

# GEn-RP at 7 GeV<sup>2</sup>

## SBS Collaboration Meeting

William Tireman

3 March 2026



# Outline

- Motivation for measuring neutron electric form factor  $G_E^n$
- Motivation for using recoil polarimetry and the experimental technique
- Previous GEn-RP experiment (E12-17-004) and lessons learned
- Experimental layout idea and estimated rates
- Challenges to be investigated

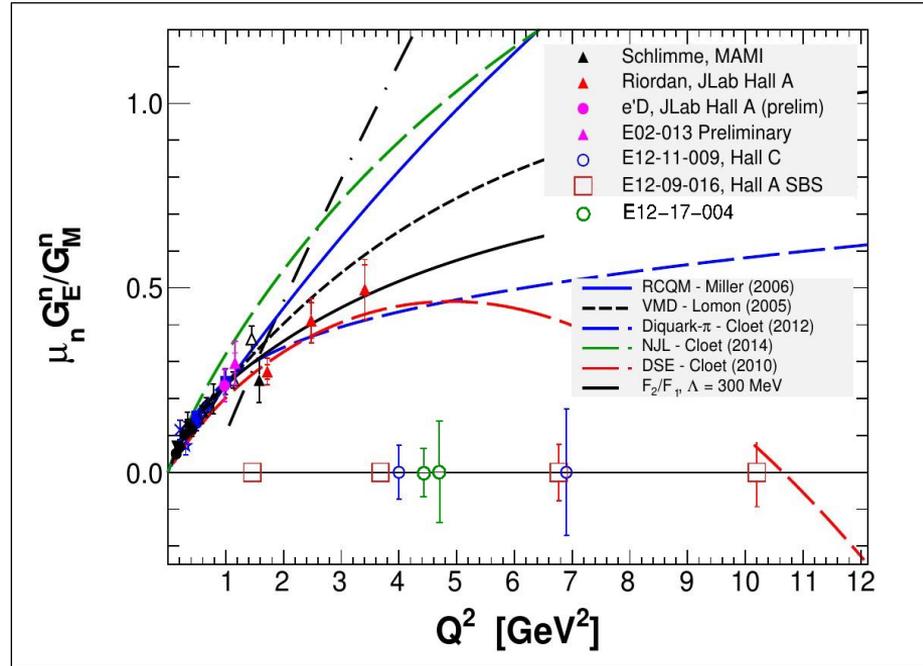


Hall C Polarimeter Hut  
E93-038 (2000)



# GEN-RP at 7 GeV<sup>2</sup>: Physics – Neutron Electric Form Factor

- Understanding the internal structure of nucleons in the high Q<sup>2</sup> regime
- Test for nuclear models and non-perturbative QCD
- Necessary for strange quark measurements
- Extension of flavor decomposition behavior at high Q<sup>2</sup>
- Challenges:
  - No free neutron target
  - nuclear corrections (FSI, MEC, ...)
  - $G_E^n$  is small value
  - Decreasing analyzing power with increased  $p_n$  for elastic np scattering



From Michael Kohl, GEN-RP Status, March 2, 2026

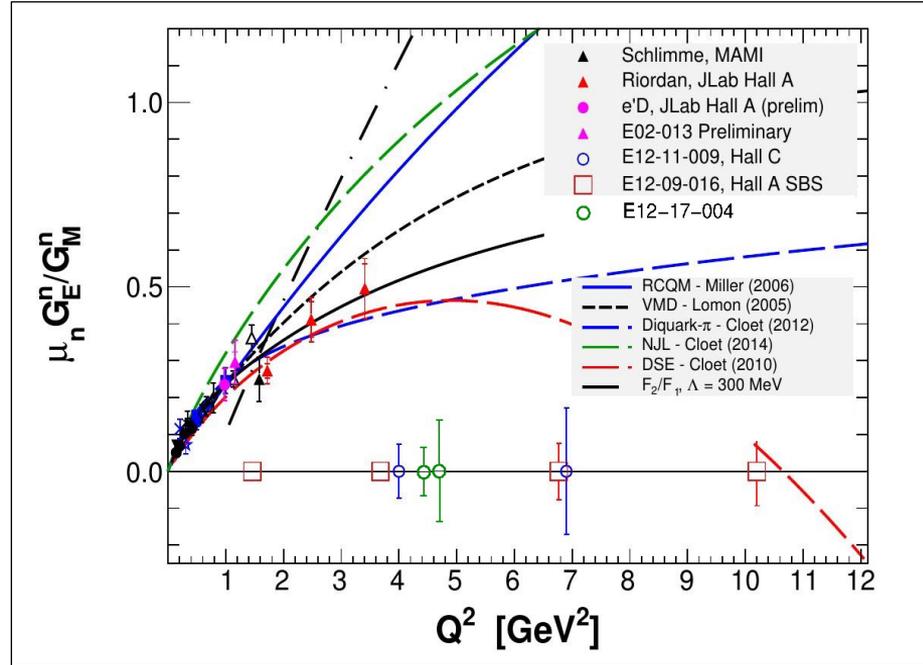
# GEN-RP at 7 $GeV^2$ : Why use recoil polarimetry over He-3?

