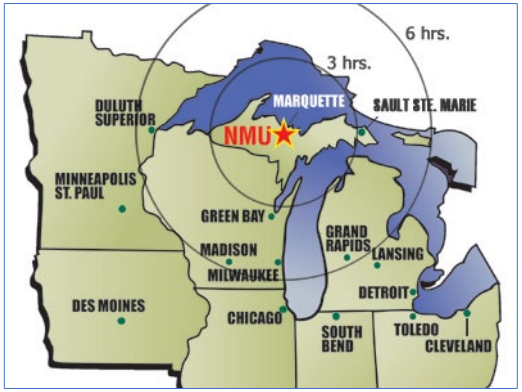


E12-17-004 GEN-RP ANALYSIS UPDATE

HALL A 2025 WINTER MEETING

William Tireman for the E12-17-004 collaboration

Co-spokesperons: Bogdan Wojtsekhowski, Michael Kohl, David Hamilton, Andrew Puckett, William Tireman

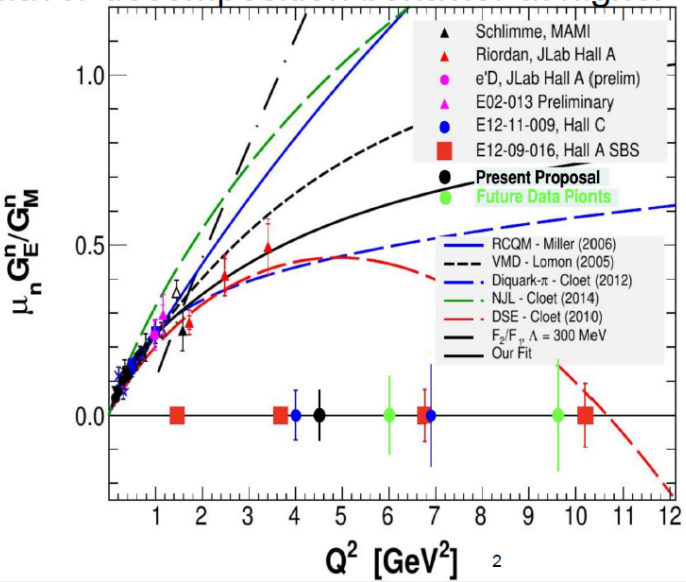
Students: Andrew Cheyne, Saru Dhital, Bhasitha Dharmasena

Outline

- Experimental overview
- Run summary
- BBcal energy an HCAL TDC timing calibrations
- HCAL energy calibrations
- Update on Proton Recoil polarimeter GEM and Scintillator Detectors
- Current plans moving forward

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



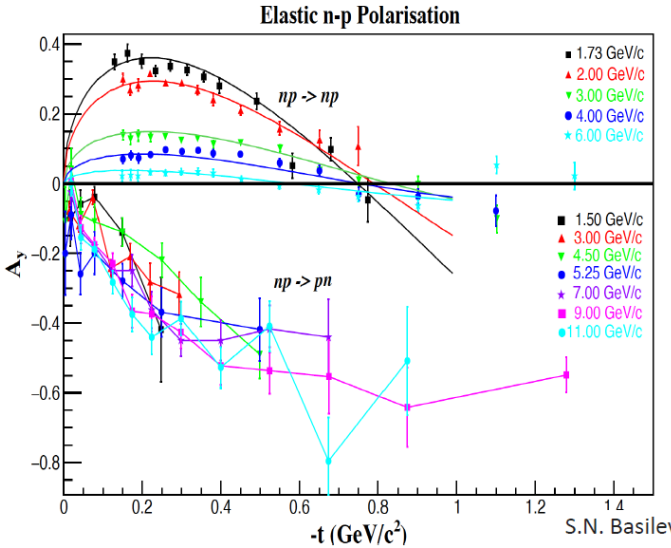
- No free neutron target due to its short life-time
- Nuclear target requires nuclear corrections
- Smallness of G_E^n

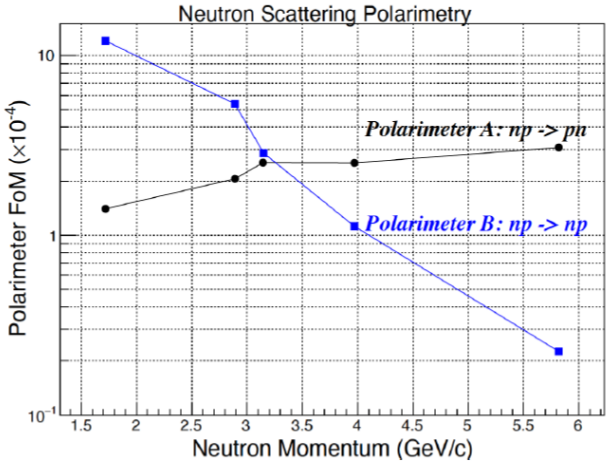
Jefferson Lab

From the GEn-RP SBS-collaboration meeting by Jiwan Poudel

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: $F^2(p_n) = \int \epsilon(p_n, \theta_n^{'})\, A_y^2(p_n, \theta_n^{'}) d\theta_n^{'}$



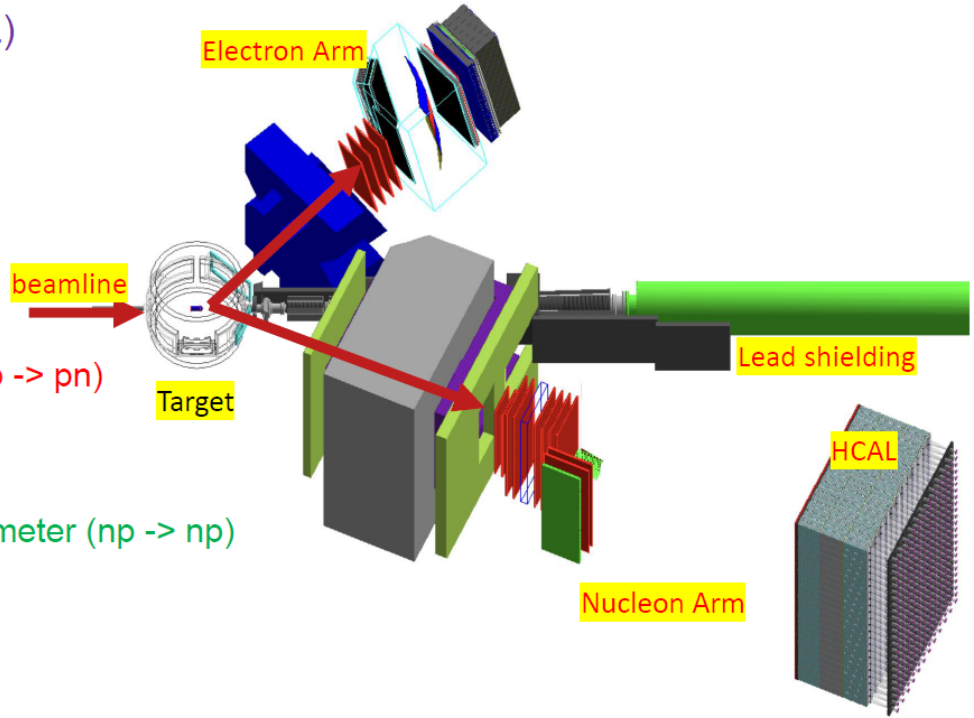


S.N. Basilev *et al., Eur. Phys. J. A* **56**, 26 (2020)

