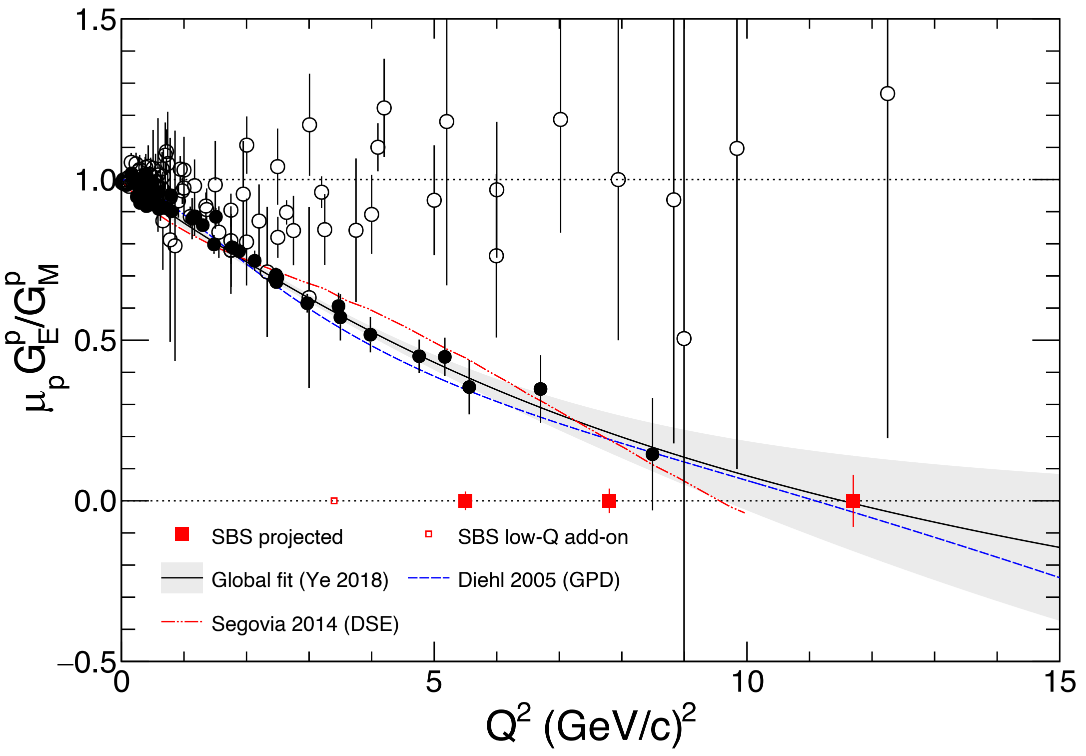
Contribution	Estimated Δ_{syst} (R_p)
Proton kinematic reconstruction	2×10^{-3}
Precession uncertainty due to magnetic field uncertainty	5×10^{-3}
Azimuthal angle reconstruction	10^{-3}
Inelastic background	$< 10^{-3}$
Beam Energy	5×10^{-4}
Radiative Corrections (”standard”)	$< 10^{-3}$
Total	6×10^{-3}

- These estimates are conservative, and based on experience gained from the GEp-2γ analysis (see, e.g., https://doi.org/10.1016/j.nima.2018.09.022) and the early SBS experiments

Addressing PAC reader and TAC comments

- Detailed replies on all comments/questions can be found in this document:
  - https://userweb.jlab.org/~puckett/PAC_READER_AND_TAC_RESPONSES_FINAL.pdf
- **On the “risk” of an “inconclusive” measurement:**
  - The risk of not reaching the precision goal for the *electron* measurement at issue before this PAC is very low if the needed PAC days are approved (and delivered).
  - The risk of not achieving the precision goal for the future *positron* beam measurements is obviously higher since a polarized positron beam with the requisite parameters does not yet exist.
  - Risks will be mitigated in the full experiment design by increasing LH2 target thickness and SBS acceptance (relative to GEP design with ”pole shims”), and optimizing the kinematics and beam time request around the parameters recommended by the PWG
  - Given the precision goals and Q^2 reach, even a null result for the difference between $e^{-}p, e^{+}p$ in this observable would still be highly valuable, even with a less aggressive statistical uncertainty goal (for the positron measurement).
- **On the choice of kinematics for *this* measurement:**
  - The reuse of the GEP setup “as-is” restricts the choice of spectrometer angles due to the acceptance of the GEP scattering chamber “vacuum snout”.
  - PR12-24-010 kinematics are nonetheless “close enough” in Q^2 to LOI kinematics and there is very large overlap in Q^2 coverage within the acceptance with the LOI (also: LOI kinematics are not written in stone).
- **On systematics and the influence of the GEM alignment procedure:** the needed accuracy of alignment and SBS optics is already largely established (see document above and backup slides in this presentation)

Summary and conclusions



- The availability of SBS makes a targeted, exploratory program of polarization transfer measurements in e^+p scattering technically feasible in a "reasonable" amount of beam time.
- This program would be complementary to other investigations of hard TPE in elastic scattering and essential in the eventual resolution of the longstanding discrepancy in the proton FF ratio
- Assuming such a program succeeds, improved electron scattering data are needed for comparison to a higher-Q^2 positron measurement
- This proposal presents a one-time opportunity to acquire the needed electron scattering data at a low cost in beam time as a small "add on" to the upcoming GEP run.

TABLE III. Kinematics, projected accuracy and beam time allocations for "GEP+". The projected statistical uncertainties in the form factor ratio include the assumption of 70% overall event reconstruction efficiency due to the combined efficiencies of the individual detectors, including DAQ dead-time.

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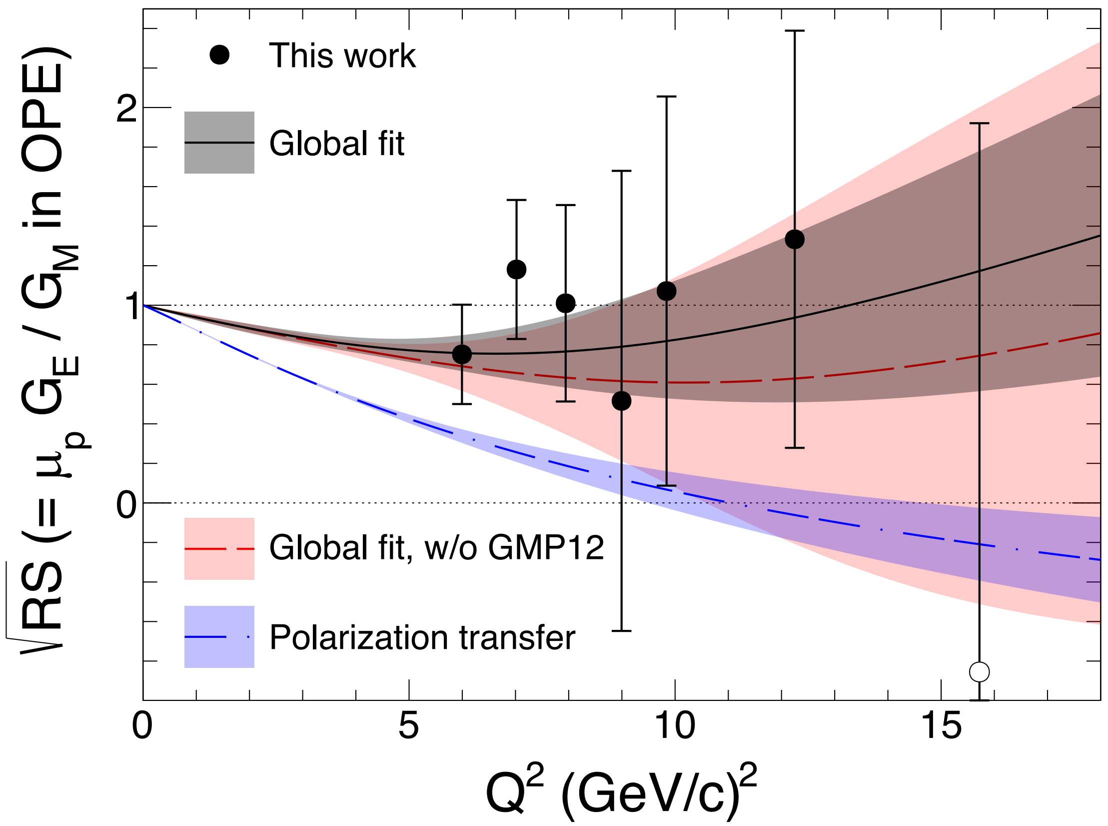
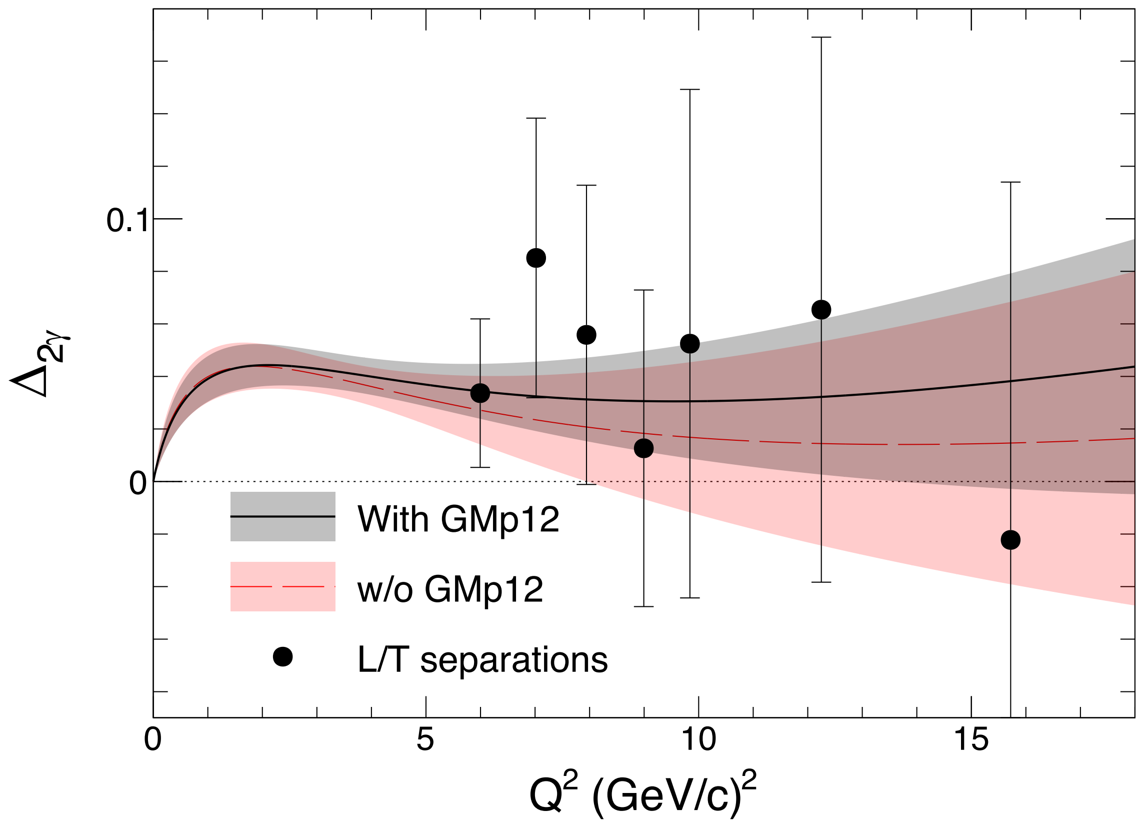
Approved/scheduled	10.6	10.0-14.5	11.7	30.0	4.79	16.9	7.08	0.99	13	32	0.081