- Advantages

- Independent measurement of  $G_E^n$
- Access to  $G_E^n$  with different systematics
- No polarized target complications
- Systematic uncertainties typically less than 3%
- Less dependence on nuclear model corrections
- Cleaner suppression/separation of inelastic events

- Disadvantage

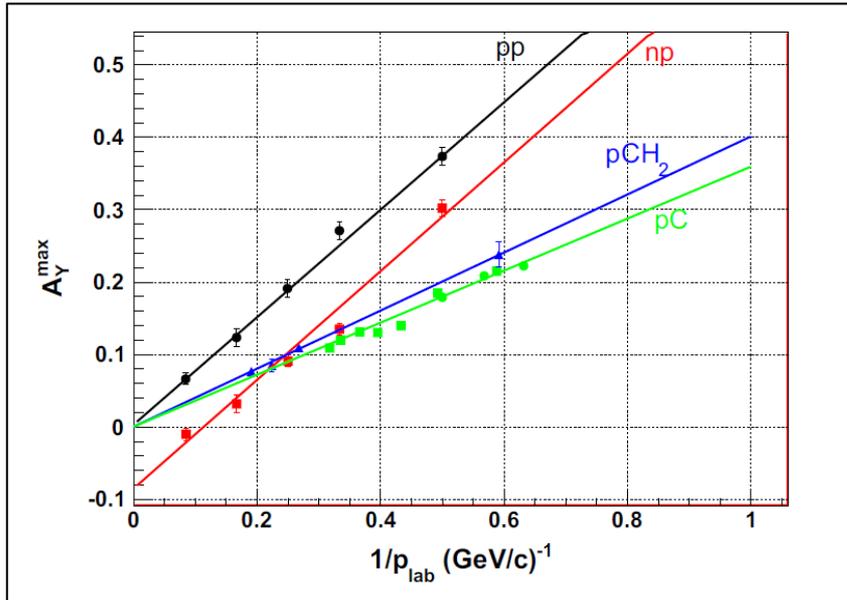
- Lower over all rate due to double scattering
- Event rate is dependent on analyzing power of polarimeter material
- High flux rates from target on forward tracking detectors limits luminosity and efficiency



From Michael Kohl, GEN-RP Status, March 2, 2026



# GEN-RP at 7 $GeV^2$ : Motivation for Charge Exchange Polarimetry



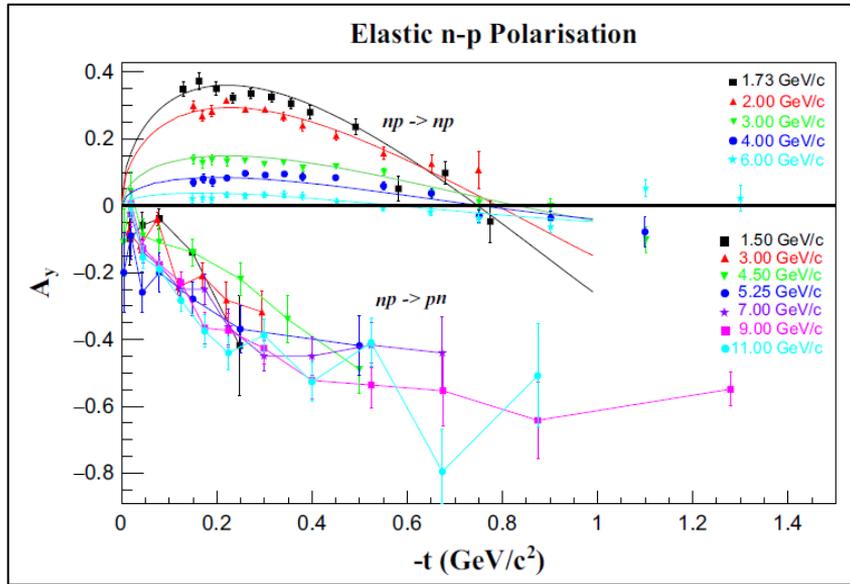
S.N. Basilev et al., Eur. Phys. J. A (2020) 56:26

