Updates on GEn-RP and KLL Experiments

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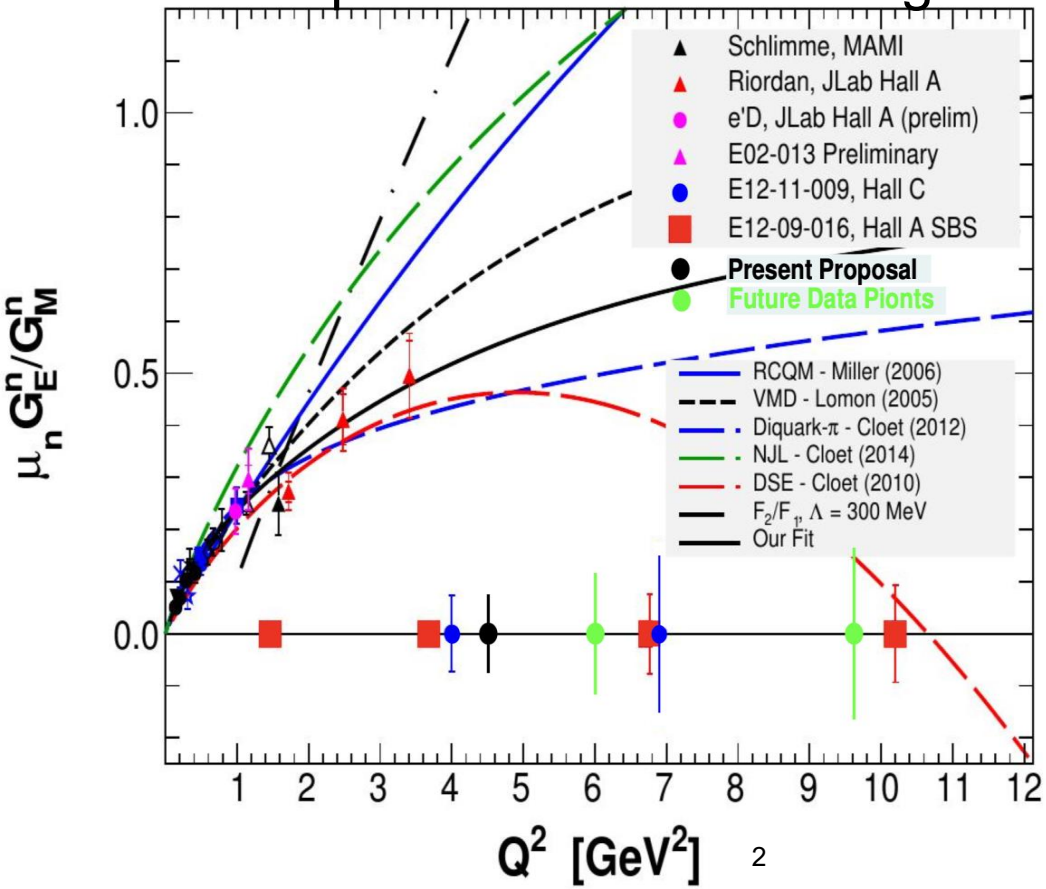
Jefferson Lab
(for the SBS Collaboration)

SBS Collaboration Meeting
September 2024

Physics Motivation

- Understanding the internal structure of nucleons at higher Q^2 regime
- Test of nuclear models (VMD, pQCD, DSE…)
- Powerful tool to understand non-perturbative QCD
- Extension of flavor decomposition behavior at higher Q^2



- No free neutron target due to its short life-time
- Nuclear target requires nuclear corrections
- Smallness of G_E^n

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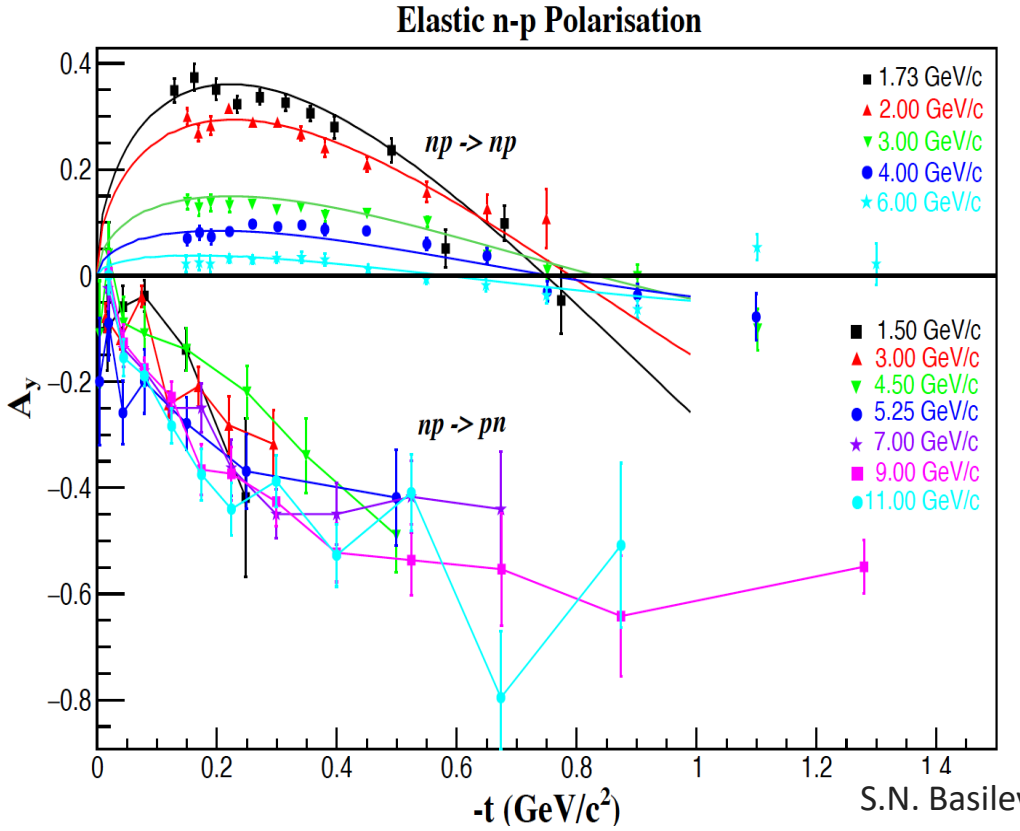
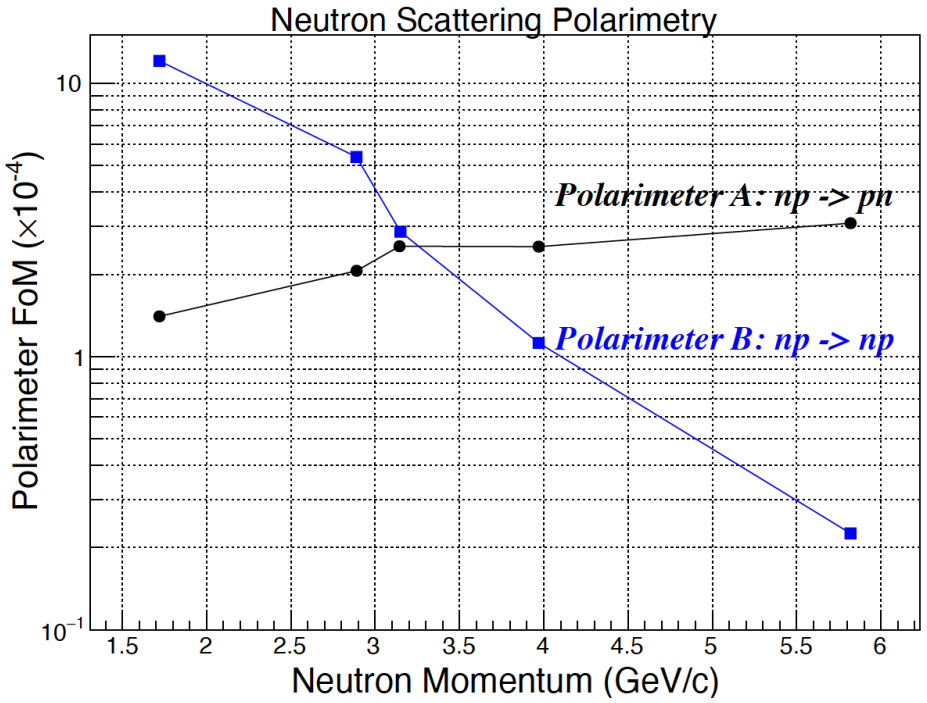
Motivation: Polarimetry

- Result from JINR shows the analyzing power (A_y) has no apparent dependence on momentum in charge exchange (np->pn) reaction, but drops very fast in np->np
- Charge exchange interaction has higher analyzing power at higher t
- Higher Figure of Merit (FOM) in np->pn polarimetry: $F^2(p_n) = \int \epsilon(p_n, \theta'_n)\, A_y^2(p_n, \theta'_n) d\theta'_n$