Thank you for your attention and consideration!
Questions?

Backups

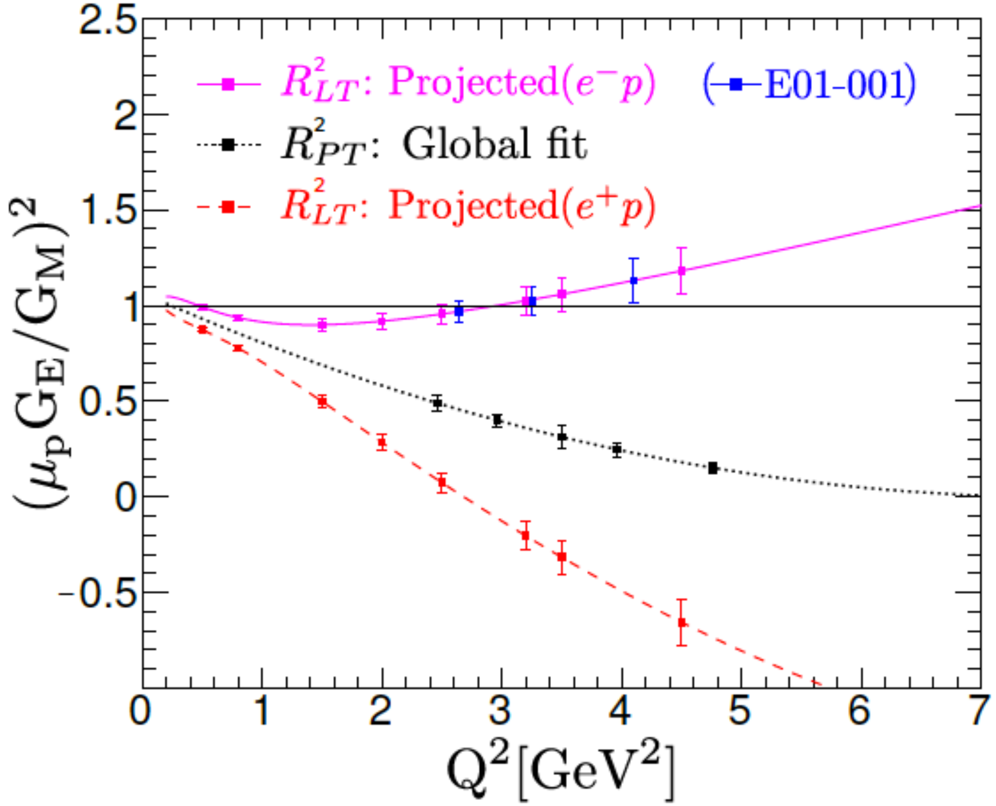
Size of the discrepancy at large Q^2

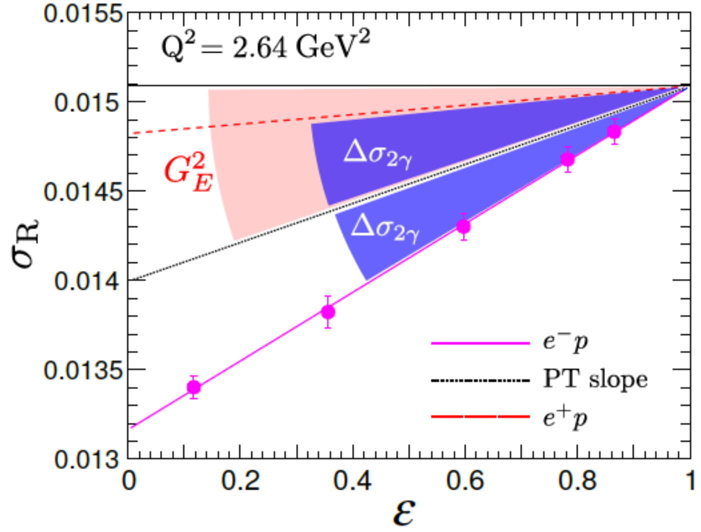


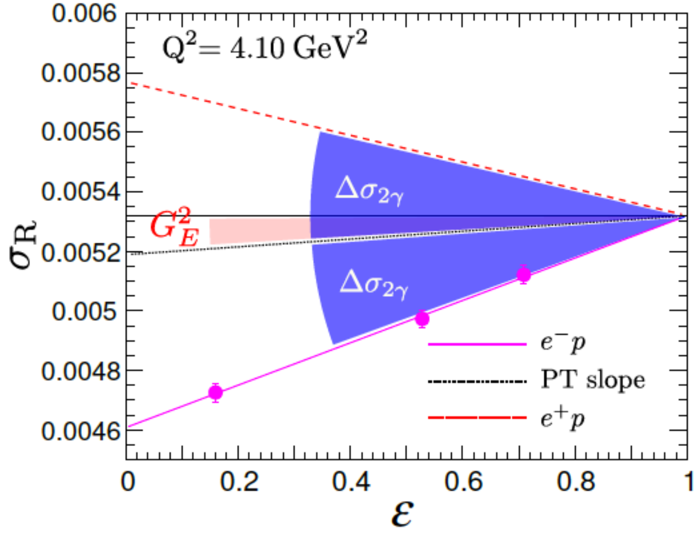


- From "Form Factors and Two-Photon Exchange in High-Energy Elastic Electron Proton Scattering": Christy *et al.*, Phys.Rev.Lett. 128 (2022) 10, 102002
- New model-independent L/T separations in the 6-16 GeV^2 region combine the Hall A GMP12 data with older JLab and SLAC data, indicating that a TPE effect of $(4.2 \pm 2.1)\%$ (linear in ϵ) would account for the discrepancy in this region, AFTER updating RC to the state-of-the-art based on Maximon-Tjon (using original Mo-Tsai RC gives $\Delta_{2\gamma} = (6.6 \pm 2.1)\%$)

Positron-proton “Super-Rosenbluth” proposal (PAC51)