- Analyzing power for elastic np recoil polarimetry decreases as  $1/p_{lab}$  as can be seen in plot from JINR paper
  - $A_y$  drops to  $\sim 0.1$
- Above 3  $GeV/c$  it is difficult to do np elastic scattering where the neutron is detected
  - Scattered neutron between  $5^\circ - 20^\circ$  [Ladygin 1999] so hard to detect [PR12-12-012]
- Detecting large angle recoil proton from np elastic scattering difficult but possible [E12-11-009, E12-17-004]

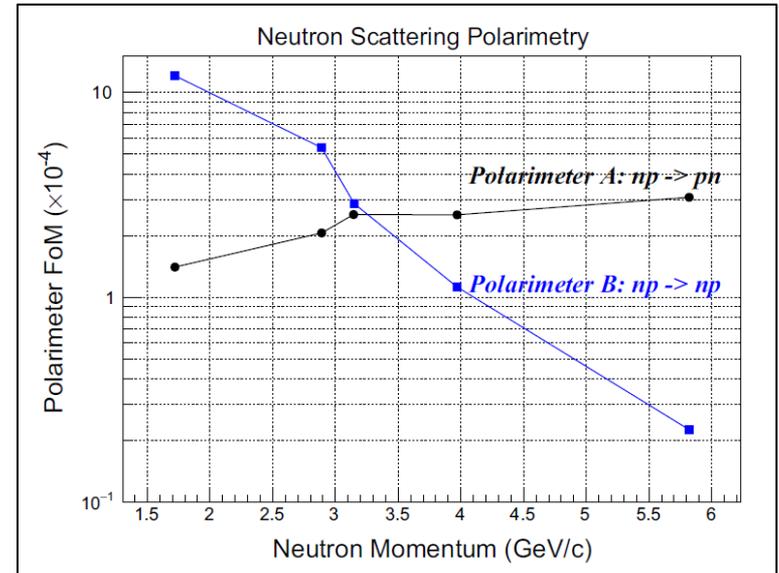


# GEN-RP at 7 GeV<sup>2</sup>: Motivation for Charge Exchange Polarimetry

- JINR results show  $A_y$  nearly constant for n+p → p+n charge exchange but drops fast for n+p → n+p elastic scatt.
- FOM for JINR polarimeter is better above  $\sim 3$  GeV/c for charge exchange than (n,p) elastic scattering



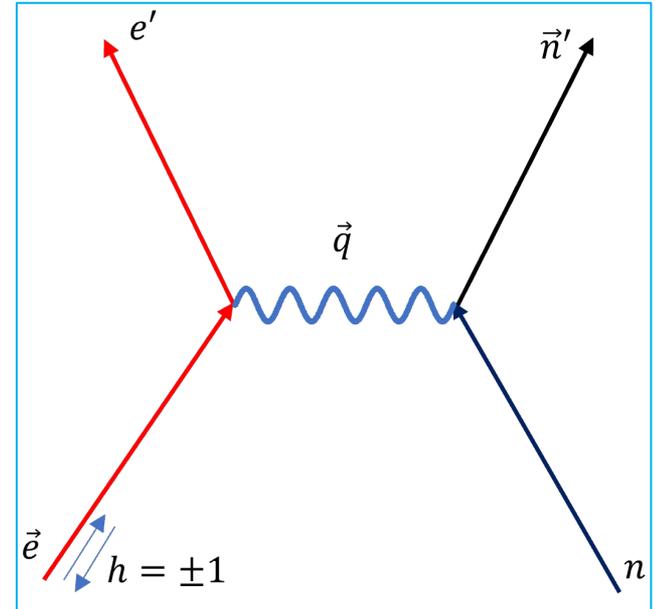
S.N. Basilev et al., Eur. Phys. J. A (2020) 56:26