From the GEn-RP SBS-collaboration meeting by Jiwan Poudel

Experimental Layout

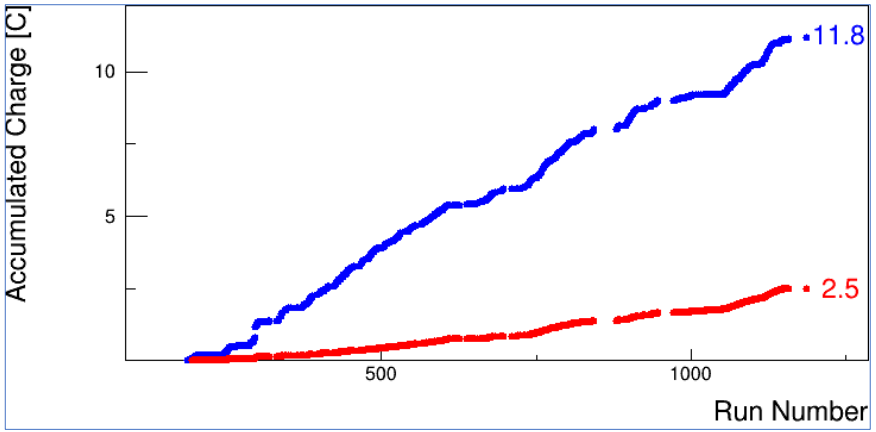
- Electron Arm: (pion in case of KLL)
  - Bigbite magnet
  - GEM detectors
  - Cherenkov
  - Timing hodoscope
  - Pre-shower and Shower detector
- Nucleon Arm:
  - Super-bigbite magnet
  - Charge exchange polarimeter (np -> pn)
    - Inline GEM detectors
    - Passive Fe Analyzer
    - Hadron Calorimeter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



From the GEn-RP SBS-collaboration meeting by Jiwan Poudel

Summary of data collection

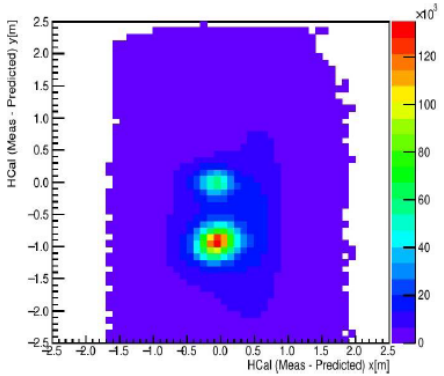
- GEn-RP experiment ran from April 17 to May 14, 2024
  - Beam current 10-12 μA on 15 cm LD_2
  - Beam energy 4.3 GeV
  - Raster of 2 x 2 mm
  - Beam polarization: 82%
  - BB and SBS magnets: 100%
  - BB at 42.5° and SBS at 24.7°
  - HCAL at 9 m
  - Trigger rate: 3-4 kHz
  - Total accumulated charge on LD_2: 11.8 C



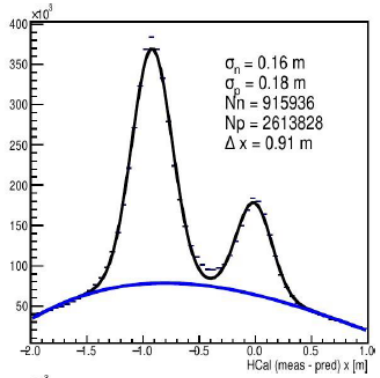
From David Hamilton, University of Glasgow
Summary: 22 May 2024