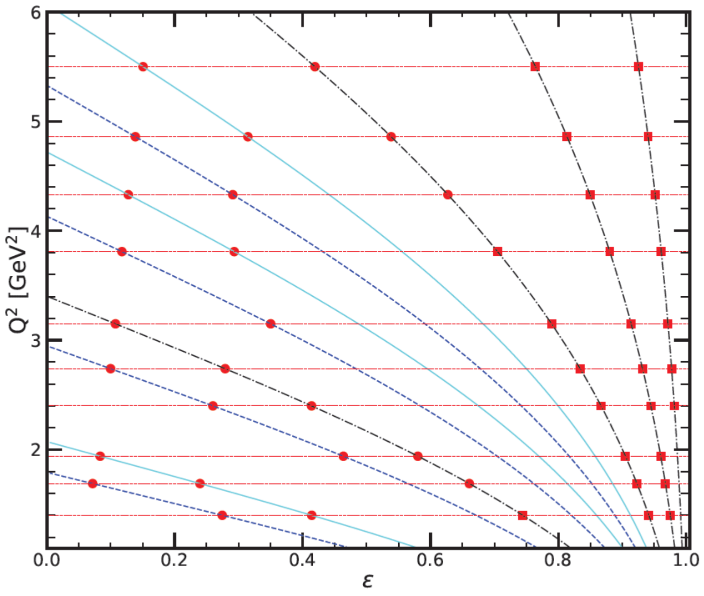




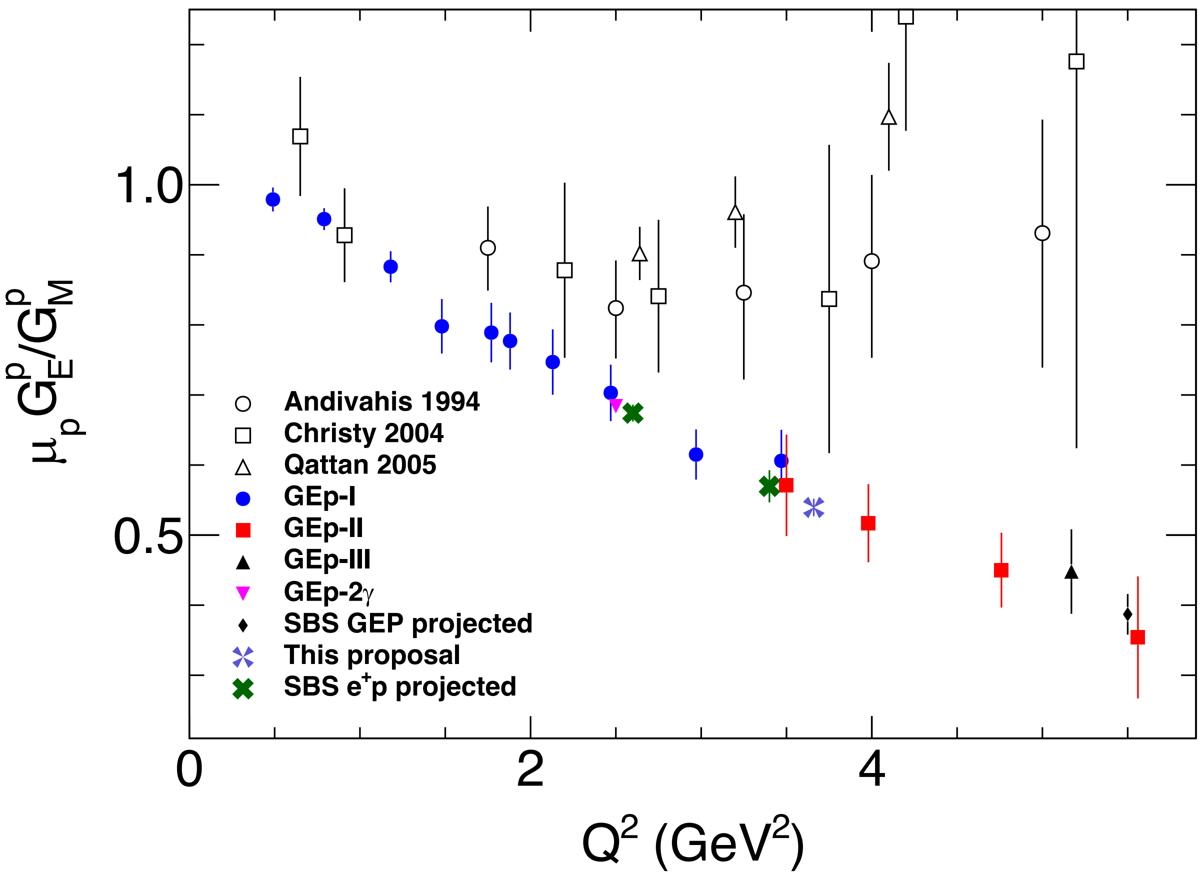


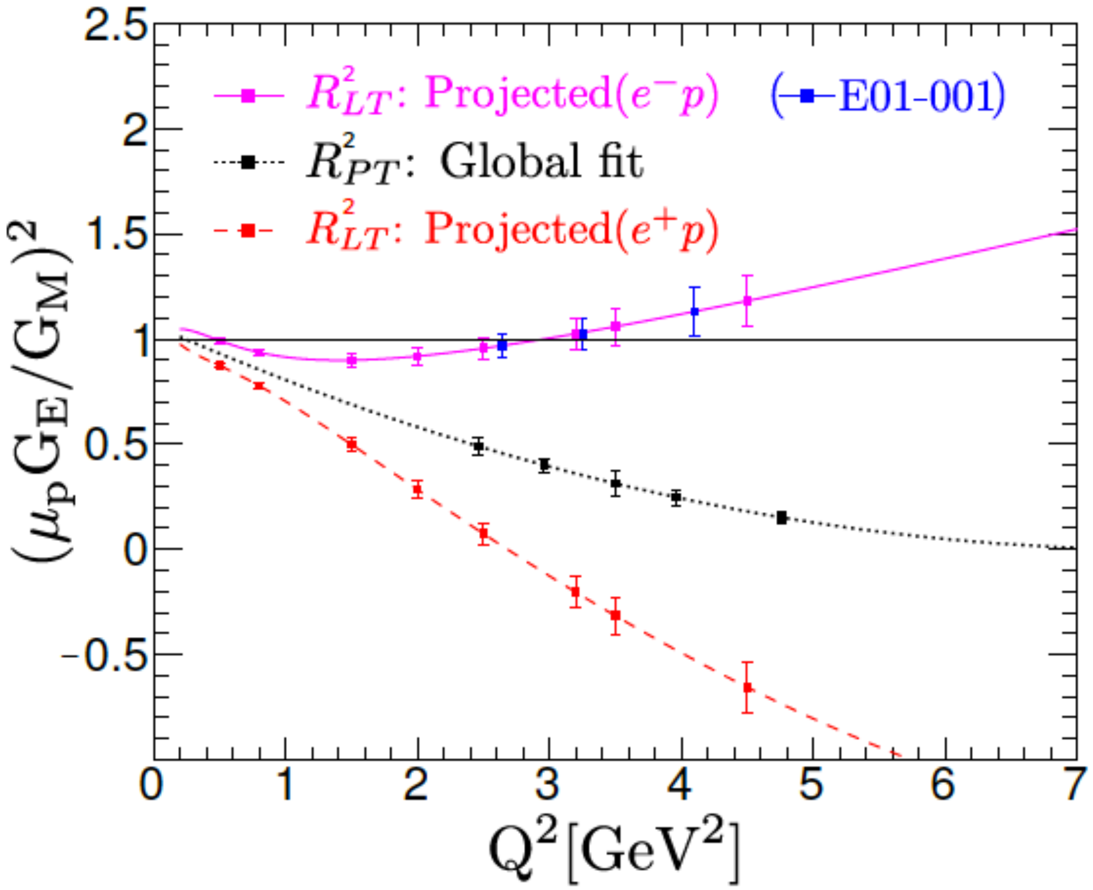
- Several proposals exist to measure $\frac{e^+p}{e^-p}$ cross section ratios, including a (conditionally approved) proposal for Hall B.
- “Super-Rosenbluth” method involving proton detection enables precision L/T separations in e^+p scattering

- Spokespersons: M. Nycz, J. Arrington, S. N. Santiesteban, M. Yurov
- If TPE fully explains the discrepancy, the Rosenbluth Slope (RS) for positrons should fall well below the PT data and turn negative.
- **Status: Approved**



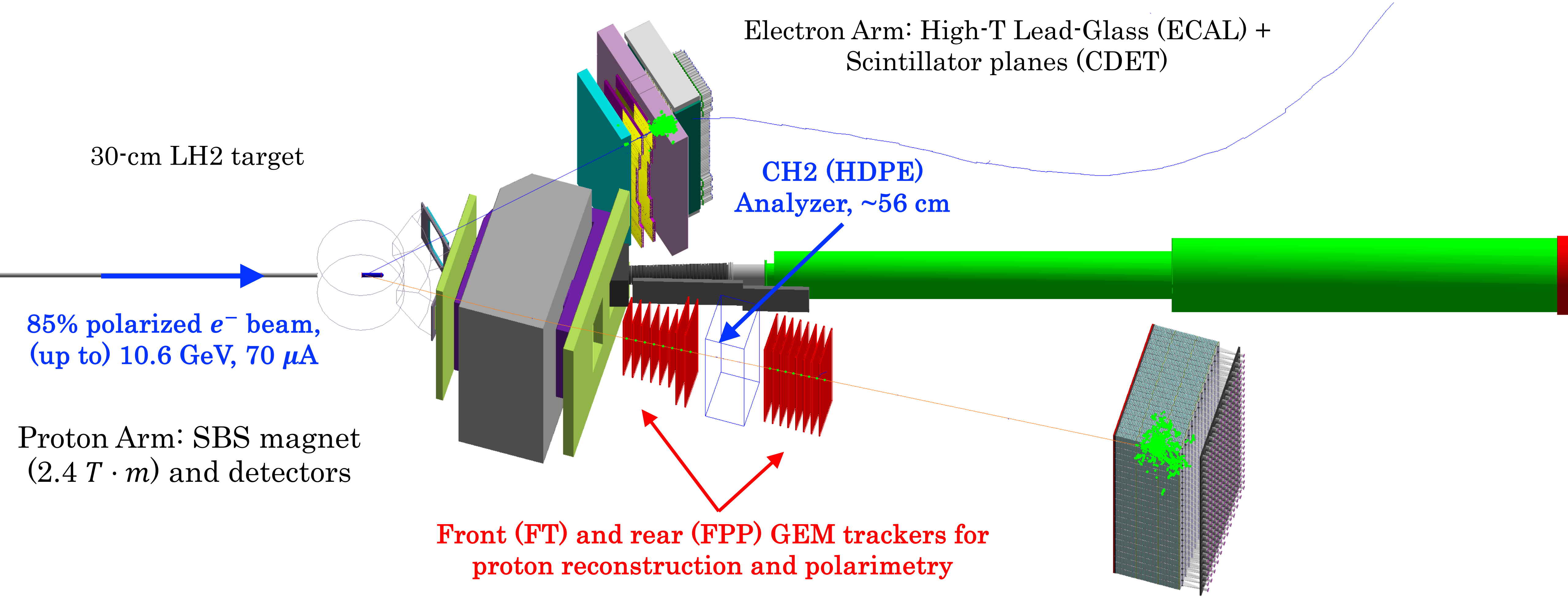
SBS Positron Polarization Transfer: Q^2 dependence and comparison to future L/T separations





- Comparison between L/T separations and PT observables in positron scattering is an essential part of the eventual resolution of the discrepancy.
- Improved precision of electron scattering data in this Q^2