Polarimeter A is Cu charged exchange  
Polarimeter B is CH scintillator

# GEN-RP at 7 GeV<sup>2</sup>: Polarimetry Technique

- Polarization Transfer:  ${}^2H(\vec{e}, e'\vec{n})p$
- $$P_x = -hP_e \frac{2\sqrt{\tau(1+\tau)} \tan\frac{\theta_e}{2} G_E G_M}{G_E^2 + \tau G_M^2 (1 + 2(1+\tau) \tan^2\frac{\theta_e}{2})}$$
- $P_y = 0$
- $$P_z = hP_e \frac{\sqrt{1+\tau+(1+\tau)^2 \tan^2\frac{\theta_e}{2}} \tan^2\frac{\theta_e}{2} G_M^2}{G_E^2 + \tau G_M^2 (1 + 2(1+\tau) \tan^2\frac{\theta_e}{2})}$$
- $$\frac{P_x}{P_z} = \frac{1}{\sqrt{\tau+\tau(1+\tau)} \tan^2\frac{\theta_e}{2}} \frac{G_E}{G_M}$$
- Form factor ratio is independent of analyzing power ( $A_y$ )



# GEN-RP at 7 GeV<sup>2</sup>: Polarimetry Technique

- SBS magnet precesses the polarizations making the longitudinal component measurable
- Scattering in the analyzer depends on the spin-orbit interaction which yields an asymmetry

$$\frac{P_x}{P_z} = \frac{1}{\sqrt{\tau + \tau(1 + \tau) \tan^2 \frac{\theta_e}{2}}} \cdot \frac{G_E}{G_M}$$

$$F(\theta'_n) = C \{ 1 \pm |P_x^*| \sin \theta'_n \pm |P_y^*| \cos \theta'_n \}$$

$$C = F_{++} + F_{--} + F_{+-} + F_{-+}$$

$$F_x = (F_{++} - F_{-+} + F_{+-} - F_{--}) / C$$

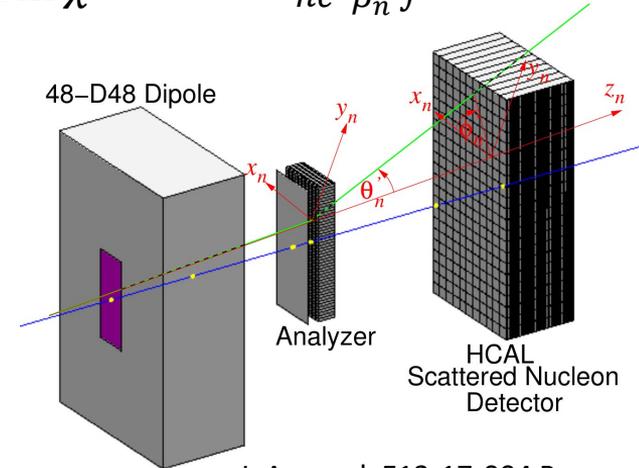
$$F_y = (F_{++} - F_{+-} + F_{-+} - F_{--}) / C$$

- Fit distributions to extract  $P_x^*(\delta P_x^*)$  and  $P_y^*(\delta P_y^*)$