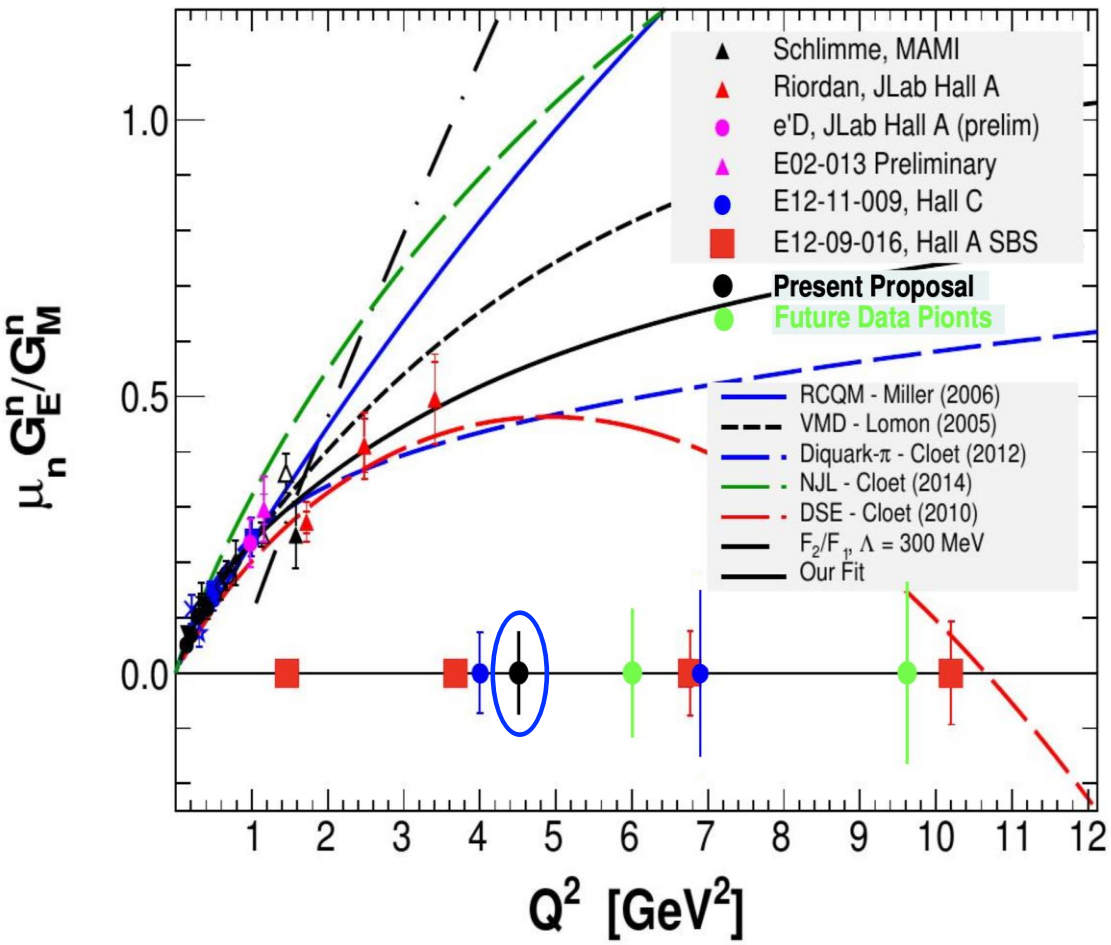
S.N. Basilev *et al., Eur. Phys. J. A* **56**, 26 (2020)

GEn-Recoil Polarimetry (Gen-RP) with SBS

- Polarized electron scattered on deuterium target to measure neutron form factor ratio (G_E^n/G_M^n)
- Polarization transfer method: $\vec{e}N \rightarrow e\vec{N}$
- Neutron polarimeter added to the SBS-arm
  - Charge exchange polarimeter (np->pn)
  - Large angle Recoil polarimeter (np->np)

- Independent of beam polarization and analyzing power of polarimetry, but need to maximize for higher efficiency (and higher statistics)
  - np->pn cross-section lower than np->np
- Possible to access without changing beam energy and detectors
- Successfully completed data taking in May 2024

$Q^2 \sim 4.4$ (GeV/c)^2



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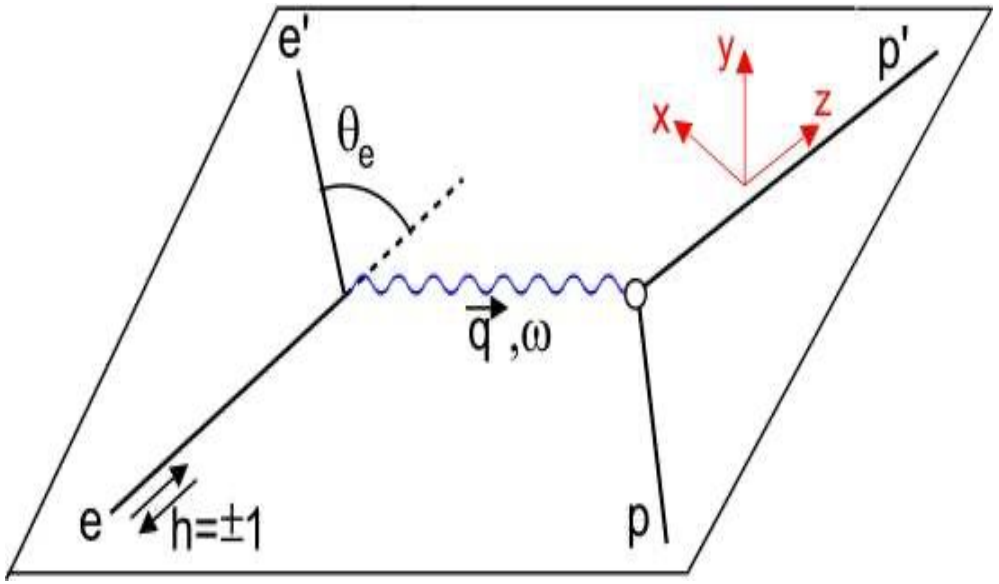
Formalism: Polarimetry Technique

- Accessing form factors:
  - Polarization transfer method: $\vec{e}N \rightarrow e\vec{N}$
  - Longitudinal (P_l) and transverse (P_t) component of nucleon (no normal component on reaction plane)



$$P_l = \sqrt{\tau(1+\tau)}\frac{E_e + E_{e'}}{M} G_M^2 \tan^2\frac{\theta_e}{2} / I_0$$

$$P_t = -2\sqrt{\tau(1+\tau)} G_E G_M \tan\frac{\theta_e}{2} / I_0$$

$$I_0 \propto G_E^2 + \frac{\tau}{\epsilon} G_M^2$$

$$\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{E_e + E_{e'}}{2M}\tan\frac{\theta_e}{2}$$

- Form Factor ratio is independent of analyzing power (A_y)

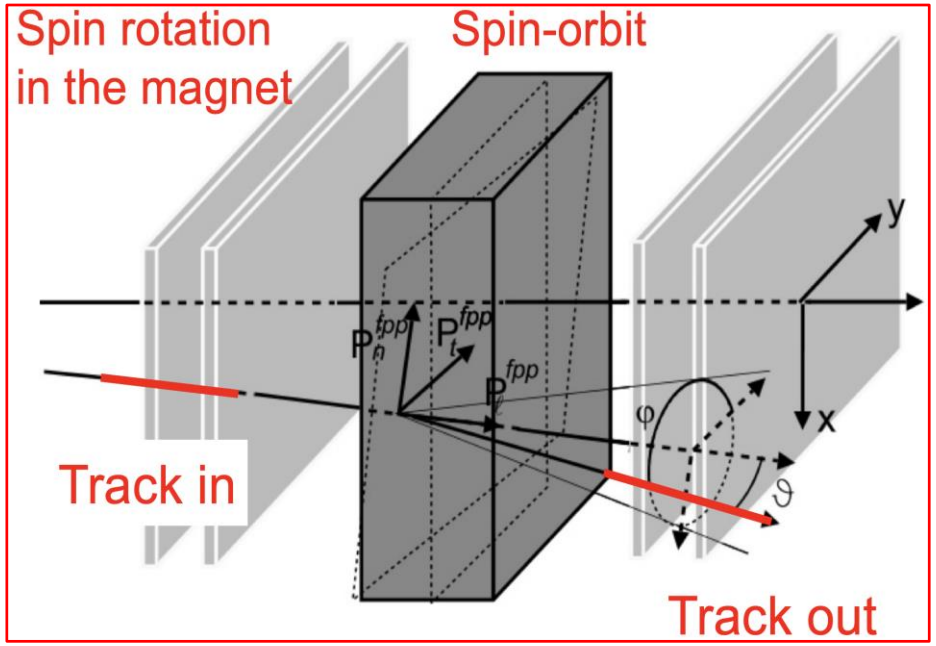
Formalism: Polarimetry Technique

- Accessing ratio of P_t and P_l:
  - via detection probability in polarimeter with ± beam polarization

$$f^{\pm}(\vartheta,\varphi) = \frac{\epsilon(\vartheta,\varphi)}{2\pi}(1 \pm A_y(P_x^{fpp}\sin\varphi - P_y^{fpp}\cos\varphi))$$