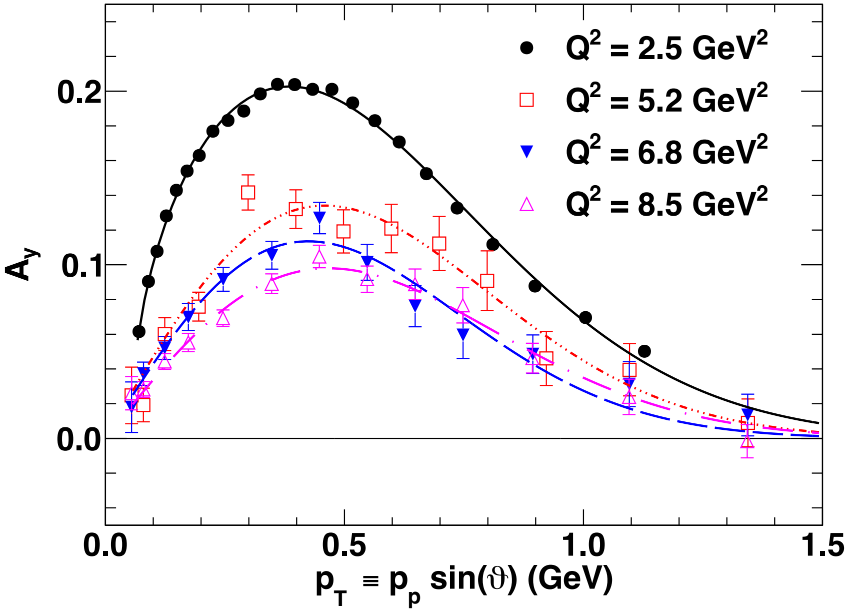
SBS GEP in *g4sbs* (GEANT4-based Monte Carlo framework for SBS program)

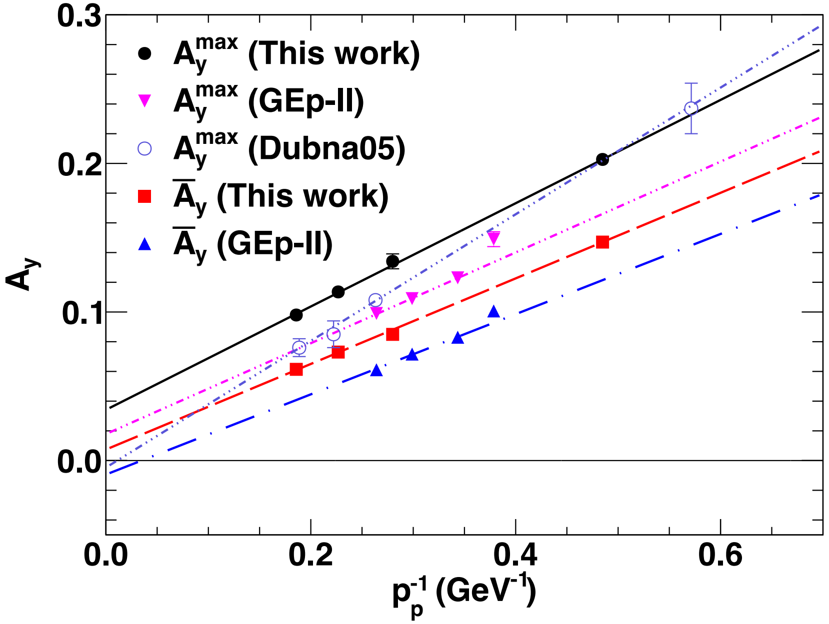


https://github.com/JeffersonLab/g4sbs

Analyzing power

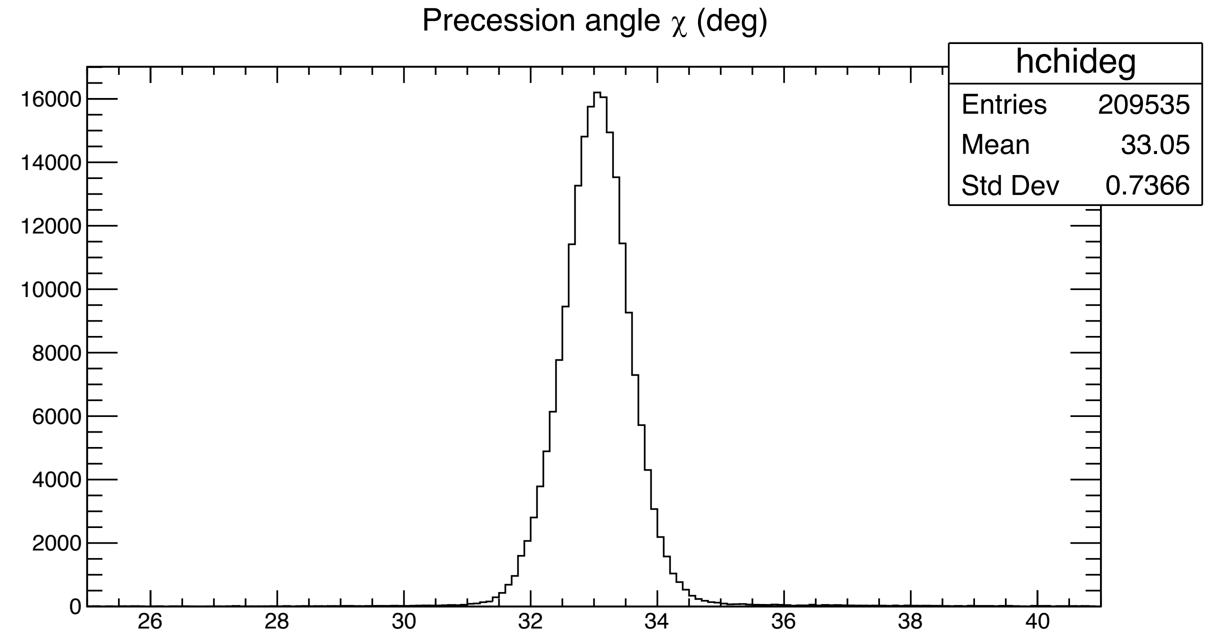
$$
\begin{aligned}
\mathcal{F} &\equiv \sum_{i=1}^{N_{event}} (P_e A_y)^2, \\
\Delta P_{x,y}^{FPP} &= \sqrt{\frac{2}{\mathcal{F}}}, \\
P_y^{FPP} &\approx P_t \\
P_x^{FPP} &\approx -P_\ell \sin(\chi) \\
R_p \equiv \mu_p \frac{G_E^p}{G_M^p} &= -\mu_p \frac{P_t}{P_\ell}\sqrt{\frac{\tau(1+\epsilon)}{2\epsilon}}, \\
\left(\frac{\Delta R}{R}\right)^2 &= \left(\frac{\Delta P_t}{P_t}\right)^2 + \left(\frac{\Delta P_\ell}{P_\ell}\right)^2,
\end{aligned}
$$

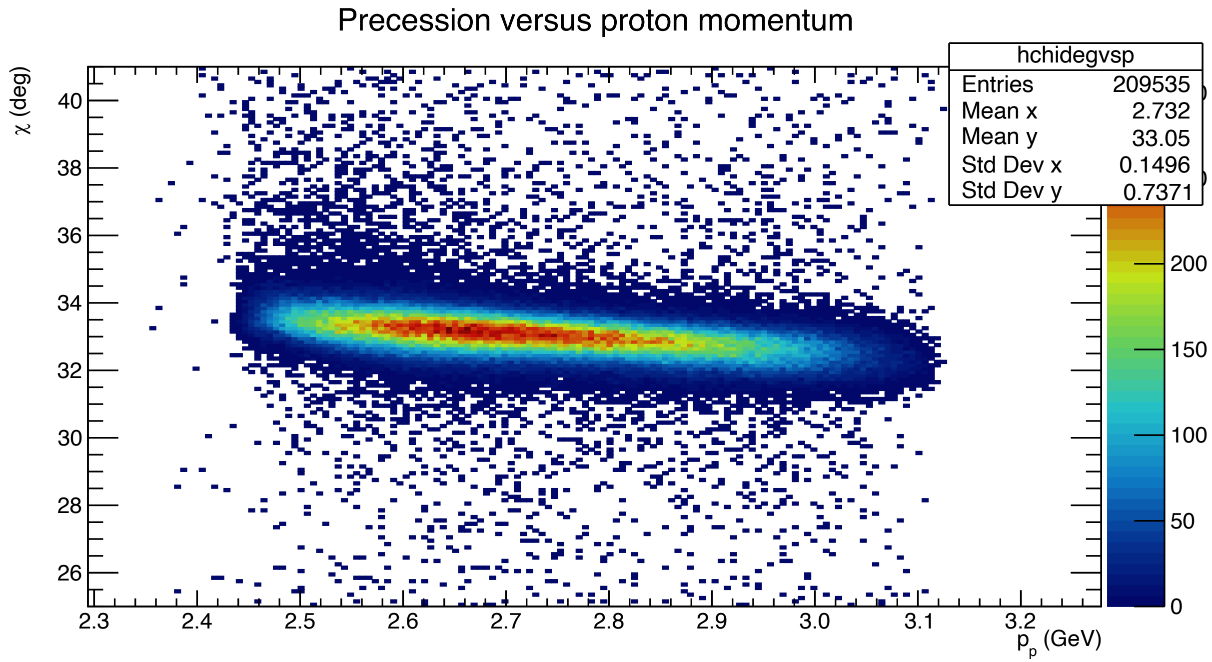




- Figures above from Puckett *et al.* PRC 96, 055203 (2017)
- Expectations for proton + CH_2 analyzing power are well-anchored from 6 GeV era experiments

Spin Precession





- Planned SBS field setting of 39% of maximum gives ~33-degree spin rotation.
- This field setting is chosen to maximize acceptance/event rate.
- A larger asymmetry can be obtained using stronger field, but at some cost in acceptance/event rate. But this only improves the precision of P_ℓ, not P_t!
- Even at 33-degree precession angle, P_ℓ will be measured with ~3X better relative precision than P_t

PAC51 Report on LOI12-23-008:

LOI12+23-008

Title: Polarization Transfer in Positron-Proton Elastic Scattering

Spokespersons: A. Puckett (contact), J. Bernauer, A. Schmidt

Motivation: This LOI proposes to measure the polarization transfer from the initial lepton to the final proton in elastic positron-proton scattering e +p → e + p for a series of momentum transfers Q^2 and virtual photon polarizations ϵ where a large discrepancy exists between the proton form factor ratio G^p_E/G^p_M extracted from cross section and polarization transfer measurements. Comparing the proposed positron measurements to existing data with electron beams will allow a determination of the two-photon exchange (TPE) contribution to the polarization transfer observable. An ancillary measurement with electrons at $Q^2 = 3.4$ GeV^2 is envisaged as well.