$$P_x^* = A_y^{eff} P_e P_x$$

$$P_y^* = A_y^{eff} P_e P_z \sin \chi$$

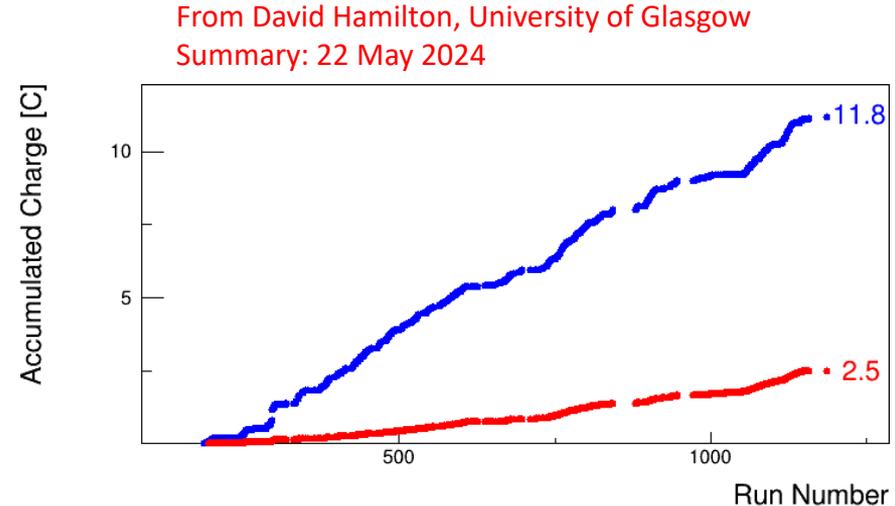
$$\chi = \frac{2\mu_n}{\hbar c} \frac{1}{\beta_n} \int B \cdot dl$$



J. Annand, E12-17-004 Proposal

# GEN-RP at 7 $GeV^2$ : Summary of 2024 GEN-RP at 4.4 $GeV^2$

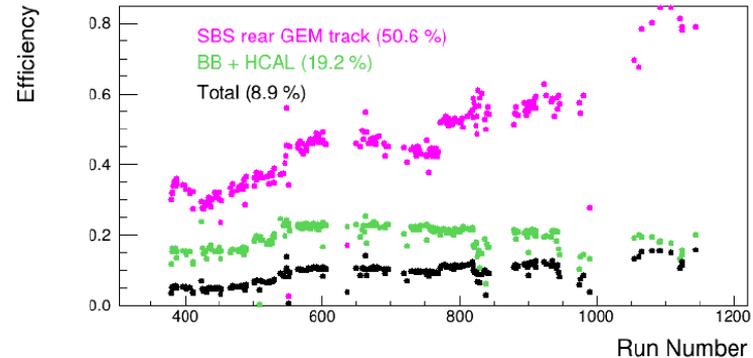
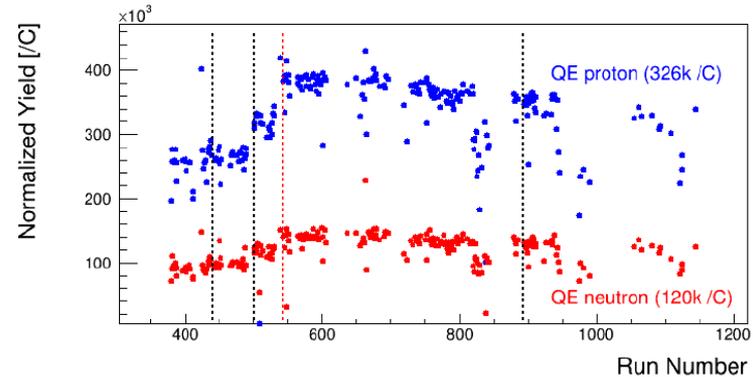
- GEN-RP experiment ran from April 17 to May 14, 2024
  - Beam current 10-12  $\mu A$  on 15 cm LD<sub>2</sub> (proposal: 10 cm at 40  $\mu A$ )
  - Beam energy 4.3 GeV
  - Beam polarization: 82%
  - BB and SBS magnets: 100%
  - BB at 42.5° and SBS at 24.7°
  - HCAL at 9 m
  - Trigger rate: 3-4 kHz
  - Total accumulated charge on LD<sub>2</sub>: 11.8 C



# GEN-RP at 7 GeV<sup>2</sup>: Lessons Learned from GEN-RP at 4.4 GeV<sup>2</sup>

- Raw normalized data yields from BB+HCAL (not live time corrected)
  - black lines are trigger threshold changes
  - red line is a change to FADC pedestals (active analyzer)
  - Geant simulations predict yields of 1.9M (proton) and 0.7M (neutron) /C.
- Raw efficiencies extracted from the data
  - BB+HCAL efficiency dominated by BB GEM reconstruction efficiency, where there is scope for improvement.
  - SBS rear GEM tracking efficiency increased steadily from 30 – 80%.
  - Overall efficiency is the product of the two was around 10%; we had assumed 50%.
- **Take-aways:**
  - **BB + HCAL efficiency needs improvement**
  - **GEM tracking efficiency needs to be improved**
  - **Photon flux on front GEMs resulted in high occupancy**