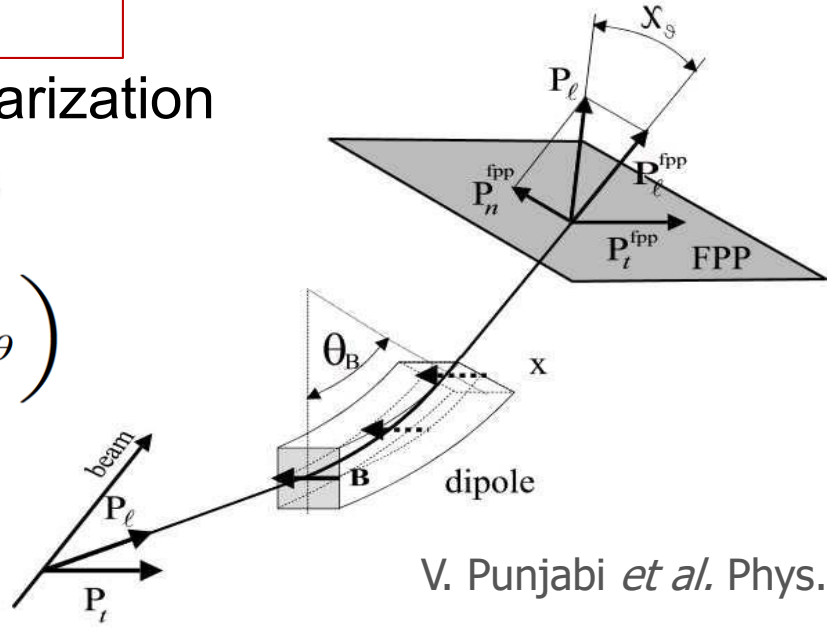
Asymmetry $$A = \frac{f^+ - f^-}{f^+ + f^-} = (A_y P_x^{fpp}\sin\varphi - A_y P_y^{fpp}\cos\varphi)$$

$$\frac{P_t}{P_l} \approx \frac{P_x^{fpp}}{P_y^{fpp}}\sin\chi_\theta$$



- Form Factor ratio is independent of beam polarization and Analyzing power (A_y)

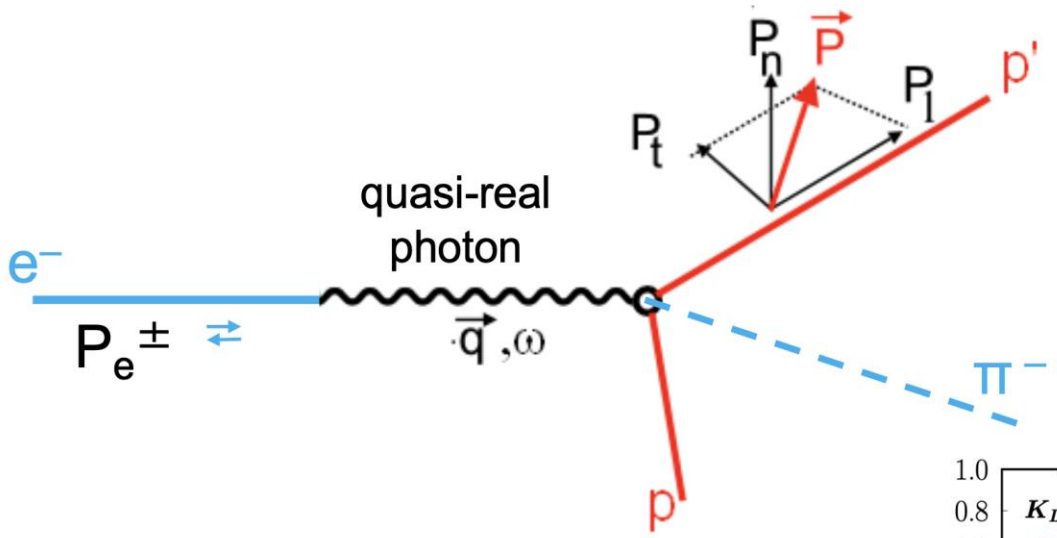
$$\frac{G_E}{G_M} = -\frac{E_e + E_{e'}}{2M}\tan\frac{\theta_e}{2}\left(\frac{P_x^{fpp}}{P_y^{fpp}}\sin\chi_\theta\right)$$



V. Punjabi *et al.* Phys. Rev. C **71**, 055202

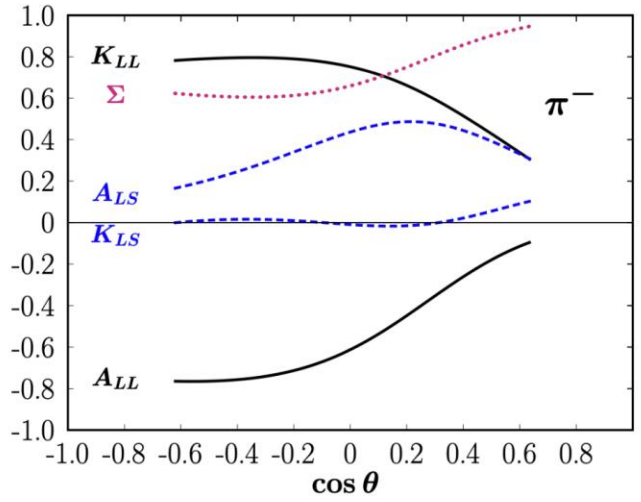
Wide-Angle Pion Photoproduction (KLL)

- Double polarization Observable (KLL) for pion photoproduction in wide angle regime
- Polarization transfer to the final state nucleon
- Constraint to twist-2 and 3 amplitudes in pion photoproduction
- Large asymmetry for KLL, and opposite to ALL, if twist-3 is dominant



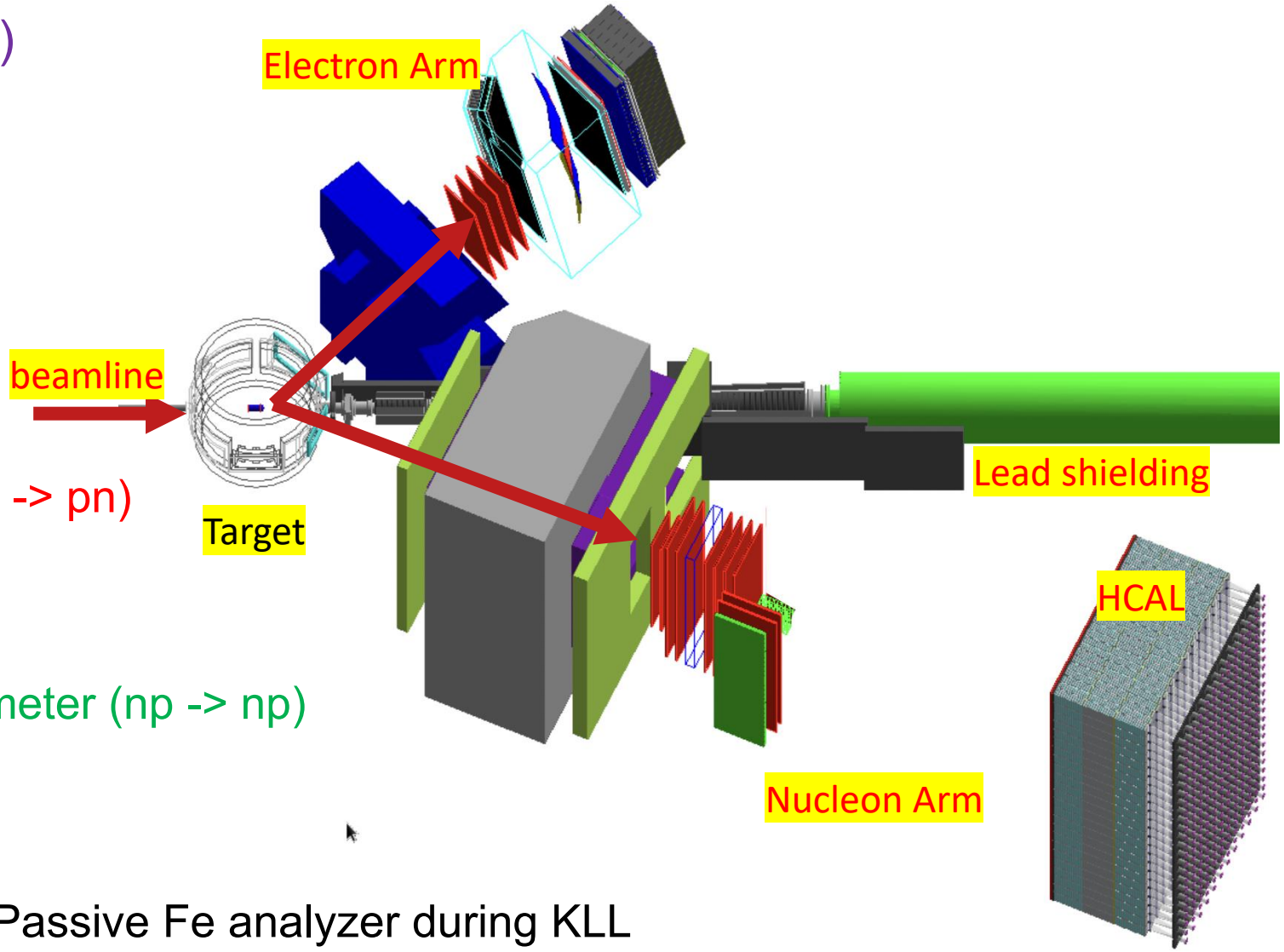
$P_t = P_x$
$P_n = P_y$
$P_l = P_z$

$$K_{LL} = \frac{d\sigma(+,\rightarrow) - d\sigma(-,\rightarrow)}{d\sigma(+,\rightarrow) + d\sigma(-,\rightarrow)}$$