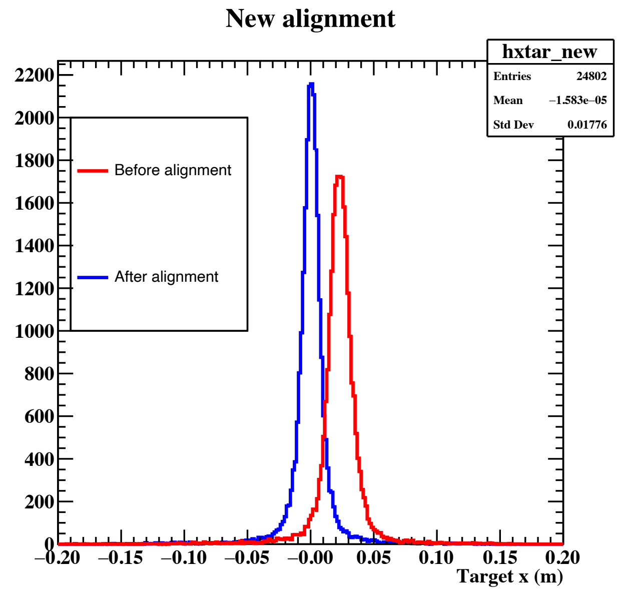
Measurement and Feasibility: The polarization transfer in electron-proton scattering has been extensively measured at JLab, and the present LOI extends such measurements to a positron beam. Experimental details are not given.

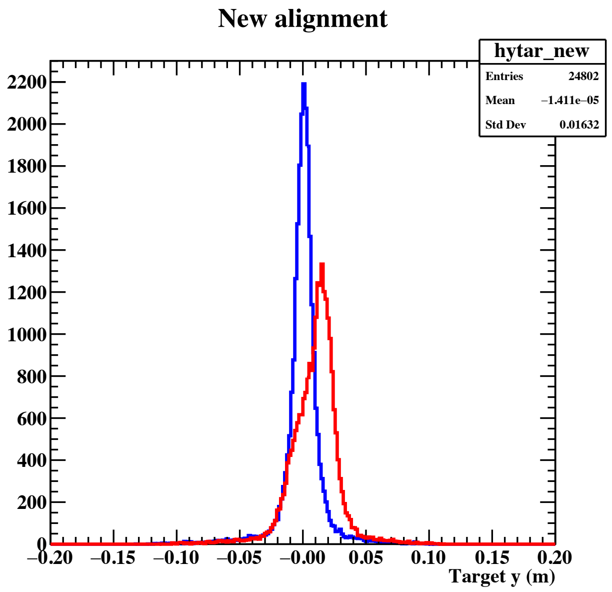
Issues: The bulk of material presented in the letter relies on a previous study that assumed a higher beam current for polarized positrons than is currently foreseen. The PAC recommends to use the beam parameters specified by the positron working group as a baseline for a proposal.

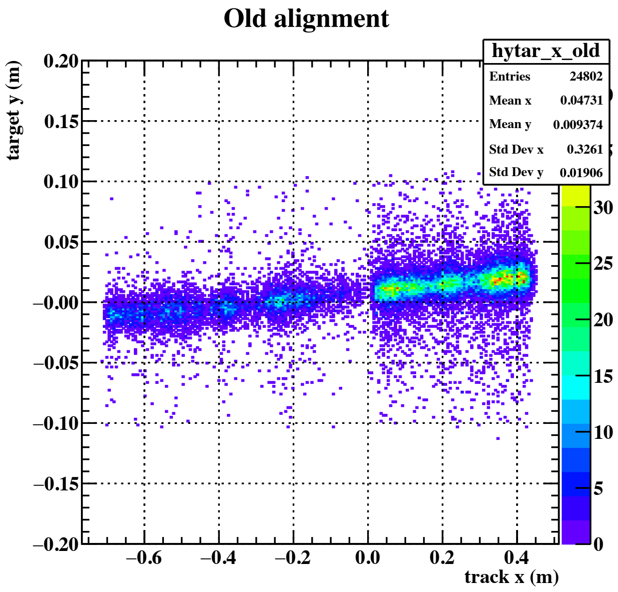
Summary: The proposed measurement would be a valuable addition to the quantitative study of TPE effects in elastic scattering. A full proposal should include a detailed study of anticipated systematic and statistical uncertainties, along with theory predictions for the expected difference between the polarization transfer observable for positron and electron beams. The latter will be needed in order to assess the physics impact of the measurement.

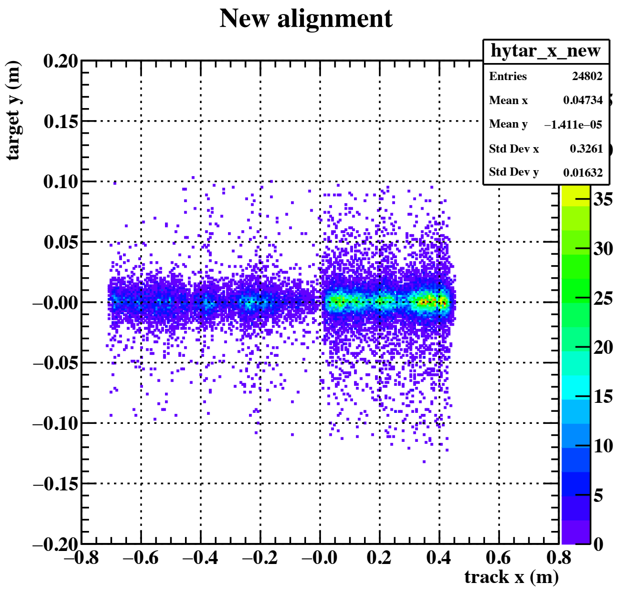
- The $\vec{e}^+p \to e^+\vec{p}$ LOI (as submitted to PAC51) can be found here: https://www.jlab.org/exp_prog/proposals/23/LOI12+23-008.pdf
- There would be no significant technical risk on any of the target or detector aspects of this proposal. All of this apparatus will be used in upcoming SBS GEP run.
- The uncertainties would be strictly statistics-limited, with small systematics.
- There are a few exploratory calculations and optimizations to do before proceeding to a full proposal

SBS GEM Alignment



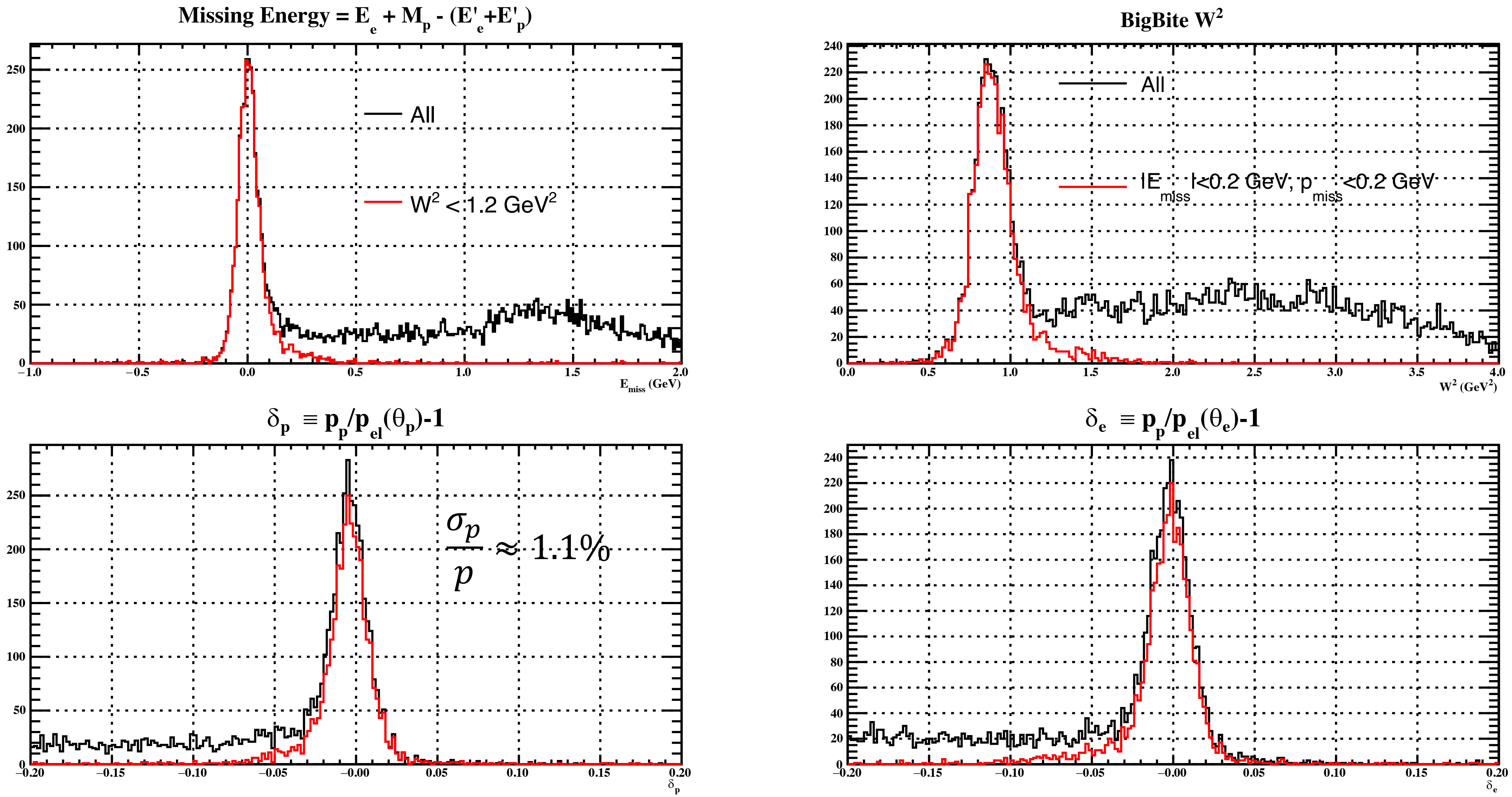






- Magnet-off runs on a thin Carbon foil provide a ”point” source of straight-line tracks through the GEMs—sufficient statistics can be acquired in ~1-3 hours.
- Constraints from beam position on target and HCAL, combined with magnet and detector survey data, allow robust, unambiguous location and orientation of the SBS GEM stack relative to the SBS magnet and the target center.