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



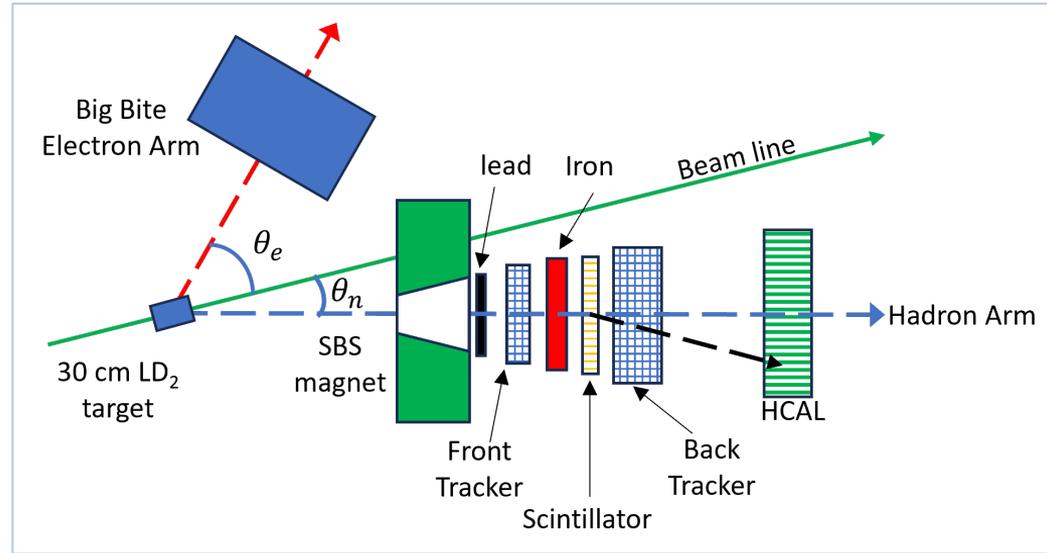
# GEn-RP at 7 $GeV^2$ : Interpolating from E12-17-004 Proposal(1)

- No new simulations (yet) so used numbers from 2017 GEn-RP Proposal for 4.5, 6.0, and 9.3  $GeV^2$  (tables 6 & 7) (J. Annand et al., E12-17-004)
  - Target: 10 cm  $LD_2$  Beam: Polarized 40  $\mu A$  Luminosity:  $1.25 \times 10^{38} cm^{-2} s^{-1}$
  - Interpolating to 7  $GeV^2$ 
    - $n(e, e'n)$  rate: 22.3 Hz
    - Beam time: 266 hours to achieve  $\delta R \sim 0.13$  (stat)
- This would still leave us with the same issues experienced in 2024 ... **new ideas needed**



# GEN-RP at 7 GeV<sup>2</sup>: Experimental Layout Concept

- GEM front tracker for veto of protons from target and charge exchange protons in lead
- Passive iron analyzer
- Scintillator layer for forward position of charge exchange proton
- GEM back tracker for tracking charge exchange proton
- HCal for hadron energy and rear position
- Additional shielding on the beamline side (not shown)
- Scintillator plane and HCAL will define a search area for the GEM back tracker
- Lead curtain to reduce photon flux



- 30-cm LD<sub>2</sub>, 50  $\mu$ A,  $E_e = 6.6$  GeV  $\theta_e \sim 35^\circ$   $Q^2 \sim 7(\text{GeV}/c)^2$
- $p_n \sim 4.5$  GeV/c  $\theta_n \sim 22^\circ$  Luminosity:  $\sim 4.6 \times 10^{38} \text{ cm}^{-2} \text{ s}^{-1}$
- **3.75x more luminosity than in 2017 proposal so how do we deal with the rates?**