Experimental Layout

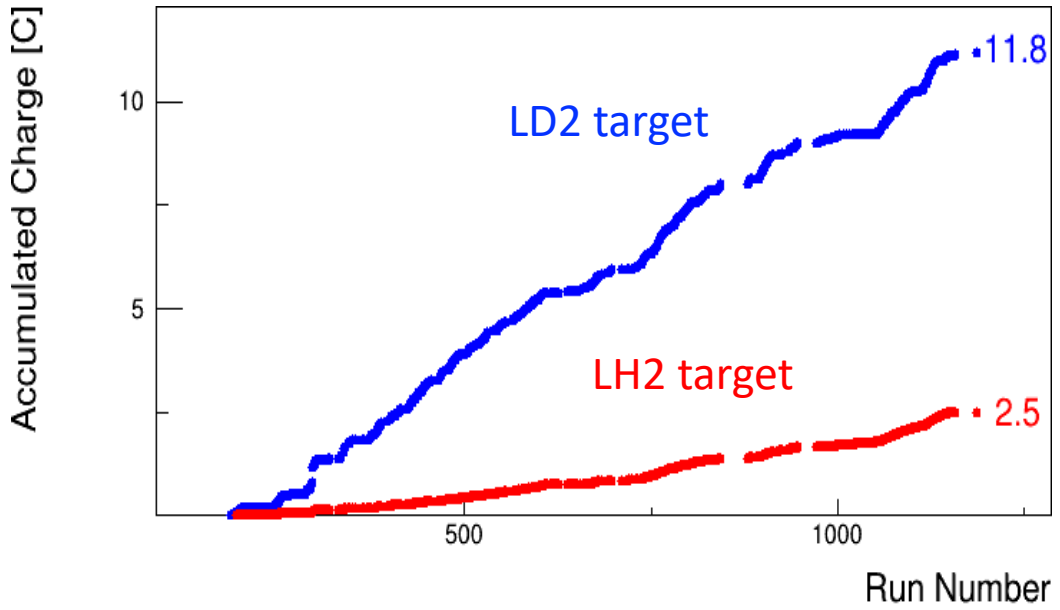
- Electron Arm: (pion in case of KLL)
  - Bigbite magnet
  - GEM detectors
  - Cherenkov
  - Timing hodoscope
  - Pre-shower and Shower detector
- Nucleon Arm:
  - Super-bigbite magnet
  - Charge exchange polarimeter (np -> pn)
    - Inline GEM detectors
    - Passive Fe Analyzer
    - Hadron Calorimeter (HCAL)
  - Large Angle Recoil Proton Polarimeter (np -> np)
    - Active analyzer
    - Side GEM detector
    - Side hodoscope



No Large Angle Recoil polarimetry and Passive Fe analyzer during KLL

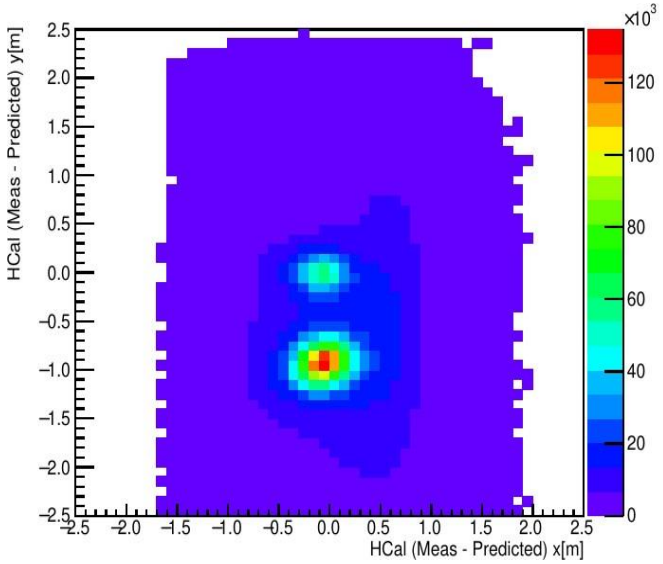
Experimental Parameters

- GEn-RP experiment ran from April 17 to May 14, 2024
  - beam current 10 - 12 uA on 15 cm LD2
  - Beam energy 4.3 GeV
  - Raster of 2 x 2 mm
  - Beam polarization: 82%
  - BB and SBS Magnets 100%
  - BB @ 42.5° and SBS @ 24.7°
  - HCAL @ 9 m
  - Trigger rate: 3 – 4 kHz
  - total accumulated charge on LD2: 11.8 C
- KLL experiment ran from May 14 to May 19, 2024
  - beam current 2.5 uA on 15 cm LD2 with radiator
  - Beam energy 6.4 GeV
  - SBS Magnets 65 - 70%
  - total accumulated charge on LD2: 0.5 C