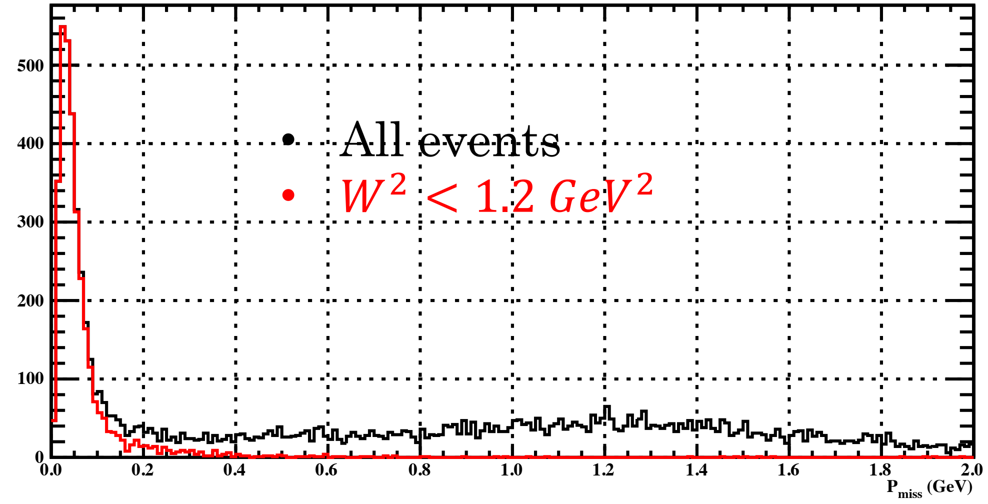
SBS optics after alignment (REAL H(e,e'p) DATA from GEN-RP!)



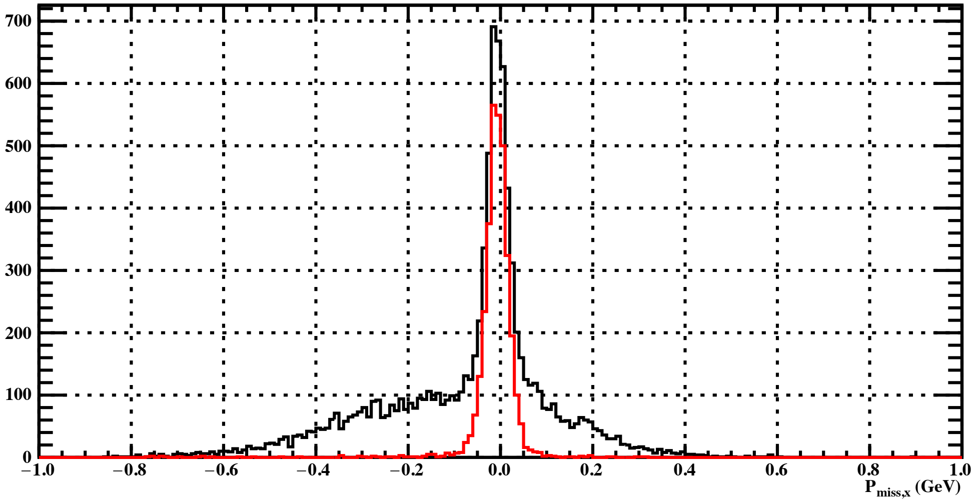
After zero-field GEM alignment, SBS optics model from TOSCA+GEANT4 gives expected resolution/accuracy of kinematic reconstruction with **no fine-tuning!**

SBS Optics: Missing Momentum Components

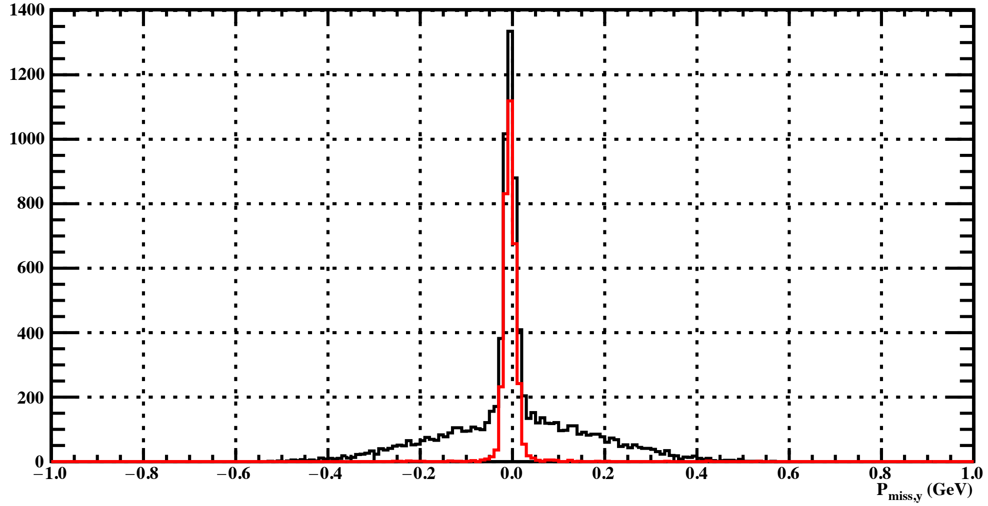
Missing Momentum Magnitude



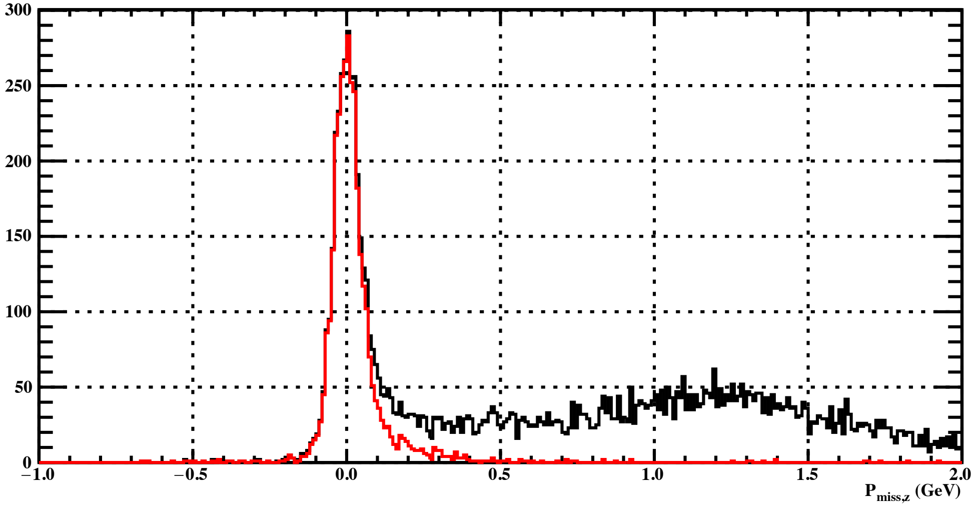
Missing momentum x (horizontal) component