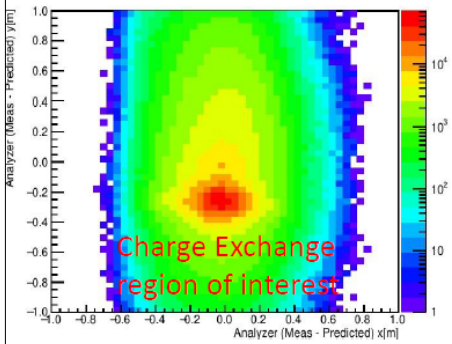
Preliminary Check on GEn-RP Data

- David Hamilton performed preliminary checks on Gen-RP dataset

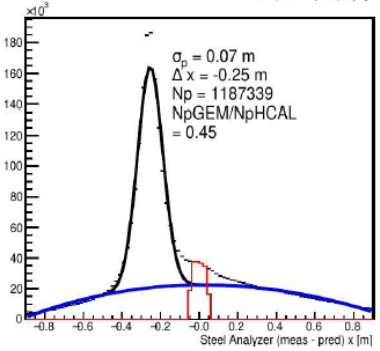


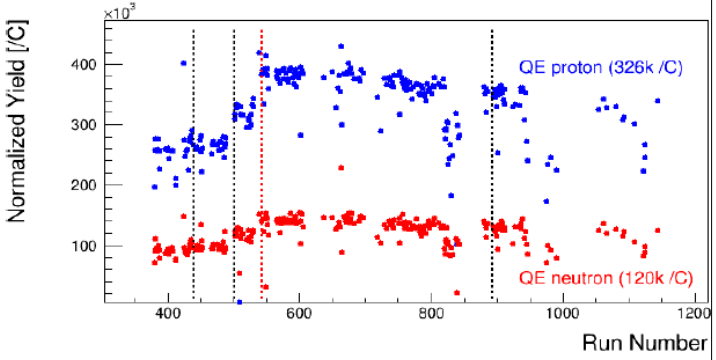
BB+HCAL

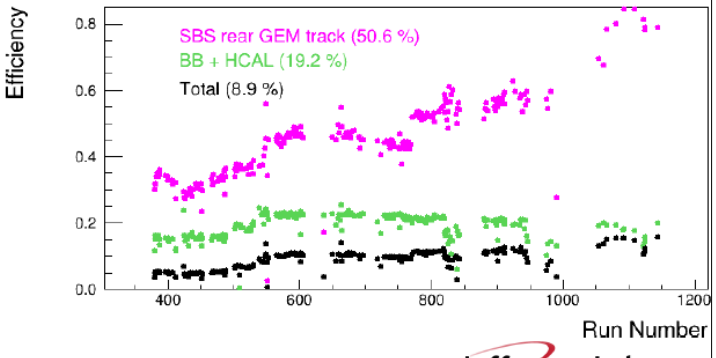




BB+SBS Rear GEMS







GEn-RP Updates

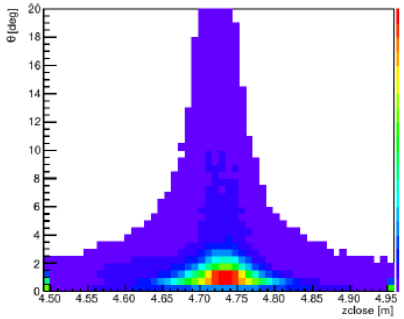
10

Jefferson Lab

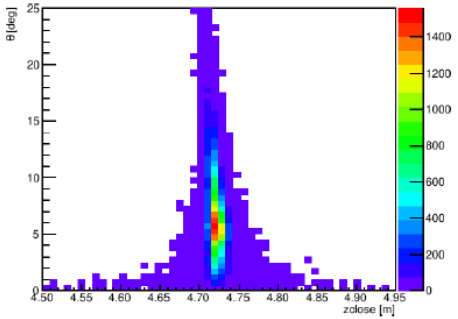
From the GEn-RP SBS-collaboration meeting by Jiwan Poudel

Preliminary Check on GEn-RP Data

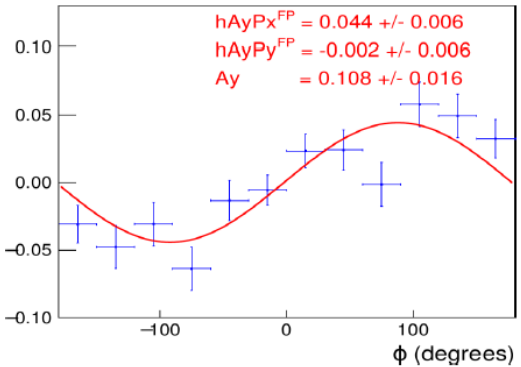
- David Hamilton performed preliminary checks on Gen-RP dataset



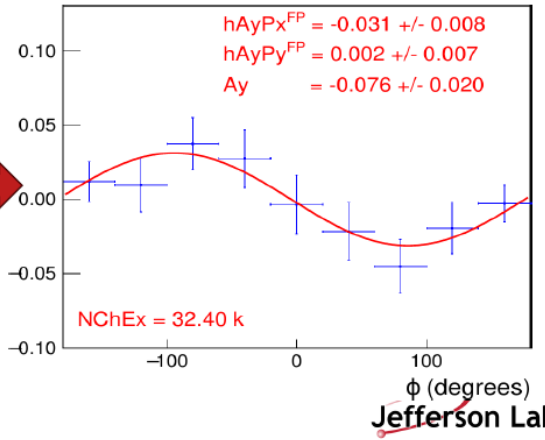
- Analysis based on ~50% of total data collected
- Calibrations and cuts are not optimized
- First GEM Layer at 4.12 m



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



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



From the GEn-RP SBS-collaboration meeting by Jiwan Poudel

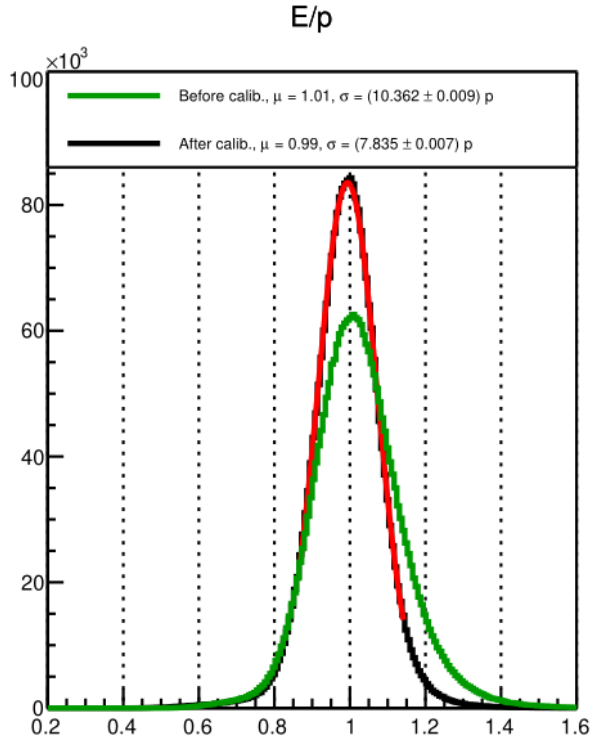
Bbcal Energy Calibration and HCAL TDC Timing Calibrations

Andrew Cheyne, University of Glasgow
Advisors: David Hamilton & Rachel Montgomery

BBCal Energy calibrations

Thanks to Provakar Datta and Kate Evans for the code and documentation.

- BBCal is almost ready for a first pass replay for GEn-RP.
- Calibrations are based on the all currently replayed LH2 data (83% of total LH2 runs)
- The data is split into 4 groups (mostly due to BBCal threshold changes - still being investigated).
- All groups showed similar improvement in sigma (~ 10% → 7%). Group 4 is shown in figure to the side.