# GEn-RP at $7 \text{ GeV}^2$ : Concerns to be investigated

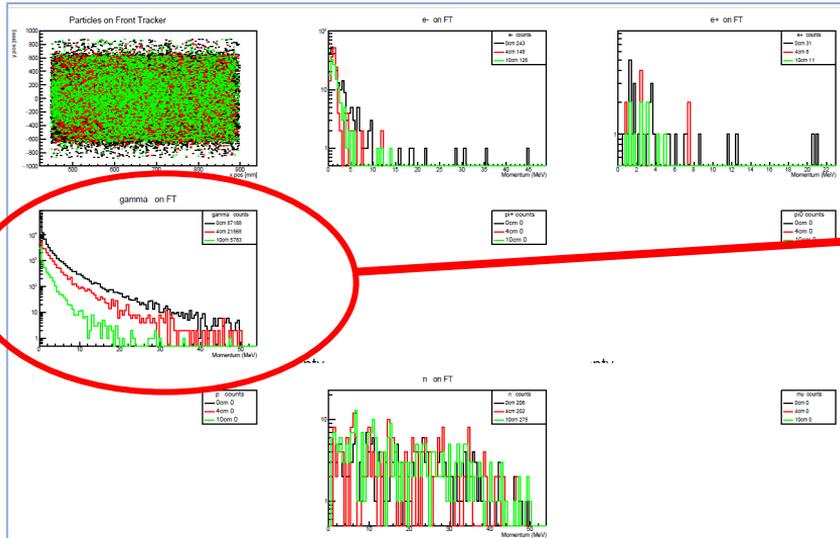
- 1) GEM occupancy and track reconstruction
- 2) Pb(p,n) charge exchange in the lead
- 3) Neutron deflection in lead resulting in a boarder proton peak at HCAL
- 4) Scintillator background rates
- 5) HCAL efficiency and resolution

I will address 1, 2, and 3 in this talk

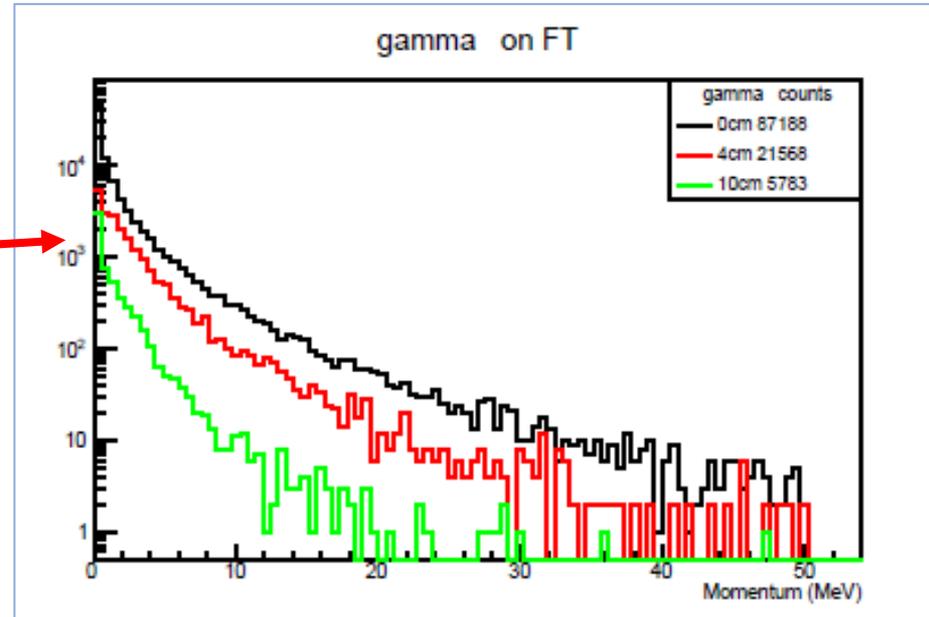


# GEN-RP at 7 $GeV^2$ : Lead impacts on photon flux

- The use of a 4-cm lead curtain will decrease photon flux by factor of 4
- Neutron flux will be cut by  $\sim 50\%$
- However, (1) Pb(n,p) charge exchange and (2) neutron elastic scattering in the lead