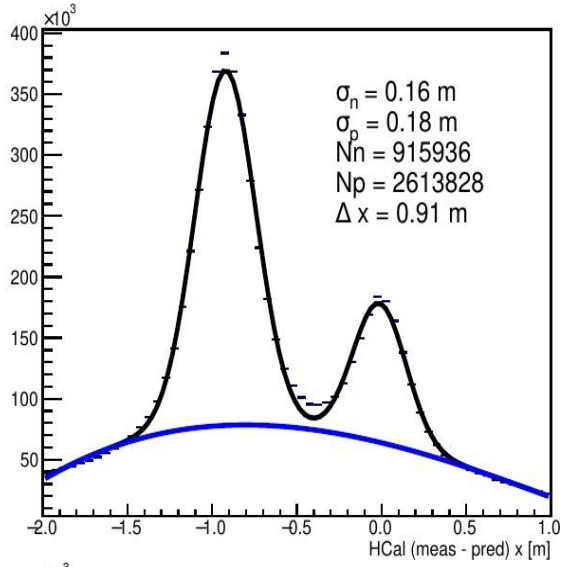


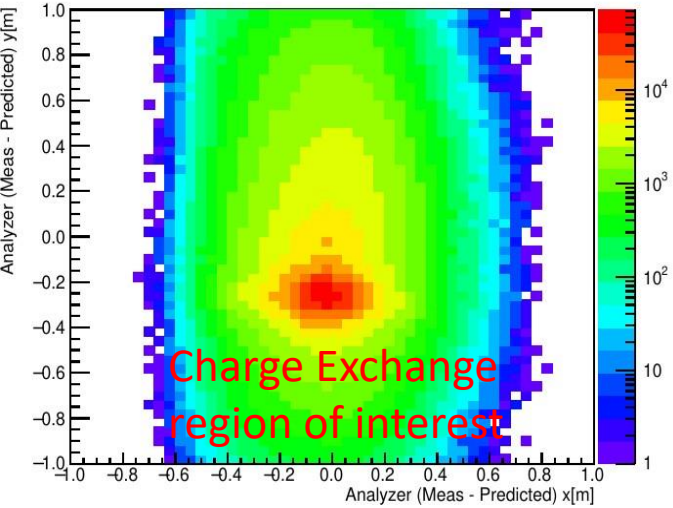
Preliminary Check on GEn-RP Data

- David Hamilton performed preliminary checks on Gen-RP dataset

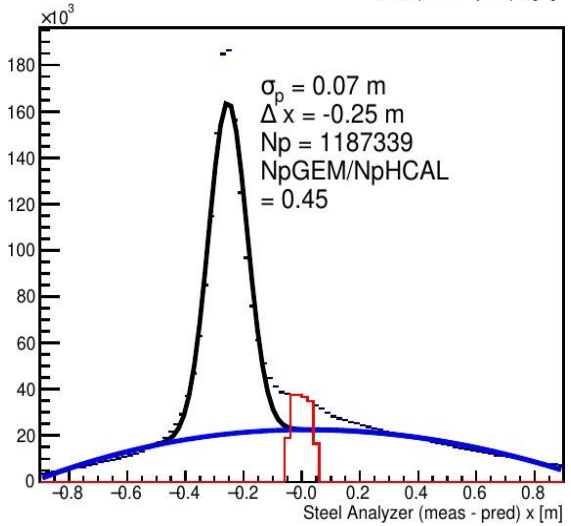


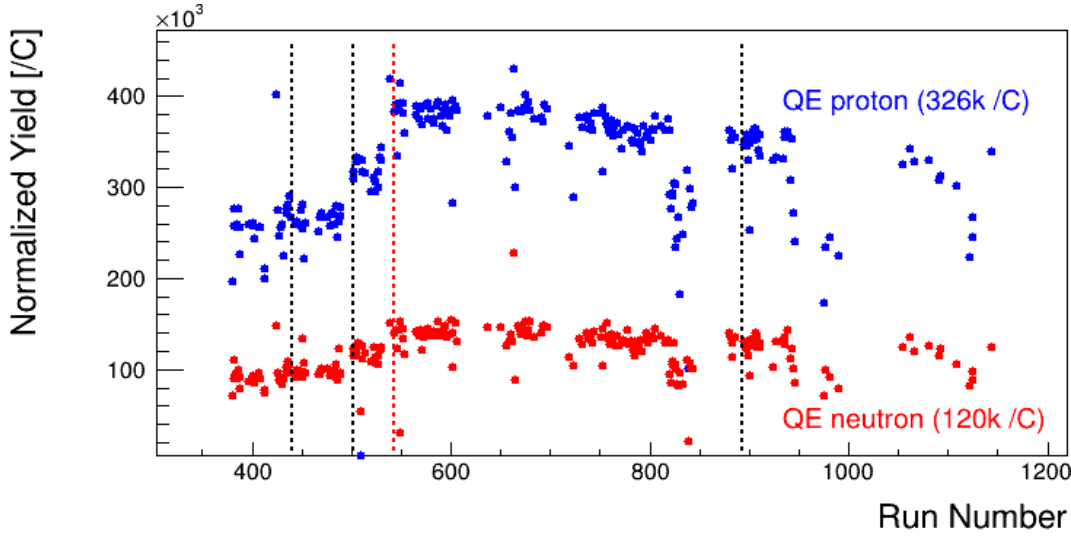
BB+HCAL

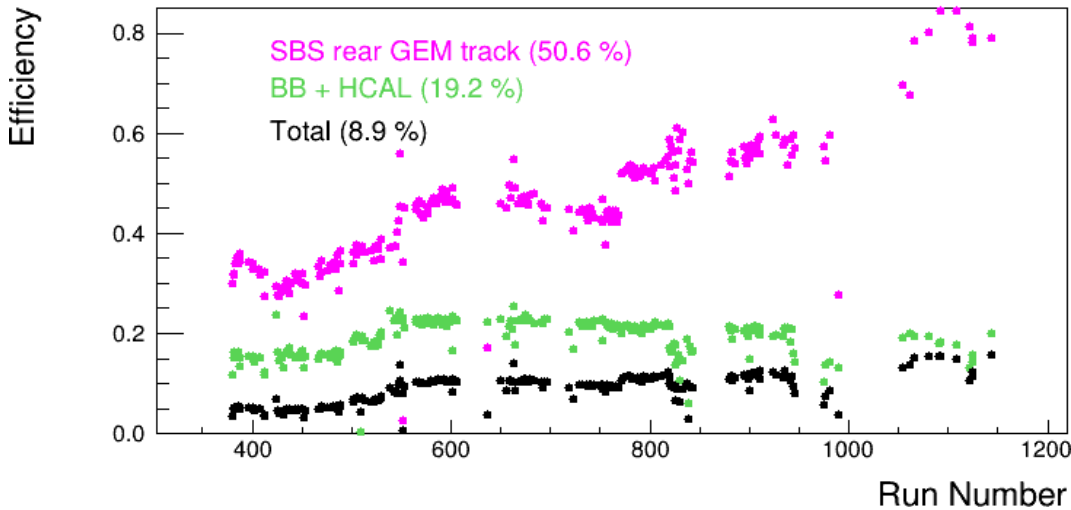




BB+SBS Rear GEMS







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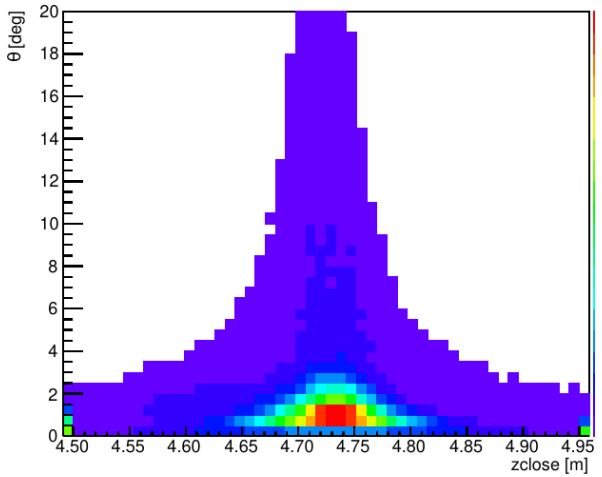
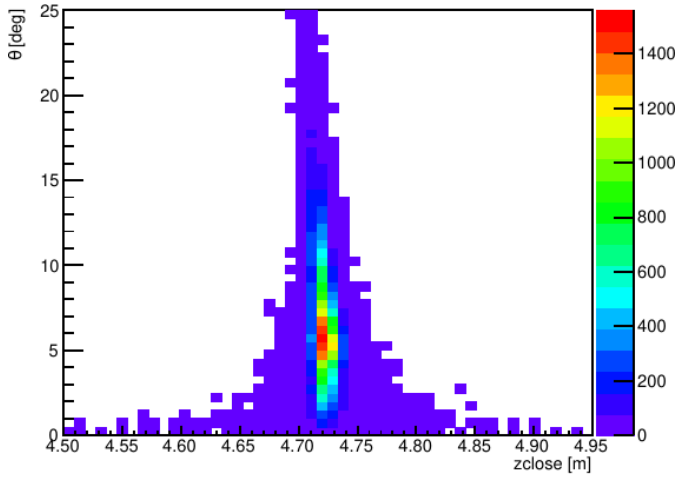


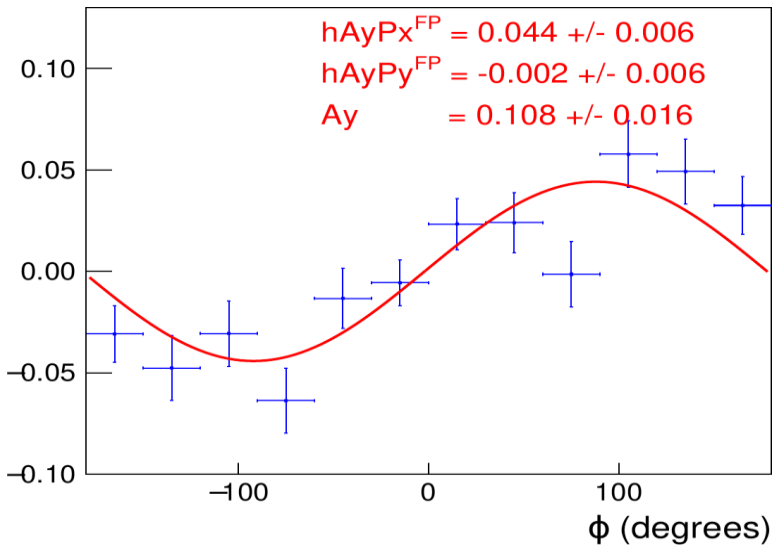
- Analysis based on ~50% of total data collected

- Calibrations and cuts are not optimized

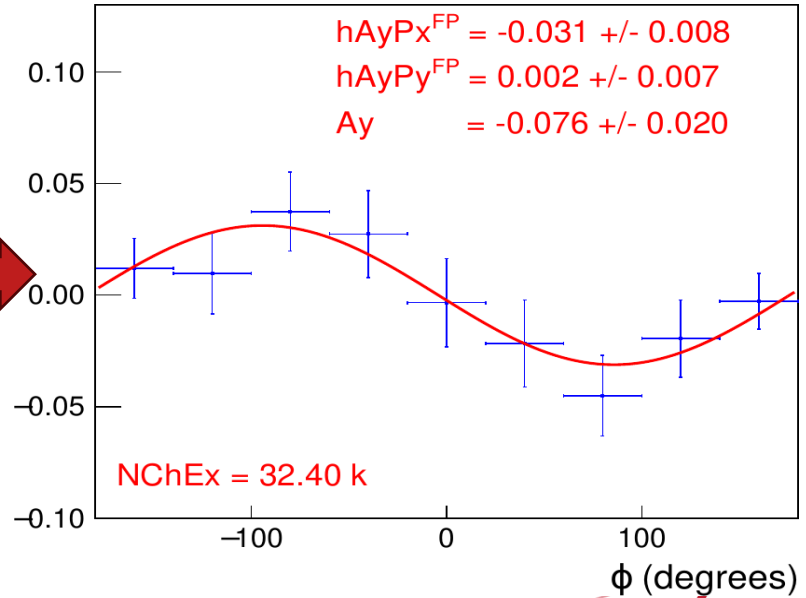
- First GEM Layer at 4.12 m



Proton-> proton channel:
Rough estimate of analyzing power as expected (sign and magnitude)