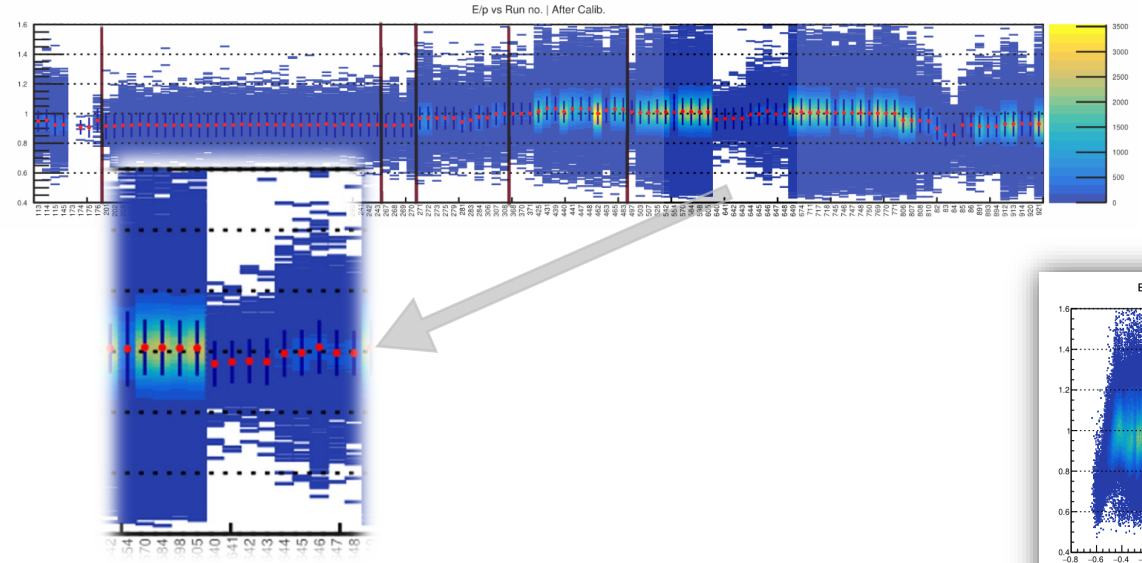


Total # events analyzed: 15066113, Preparing for replay pass: 0

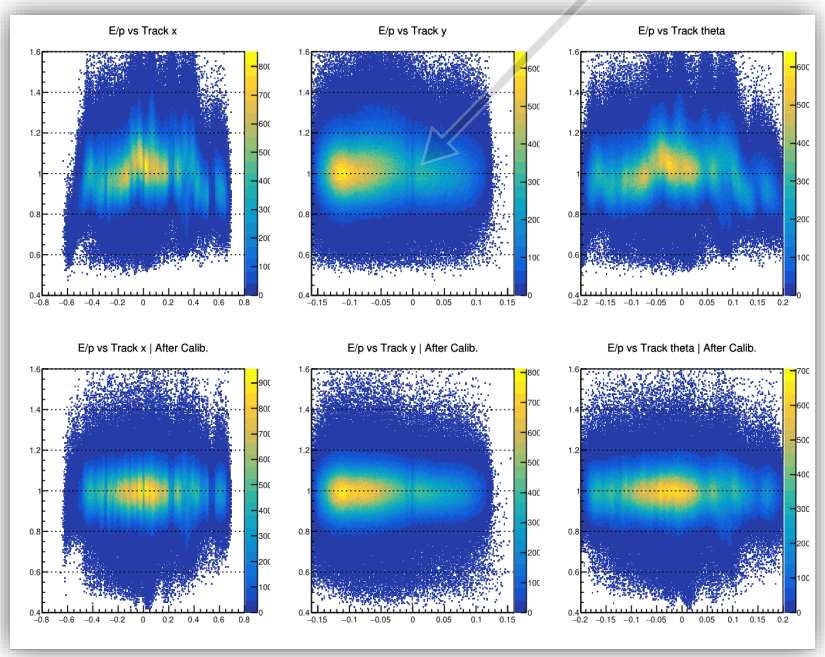
E/p (before calib.) | μ = 1.01, σ = (10.362 ± 0.009) p

E/p (after calib.) | μ = 0.99, σ = (7.835 ± 0.007) p

BBCal Energy (to do)



Investigate the bands of low occupancy in E/p.



Investigate the dips in mean E/p on run-to-run level.

- looks like they may be a beam current effect

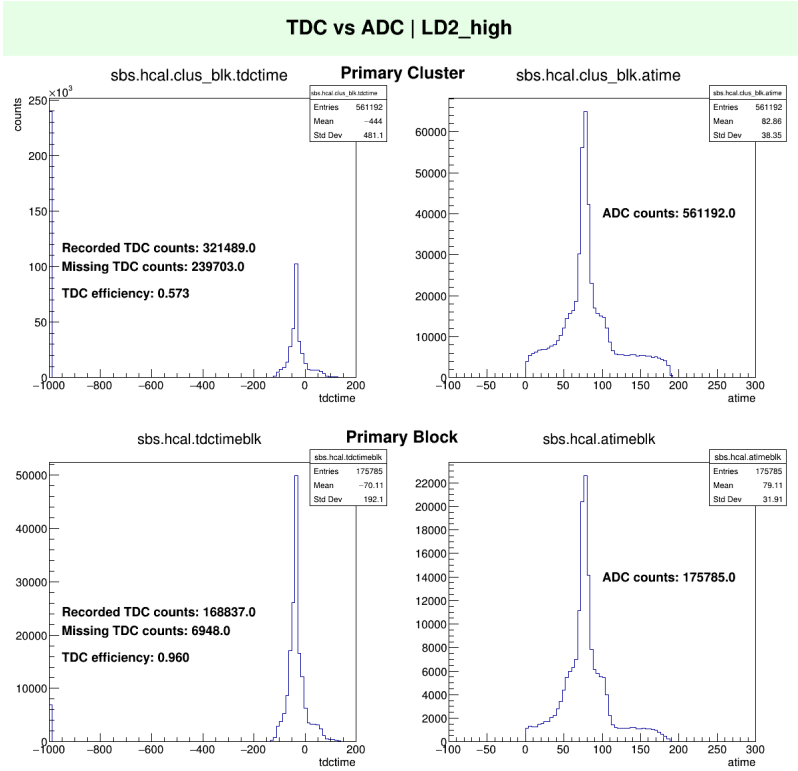
NORTHERN MICHIGAN UNIVERSITY

HCal TDC investigation

Previous experiments saw a large fraction of missing TDC information compared to ADC.

The aim is to assess the viability of using TDCs for timing information for GEn-RP.

Starting by looking at raw HCal information, specifically the ration of TDC/ADC hits



Top row shows TDC (left) and ADC (right) for all blocks in the primary cluster for all channels.

Bottom row is primary block only.

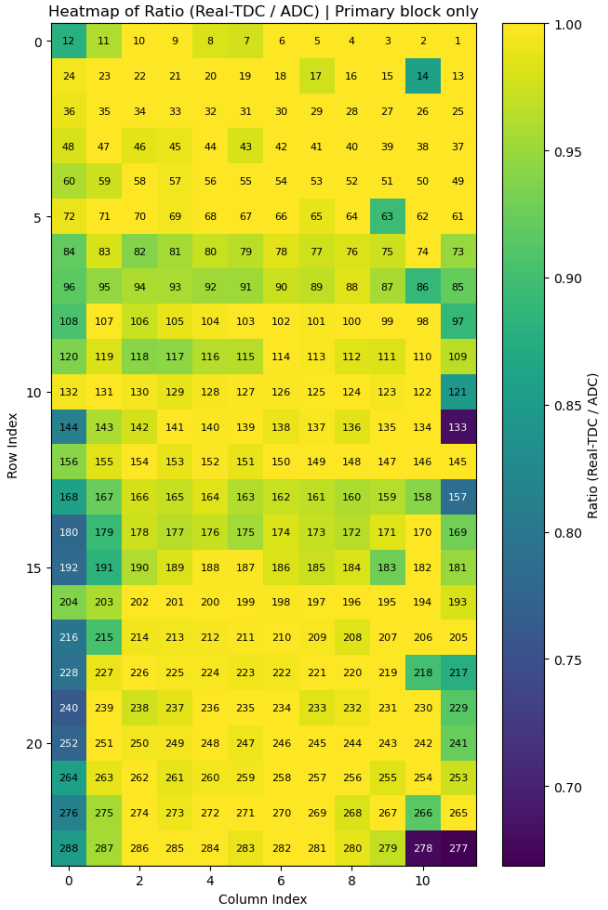
Heat map of missing times (with elastic cuts)

A heatmap of the TDC/ADC ratio shows the central region has excellent TDC information.

The color shows the ratio of TDC/ADC hits.

The number on each element is the block id.