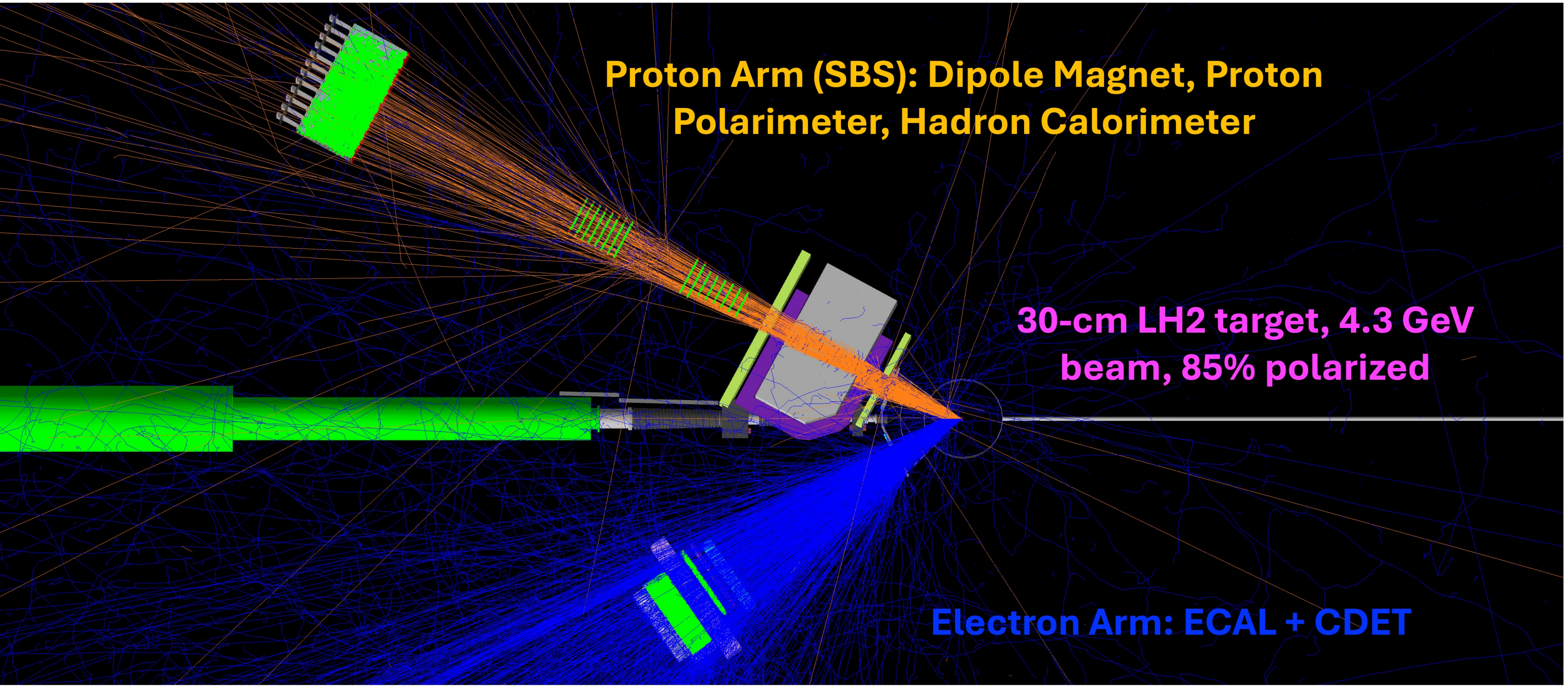
Missing momentum y (vertical) component

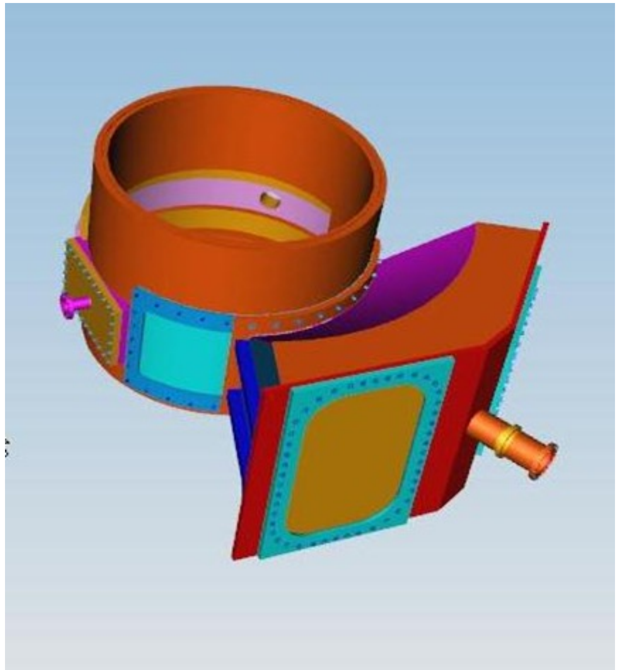


Missing momentum z component



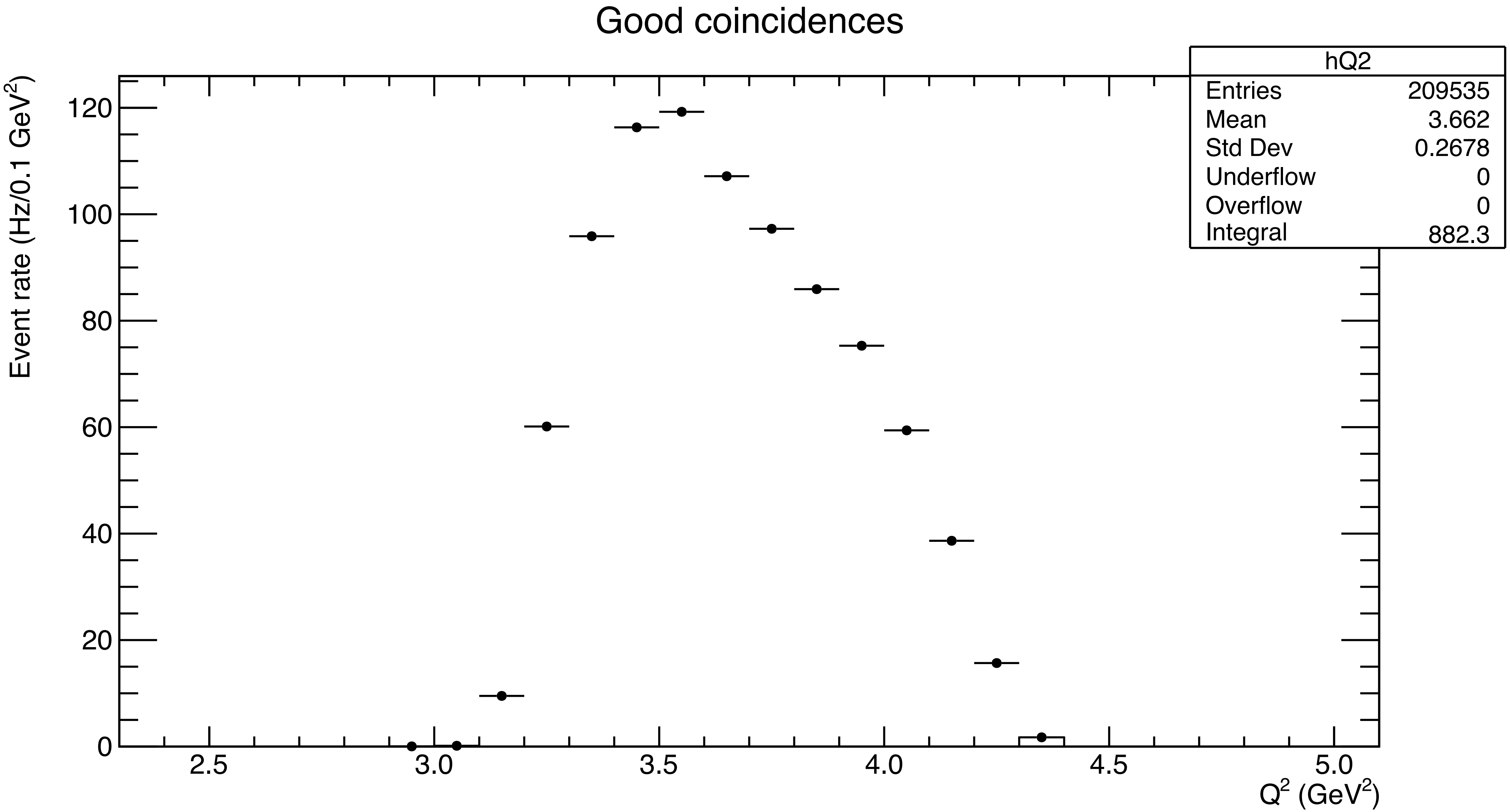
Solid-Angle matching, spectrometer angles, and GEP "Vacuum Snout"