Neutron-> proton channel:
Preliminary evidence of non-zero beam spin asymmetry

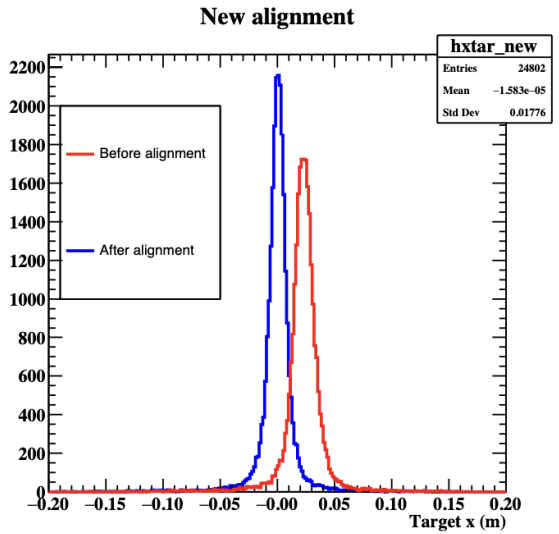


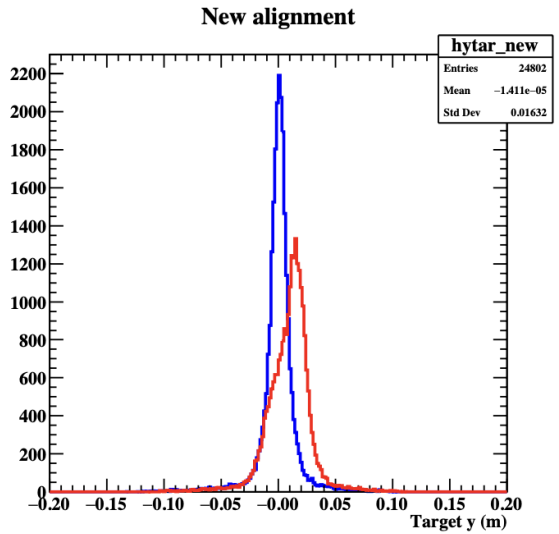
Data Analysis Progress

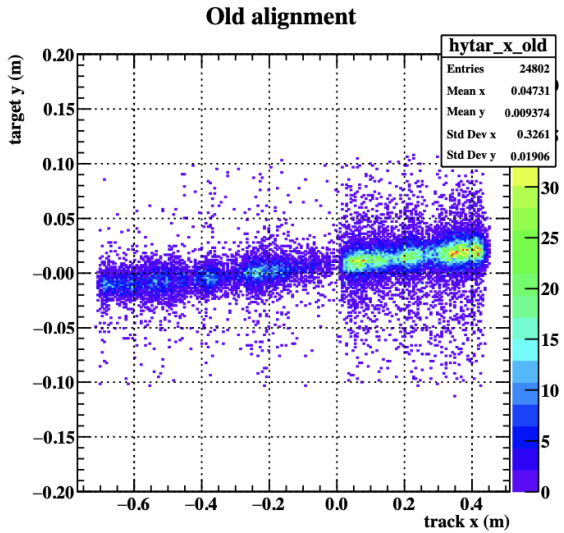
- Gen-RP Analysis meeting on Friday's at 9:00 am
- Three graduate students on GEn-RP data analysis:
  - Andrew Cheyne (Univ. of Glasgow) under David Hamilton
  - Bhasitha Dharmasena (Univ. of Virginia) under Nilanga Liyanage
  - Saru Dhital (Hampton Univ.) under Michael Kohl
- Additionally:
  - Optics and GEM Alignment: Andrew Puckett
  - Grinch calibration: Eric Fuchey
  - active analyzer: William Tireman
  - HCAL Calibration: Jiwan Poudel

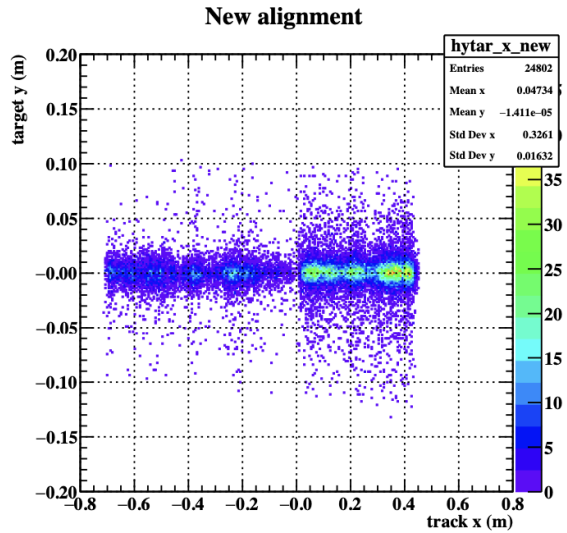
Data Analysis Progress

- SBS GEM alignment by Andrew Puckett





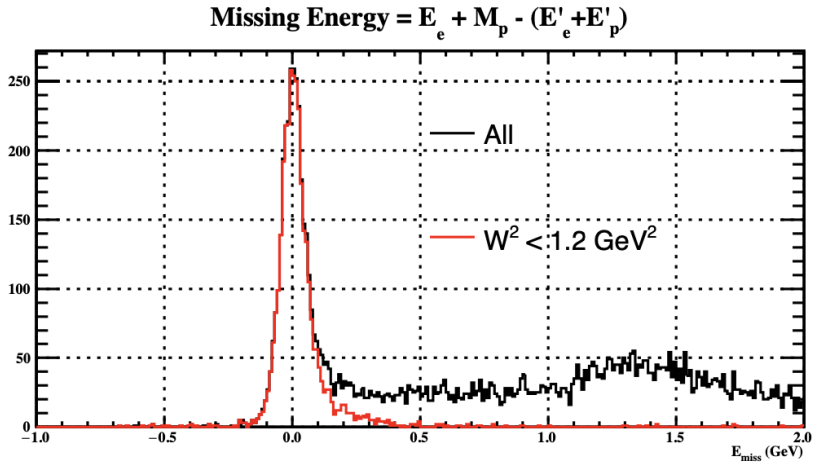


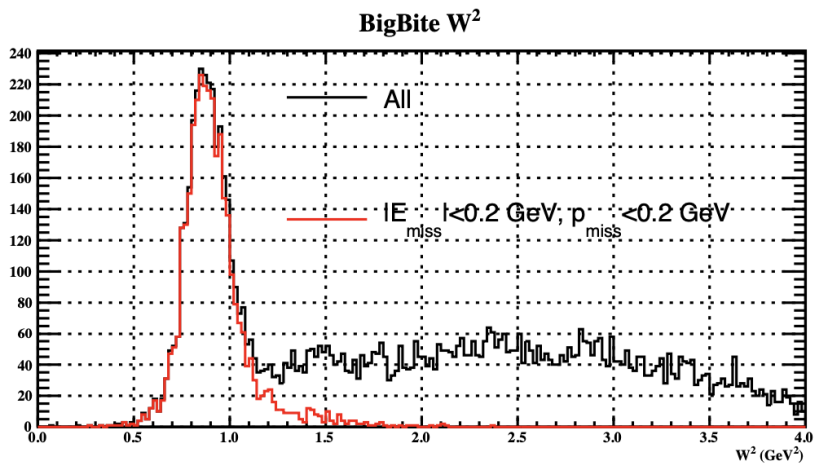


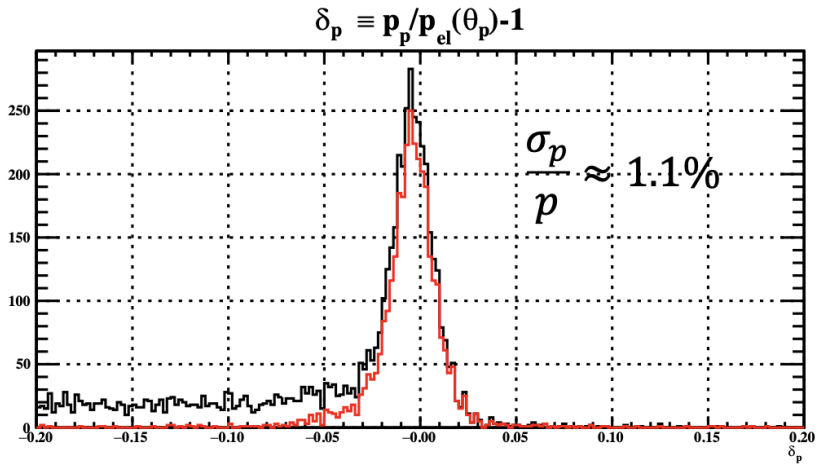
- Magnet-off runs on a thin Carbon foil provide a ”point” source of straight-line tracks through the GEMs—sufficient statistics can be acquired in ~1-3 hours.
- Constraints from beam position on target and HCAL, combined with magnet and detector survey data, allow robust, unambiguous location and orientation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