Note: This is without any extra steps recovering time from secondary blocks or more precise cuts.



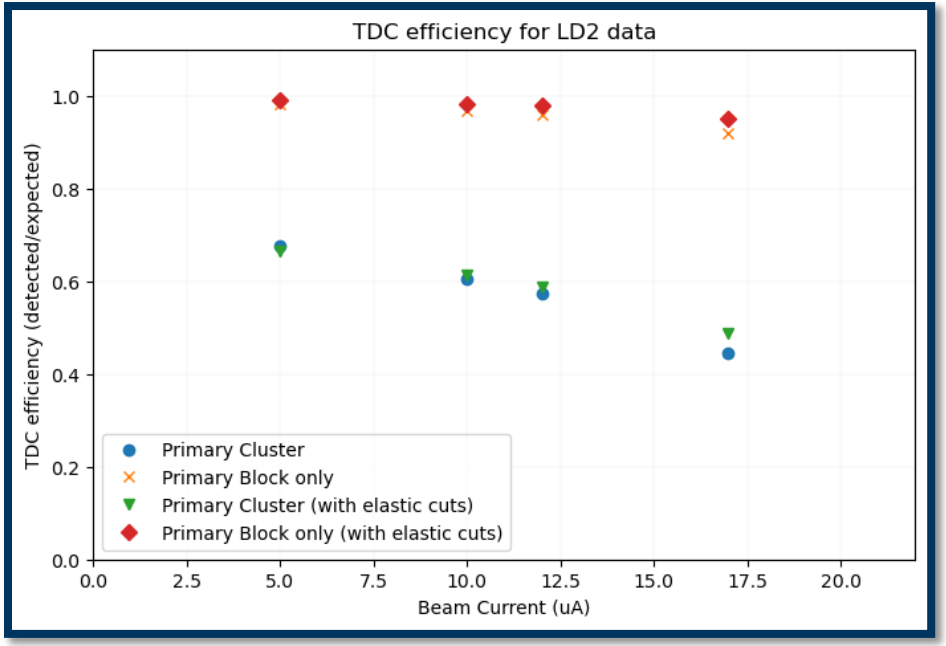
HCal TDC information

Appears to be a beam current dependence on how much TDC information was missing.

Primary Block cluster with cuts at 10-12.5uA is already close to 100%.

With more work in restricting cuts, and recovering times from secondary blocks, this can only improve!

We decided to proceed with TDC timing for GEn-RP



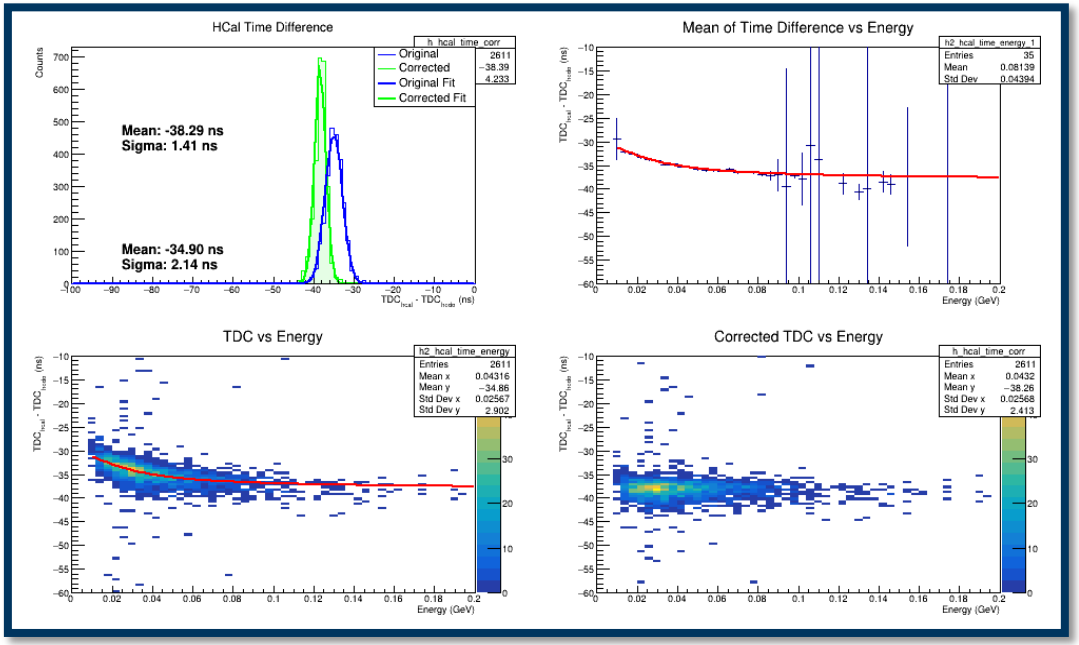
Primary Cluster here includes TDC info from all blocks in the cluster.
Primary Block only means just the highest energy block from that cluster.

Example of timewalk in HCal

Neither HCal or BBHodo are currently calibrated.

There is a large walk effect when looking at the time difference ($TDC_{hcal} - TDC_{hodo}$).

Calibrating the TDC information for these two detectors is my primary task now.



Example of timewalk in coincidence time for a single HCal block. Shows raw single block time resolution of 2.14ns.

Update HCAL Energy Calibrations

Bhasitha Dharmasena, University of Virginia
Advisor: Nilanga Liyanage

HCAL Energy Calibration

The current goal is to calibrate the HCAL energy detection by utilizing the reconstructed SBS momentum. This calibration will help refine the sampling fractions of the HCAL blocks, which can then be applied in subsequent analyses. With an accurate optics model in place, the calibration is expected to yield better results for the HCAL energy detections.