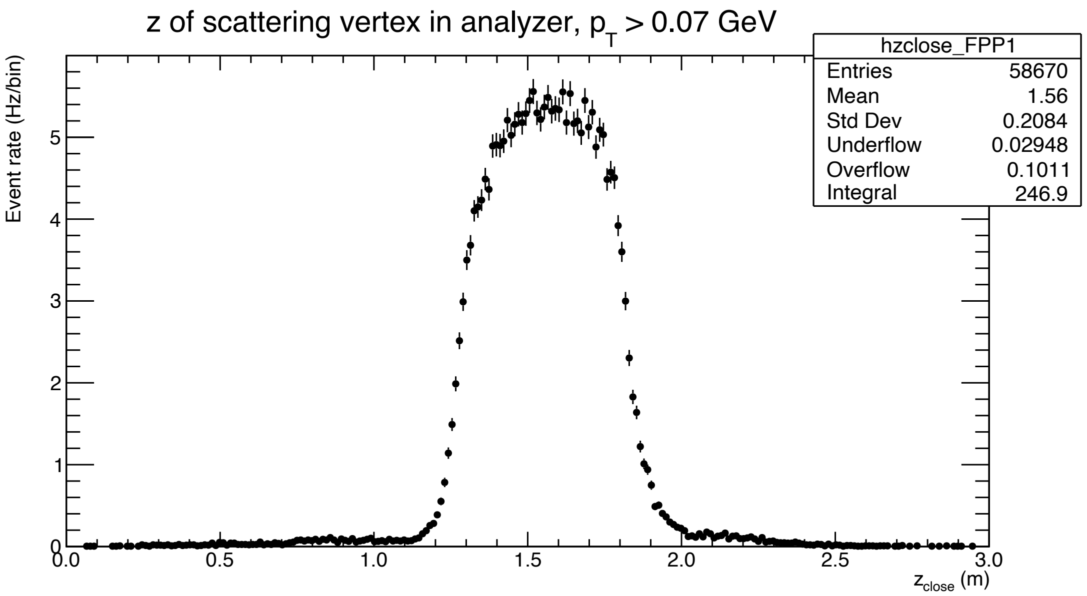


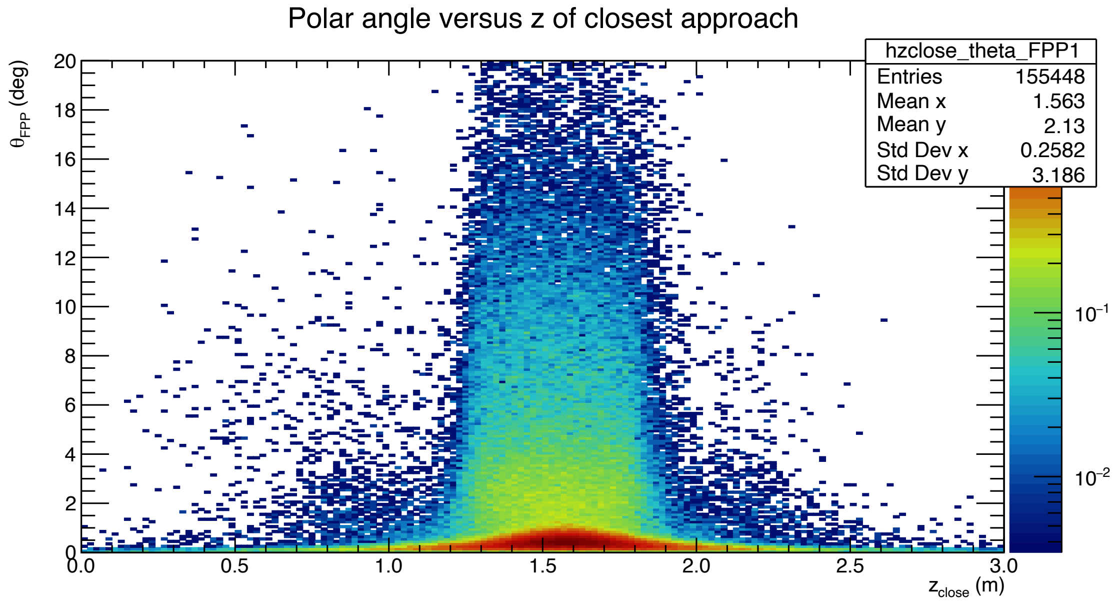
- Vacuum "snout" is designed to extend scattering chamber vacuum as close to SBS as practically possible—reduce production of backgrounds in GEMs, reduce multiple scattering, etc.
- As designed, the maximum central angle for SBS within the "snout" acceptance is 28.5 degrees.
- ECAL centered at 35 degrees, 5 m from target more than matches the useful SBS acceptance → we may push it a bit farther away to reduce trigger rate without compromising acceptance → snout does not meaningfully restrict ECAL acceptance at these angles

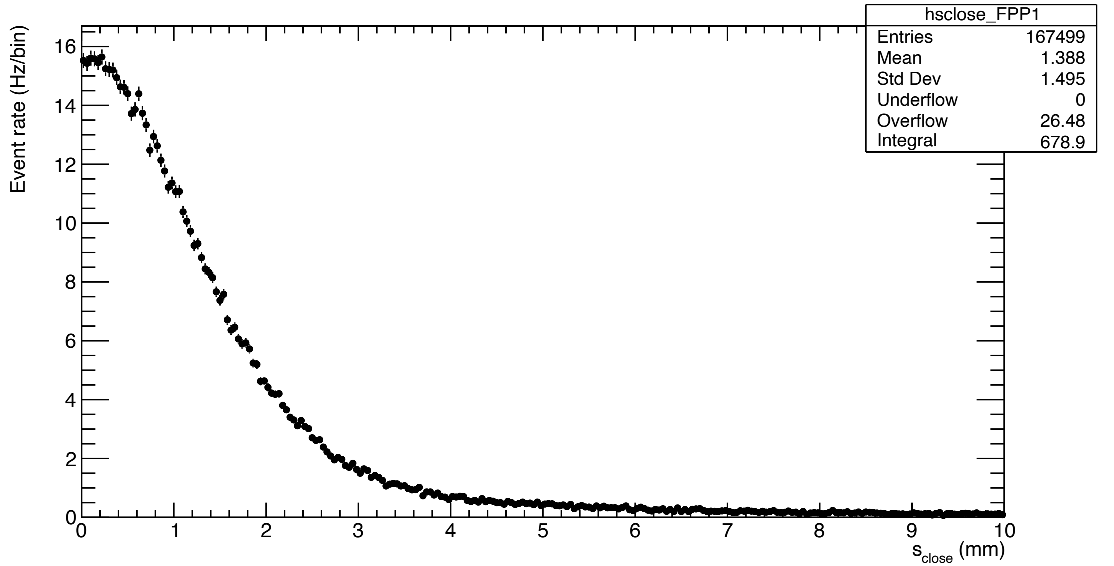
Q^2 distribution and event rate passing trigger cuts



Point and distance of closest approach

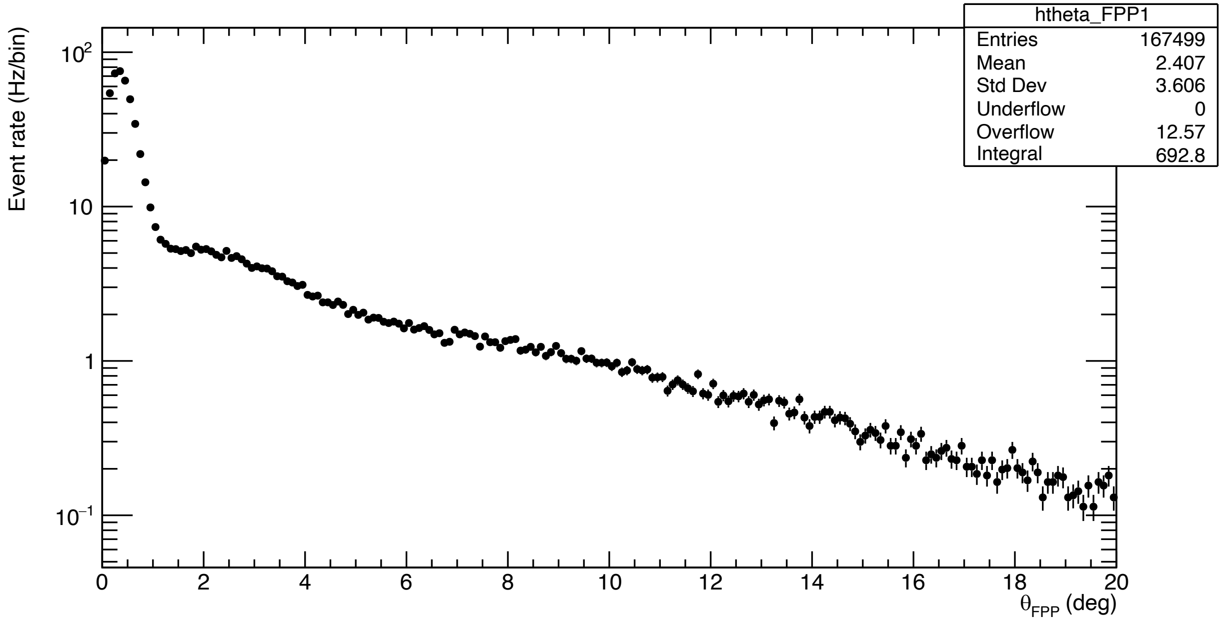


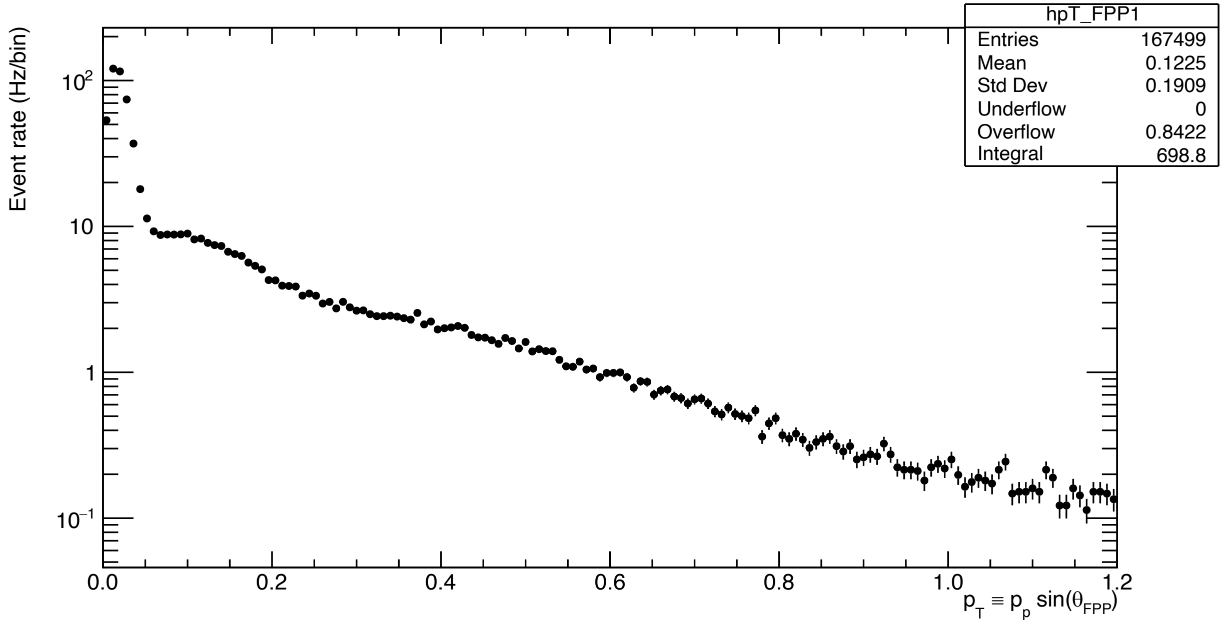




- Above, left: z of point of closest approach between incident and scattered tracks in the polarimeter
- Above, right: polar angle versus z of closest approach
- Below, right: distance of closest approach

Polar angle distributions and "transverse momentum"





- Left: polar scattering angle distribution
- Right: pseudo-transverse momentum defined as $p_T \equiv p_p \sin\vartheta$
- The "transverse momentum" is a useful concept because the angular distribution of the nuclear scattering cross section and the analyzing power exhibit roughly the same p_T dependence at any relevant Q^2