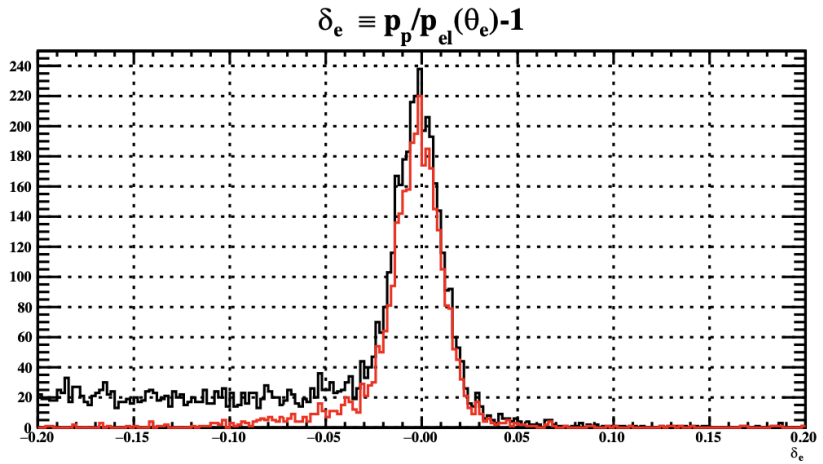
Data Analysis Progress

- SBS Optics model by Andrew Puckett





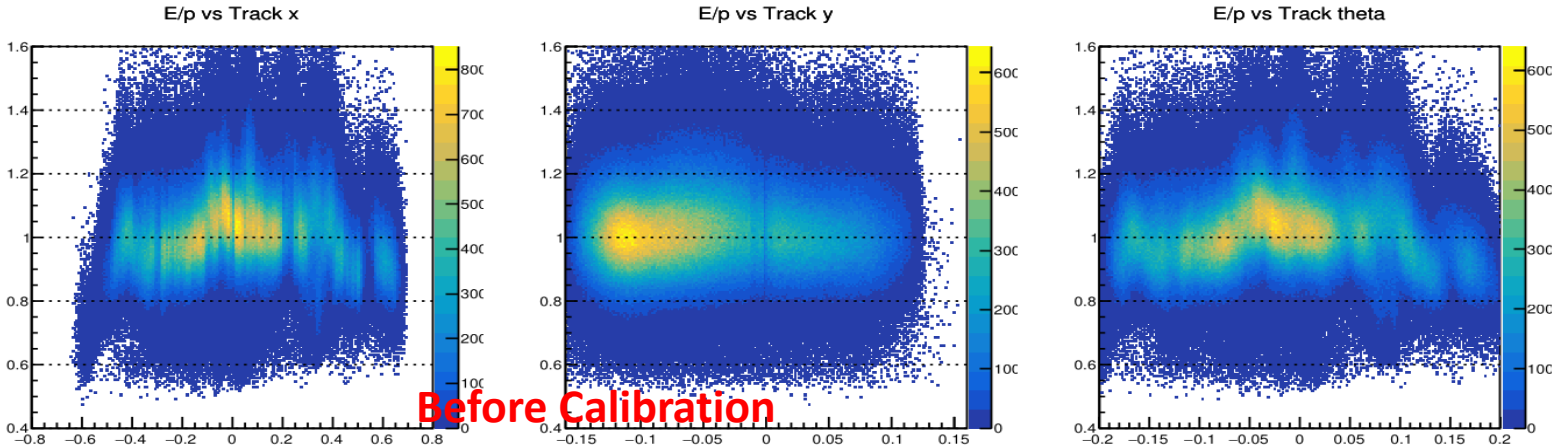




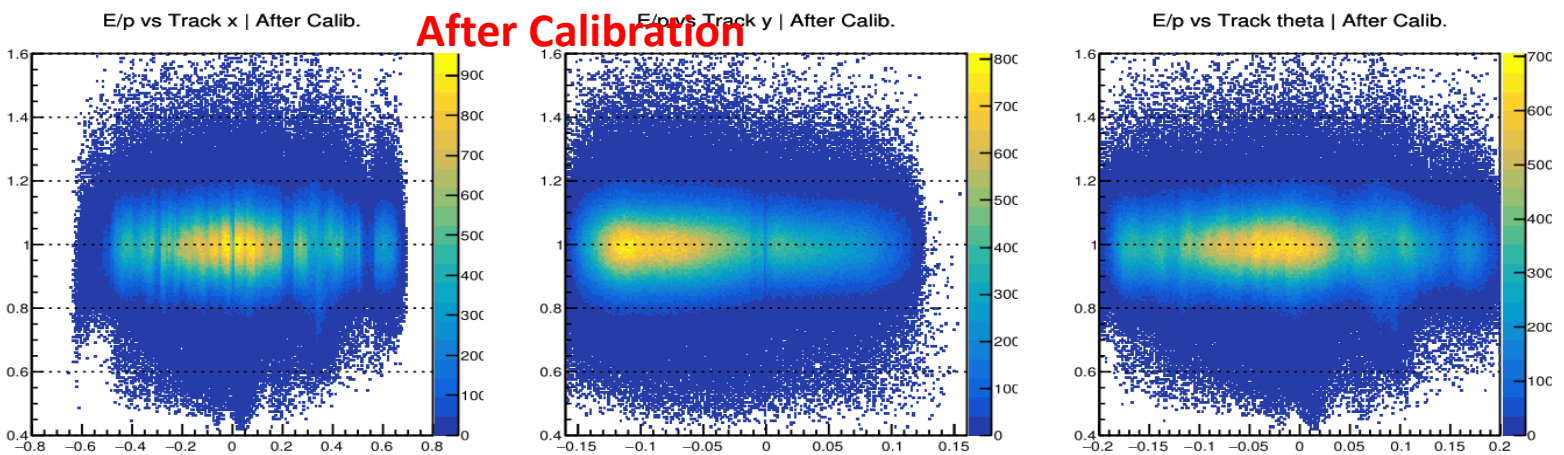
After zero-field GEM alignment, SBS optics model from TOSCA+GEANT4 gives expected resolution/accuracy of kinematic reconstruction with no fine-tuning!

Data Analysis Progress

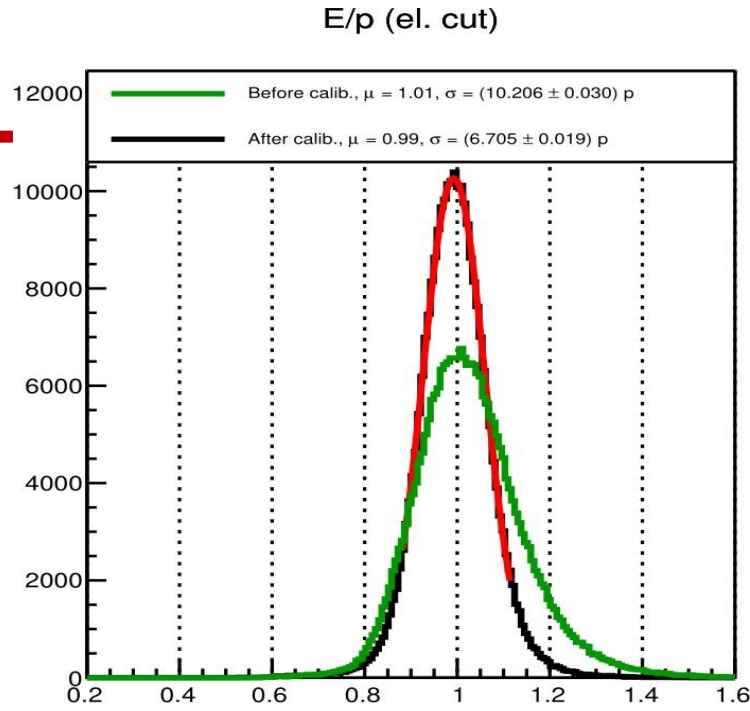
Andrew Cheyne: Looking into Bigbite Calorimeter data for the calibration