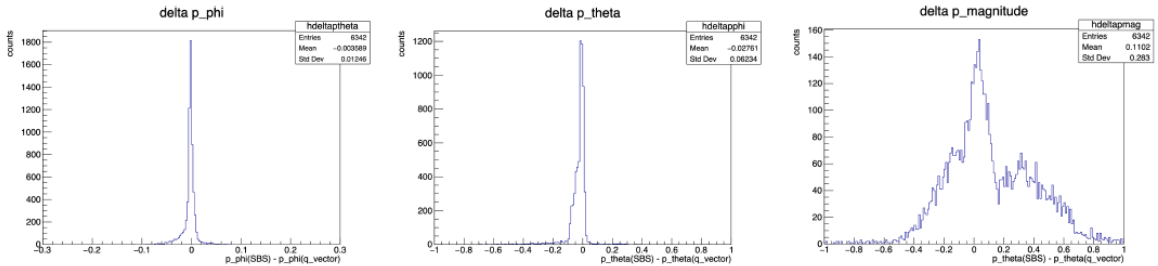


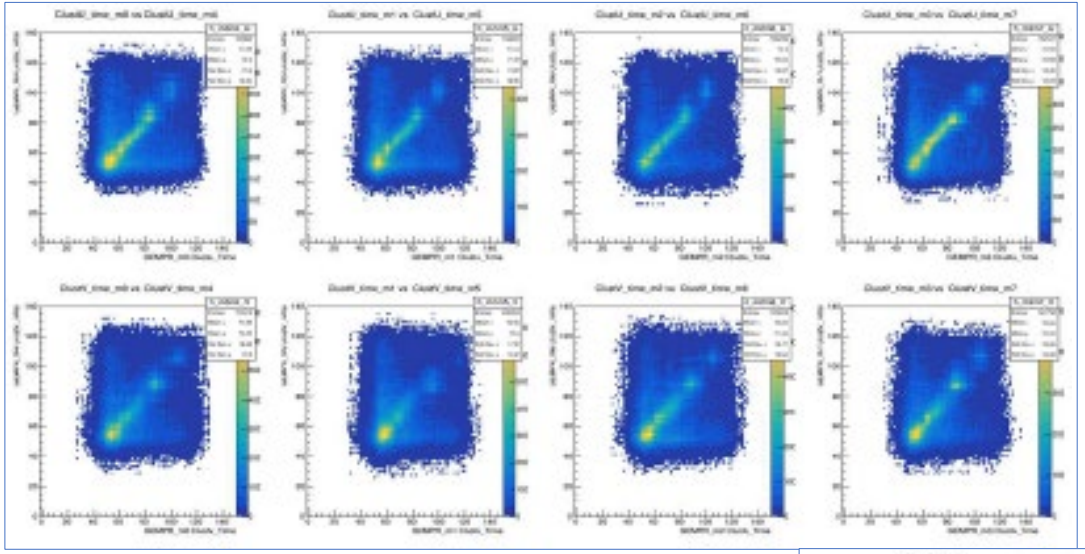
Figure: SBS reconstructed momentum vs expected (without the up-to-date optics models)

Bhasitha Dharmasena, UVa

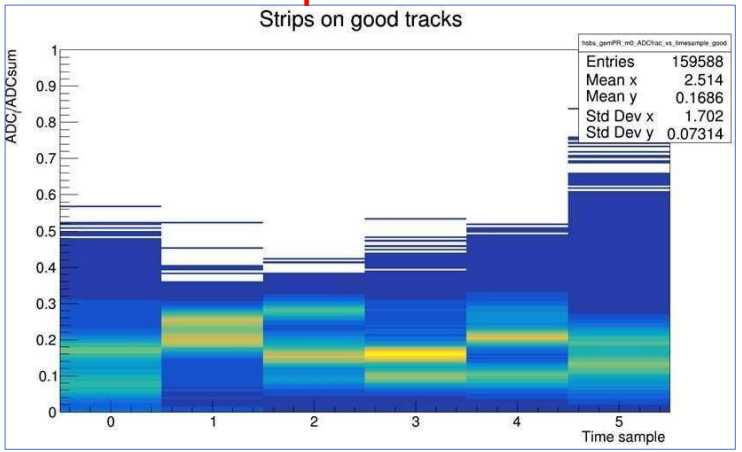
Update on Proton Recoil polarimeter GEMs and Scintillator Detectors

Saru Dhital, Hampton University
Advisor: Michael Kohl

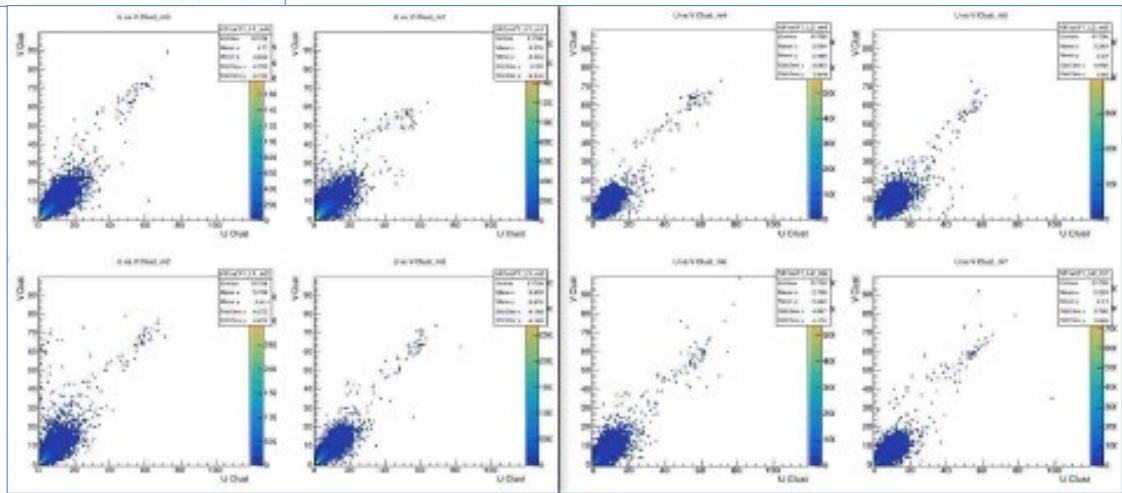
Correlation between two PR GEMs in terms of Cluster position



Time Sample Plots for PR GEMs



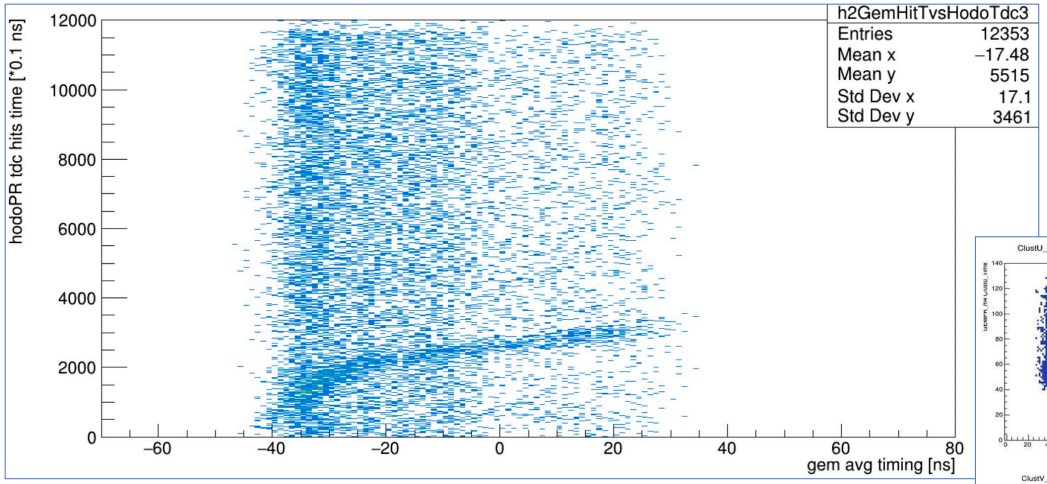
Cluster on U vs Cluster in V for PR GEMs