Geant3 Particle simulation on GEMs provided by Evaristo



# GEN-RP at 7 $GeV^2$ : Lead curtain impacts on neutron flux(1)

- Lead curtain was used in 2000-01 Hall C  $G_E^n$  experiment E93-038 (Plaster et al., PRC **73**, 025205 (2006))
  - E93-038 ran magnet initially with  $0^\circ, \pm 90^\circ$  spin precession configuration to form cross ratio
  - Found high rates in front scintillators at  $0^\circ$  but much better at  $\pm 90^\circ$  (obviously)
  - Switched to  $\pm 40^\circ$  spin precession for remainder of run to sweep protons out of polarimeter acceptance (polarimeter was shielded on all sides with concrete/steel)
- For  $Pb(p, n)$  charge exchange in lead, E93-038 found ...
  - Most protons swept into collimator wall with a small number getting through
  - At  $\pm 40^\circ$  precession correction was 0.1% or less. At 1.47  $GeV^2$  and  $0^\circ, \pm 90^\circ$  found to be 0.2%
- Neutron scattering and subsequent depolarization in the lead curtain (dilution)
  - Simulated using spin transport model (GENGEN) built “in house”
  - Correction to the  $G_n^E / G_n^M$  ratio was 0.6% at 1.47  $GeV^2$  with spin precession of  $0^\circ, \pm 90^\circ$ , 0.1% at 1.132  $GeV^2$  with  $\pm 40^\circ$  spin precession, and  $<0.1\%$  at all other points
- This will need to be check for this setup and kinematics with a detailed simulation as these experiments are not 1-to-1 comparisons. Does give us some positive direction.



## GEn-RP at $7 \text{ GeV}^2$ : Lead curtain impacts on neutron flux(2)

- Elastic scattering in the lead broadens the charge exchange proton spectrum
  - A naïve estimate yields a  $\sim 3^\circ$  angular spread
  - Since this experiment is highly dependent on angular resolution it might be too much without improvement in equipment
- Work on the  $4.4 \text{ GeV}^2$  data analysis will be looking into spin transport through magnet and materials. This will be used in sorting out if a lead curtain will be useful for future.



## GEN-RP at 7 $GeV^2$ : Interpolating from E12-17-004 Proposal(2)

- No new simulations (yet) so used numbers from 2017 GEN-RP Proposal for 4.5, 6.0, and 9.3  $GeV^2$  (tables 6 & 7) (J. Annand et al., E12-17-004)
  - Target: 10 cm  $LD_2$  Beam: Polarized 40  $\mu A$  Luminosity:  $1.25 \times 10^{38} cm^{-2} s^{-1}$
  - Interpolating to 7  $GeV^2$ 
    - $n(e, e'n)$  rate: 22.3 Hz
    - Beam time: 266 hours to achieve  $\delta R \sim 0.13$  (stat)
- Suggestion is to increased target length, beam current, and use a 4-cm lead curtain to decrease photon flux
  - Target: 30 cm  $LD_2$  Beam: Polarized 50  $\mu A$  Luminosity:  $\sim 4.6 \times 10^{38} cm^{-2} s^{-1}$
  - Increases rate by  $\sim 3.5x$
  - Lead curtain will cut neutron flux by  $\sim 50\%$
  - Beam time would need to be  $\sim 150$  hours to achieve  $\delta R \sim 0.13$  (stat)
  - FOM  $\sim 2 - 3 \times 10^{-4}$



## GEn-RP at 7 $GeV^2$ : Other ideas

- Use of a different front proton veto layer
- Improvements to GEM tracking efficiency
- Longer run time



## GEN-RP at 7 $GeV^2$ : Summary

- Ground work for extending GEN-RP to 7  $GeV^2$  is underway
- Working toward a letter of intent for PAC54 and full proposal for PAC55
- A lot of simulation work needs to be done to test ideas
- Thanks to Bogdan for discussions and ideas for this experiment idea and talk

Welcoming everyone that is interested in pushing forward with GEN-RP at 7  $GeV^2$

Collaborators whom have already raised their hands to be onboard

Michael Kohl (Hampton)

Anuruddha Rathnayake (UConn)

David Hamilton (Glasgow)

Eric Fuchey (W&M)

Bogdan Wojtsekhowski (Jlab)

Todd Averett (W&M)

Andrew Puckett (UConn)

William Tireman (NMU)