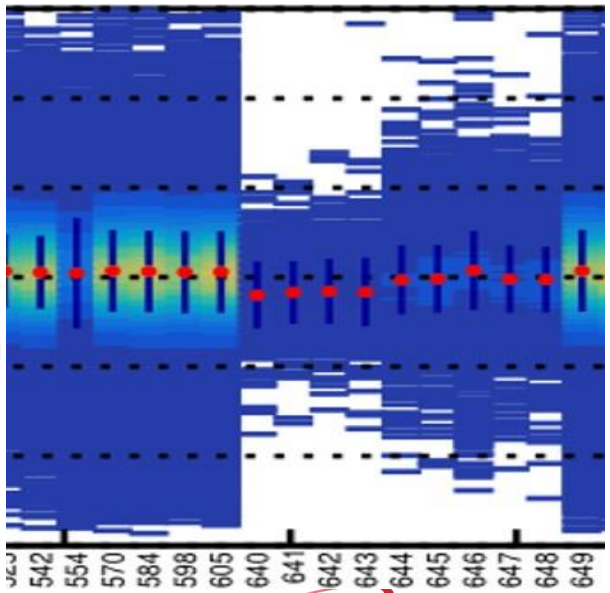
Before Calibration



After Calibration

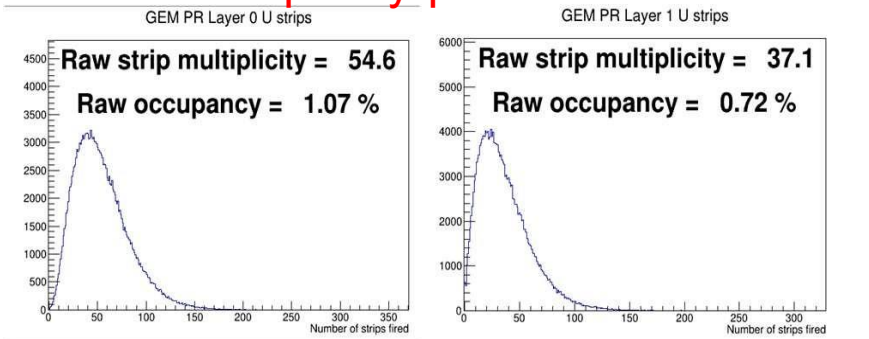


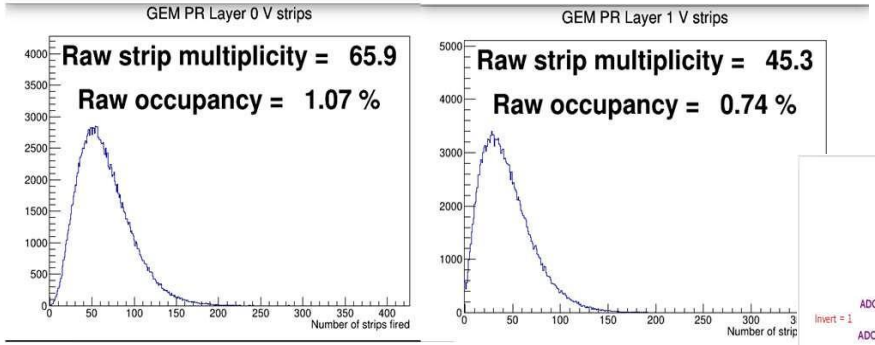
Timeline requires further Investigation



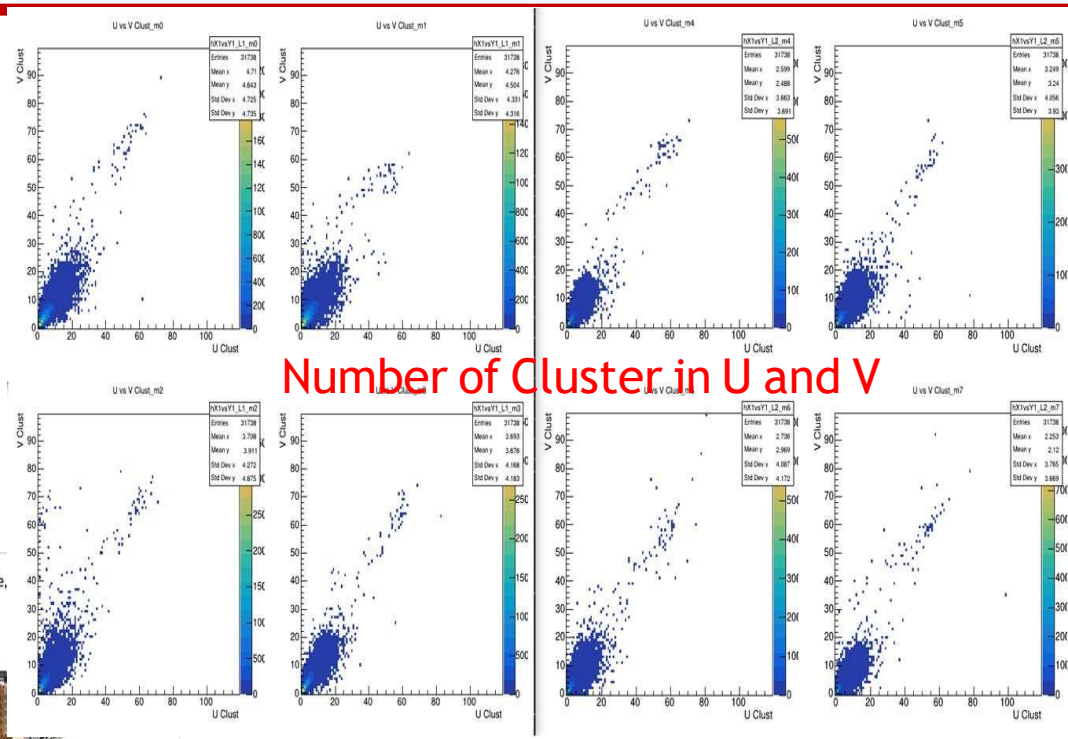
Data Analysis Progress

Occupancy plots

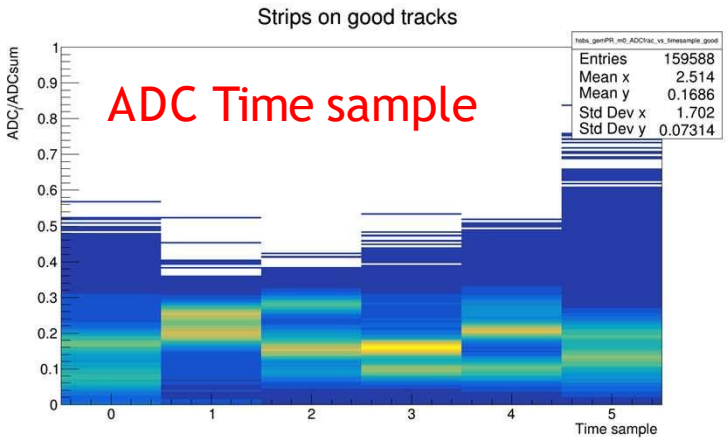


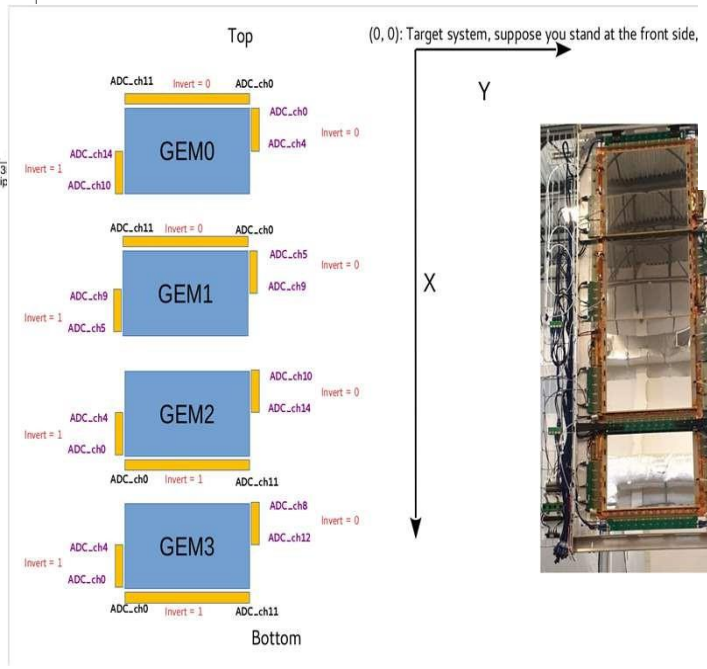


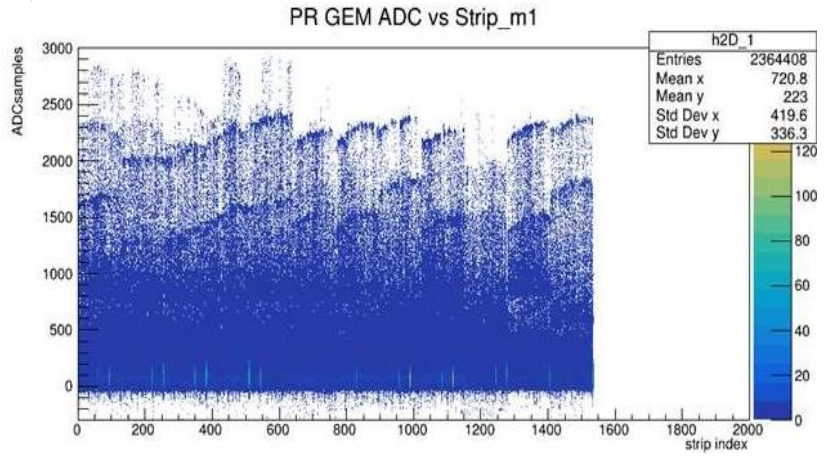
Saru Dhital: Looking into Side GEMs data for recoil polarimetry



Number of Cluster in U and V



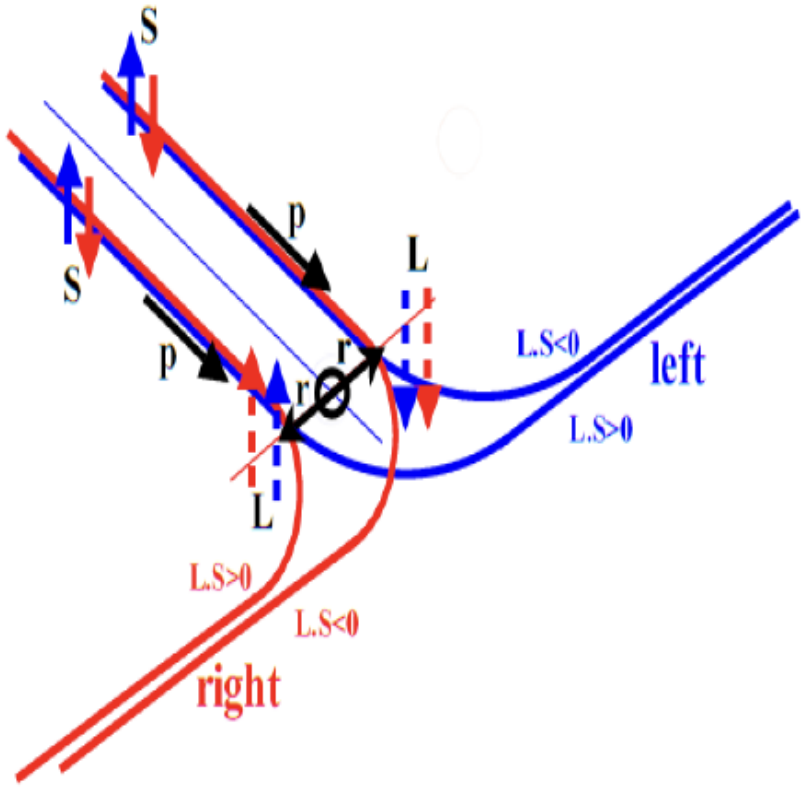




Summary

- GEn-RP and KLL use the polarization transfer technique to access physics observables
- Gen-PR utilized different polarimeters to access exchange np->pn and large angle elastic np->np interactions
- GEn-RP and KLL experiments successfully completed data taking during April/May run period in the Hall A at Jefferson lab
- Preliminary check shows encouraging result for charge exchange
- Full Analysis is in progress for both Gen-RP and KLL
- GEn-RP, if successful, is a proof of principle for larger analyzing power via charge exchange np->pn interaction which is crucial for expanding the program in future
- KLL along with ALL could provide valuable information on handbag mechanism in wide angle interactions

Backup



SAID PW analysis & data base
https://ins.columbian.gwu.edu/data-analysis-center