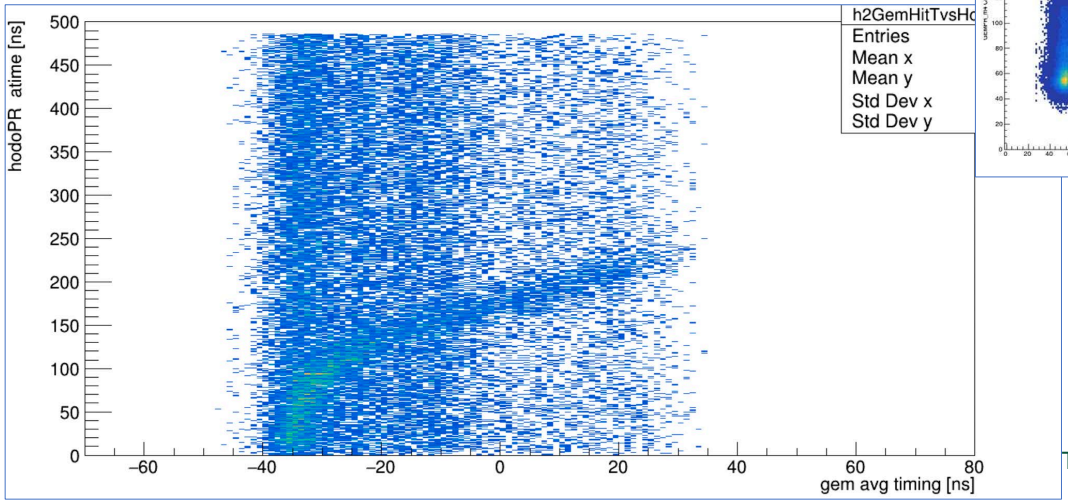
Saru Dhital, Hampton University

NORTHERN MICHIGAN UNIVERSITY

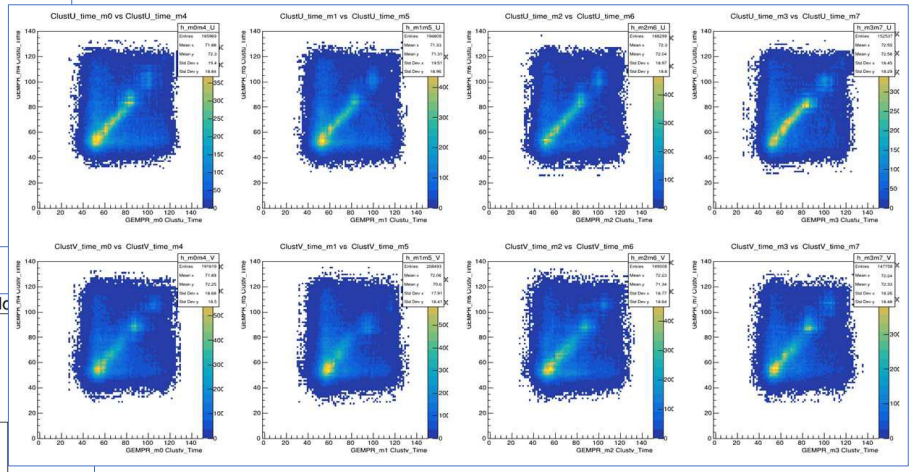
Hodoscope TDC hit time vs GEM Average time (Jiwan Poudel)



Hodoscope ADC time vs GEM Average time (Jiwan Poudel)



Correlation between two PR GEMs in terms of Cluster position



Saru Dhital, Hampton University

Summary

- GEn-RP successfully took data in April-May 2024
- BBcal, Hcal calibrations are well underway
- Refined optics needed for SBS GEMs
- Hcal Energy calibration using SBS reconstructed tracks in progress
- Proton Recoil GEM and Hodoscope plots indicate correlations; more work is needed to clean up noise
- Active analyzer data still needs to be looked into more closely

The analysis continues …

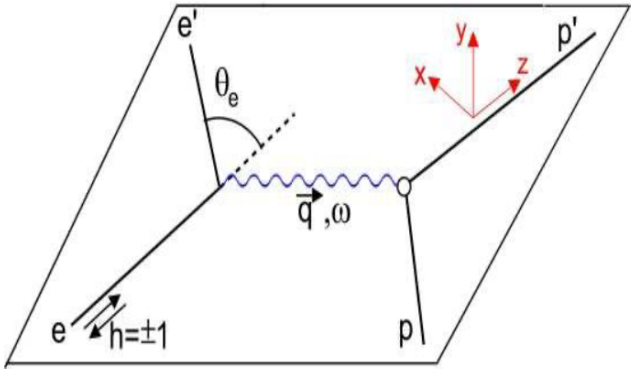
- Three graduate students on GEn-RP data analysis:
  - Andrew Cheyne (Univ. of Glasgow) under David Hamilton & Rachel Montgomery
  - Bhasitha Dharmasena (Univ. of Virginia) under Nilanga Liyanage
  - Saru Dhital(Hampton Univ.) under Michael Kohl
- Additionally:
  - Optics and GEM Alignment: Andrew Puckett
  - Grinch calibration: Eric Fuchey
  - HCAL Calibration: Jiwan Poudel
  - help from other SBS sub-system experts
- Zoom meetings Thursdays at 11 AM

Thank you

Extra slides

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)

From the GEn-RP SBS-collaboration meeting by Jiwan Poudel

Formalism: Polarimetry Technique

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

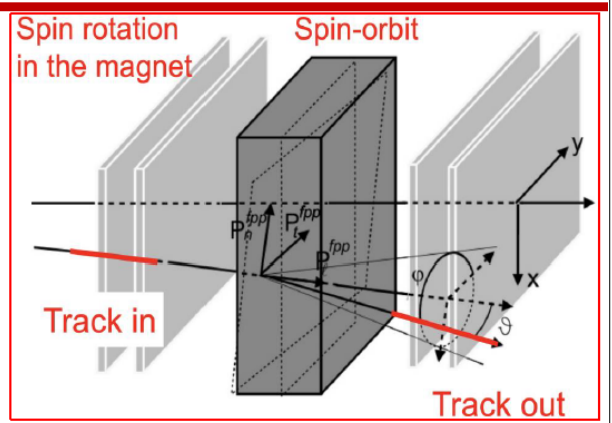
$$f^{\pm}(\vartheta,\varphi) = \frac{\epsilon(\vartheta,\varphi)}{2\pi}(1 \pm A_y(P_x^{fpp}\sin\varphi - P_y^{fpp}\cos\varphi))$$

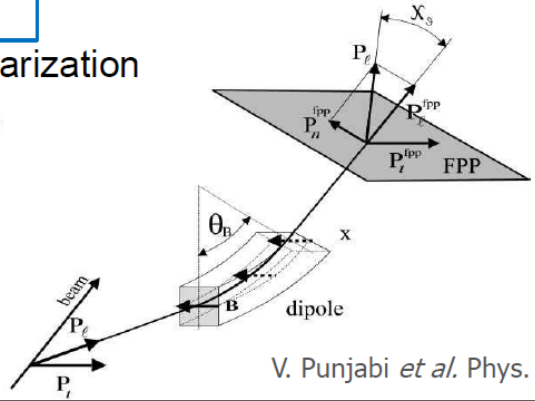
Asymmetry $$A = \frac{f^+ - f^-}{f^+ + f^-} = (A_y P_x^{fpp}\sin\varphi - A_y P_y^{fpp}\cos\varphi)$$

$$\frac{P_t}{P_l} = \frac{P_x^{fpp}}{P_y^{fpp}}\sin\chi_\theta + \gamma_p(\mu_p - 1)\Delta\phi$$

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

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





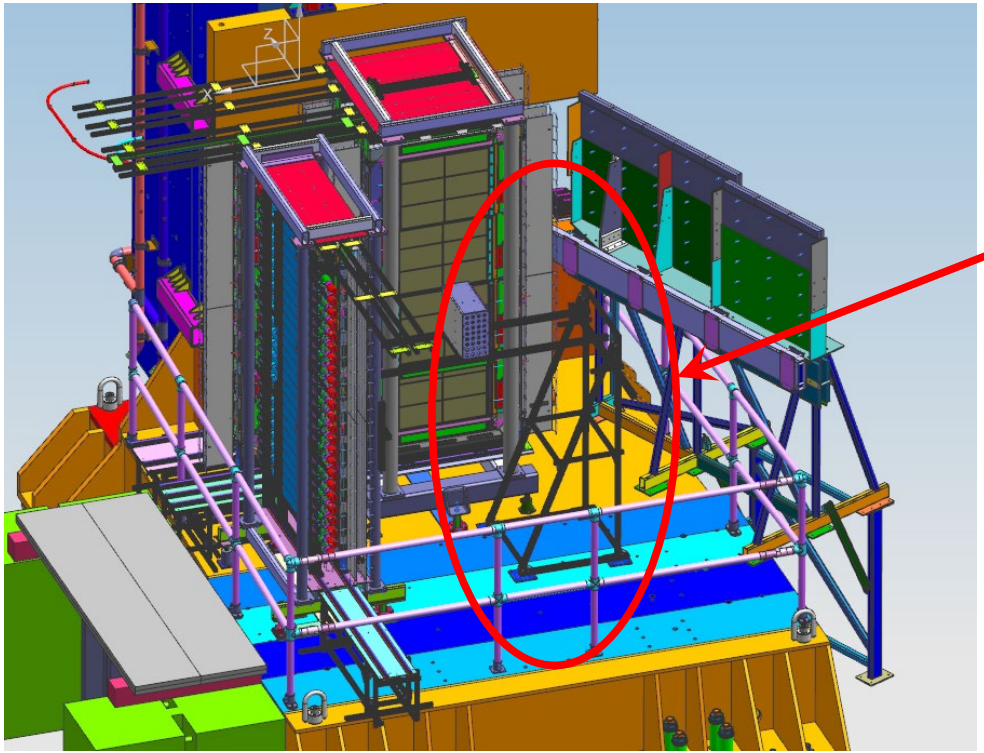
V. Punjabi *et al.* Phys. Rev. C **71**, 055202

From the GEn-RP SBS-collaboration meeting by Jiwan Poudel

E12-17-004 GEn-RP Overview

- E12-17-004 goals:
  - Measure G_{En}/G_{Mn} at $Q^2 = 4.5$ $(GeV/c)^2$ using charge-exchange recoil neutron polarimetry
    - 4.4 GeV/c Energy, P_{beam} ~80%
    - 30μA on 15-cm LD_2
  - Compare FOM for charge-exchange np→ pn scattering and the more standard np→ np
  - Demonstrate the feasibility of detecting low-energy recoil protons from an active analyzer at large angles in an unshielded environment
- Originally proposed to “piggy-back” on the GMn experiment at the 4.5 $(GeV/c)^2$ kinematic
- Finally ran April/May 2024

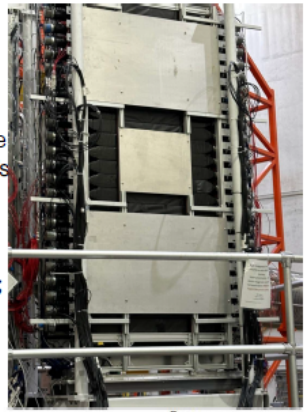
GEn-RP Support Structure Modifications (Final Design)

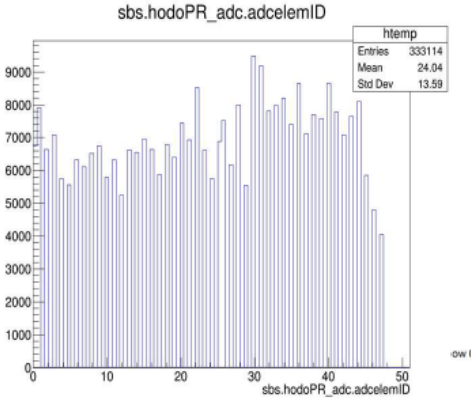


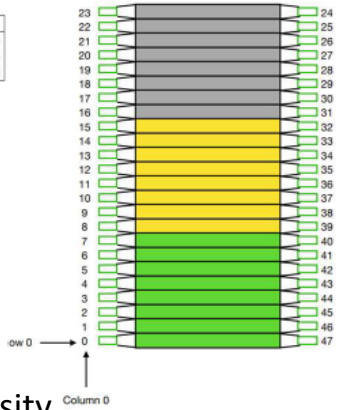
- Beam line side detector array removed
- Support structure for the active analyzer array redesigned
- Lead from beam side dipole cutout removed from design
  - Unseen from this angle

PR Hodoscope

- Two side detectors assemblies are composed of 24 scintillators bars arranged in vertical layer
- (0 – 23) = 24 scintillator bars on left side
- (24 – 47) =24 scintillator bars on right side
- Each scintillator bars are readout by PMTs + base assembly to each ends of every bar
- These bases(96 in total) are powered by individual controlled HV inputs(<-2200V ; -1300V)
- HV supply (3KV max), low current(3mA max)



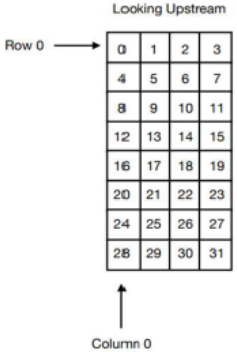




Saru Dhital, Hampton University

Active Analyzer

- Active Analyzer is composed of 32 scintillators array arranged in 4*8 array
- Each scintillator block is optically coupled to a PMTs + base assembly
- "Active Analyzer" bases are powered through individually controlled positive high voltage(<+2000V ; +1000V) and high voltage power supply(3KV max), low current (3mA max)
- The last 5 rows were connected backwards.



0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31