Status and Future GEn-RP

Michael Kohl <kohlm@jlab.org> *
for the SBS Collaboration

GEn-RP Spokespeople: D. Hamilton, M.K., A. Puckett, W. Tireman, B. Wojtsekhowski, J. Annand, E. Bellini** and N. Piskunov****

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** Retired

Thank you for input from

- **Graduate students**
  Andrew Cheyne, Bhasitha Dharmasena, Sarashowati Dhital

- **For the latest previous review of GEn-RP (E12-17-004) see**
  Bhasita Dharmasena, Hall A Collaboration Meeting, Jan 21-22, 2026
  https://indico.jlab.org/event/994/contributions/17905/attachments/13619/21985/Hall-A%20Winter%20Meeting%202026.pdf

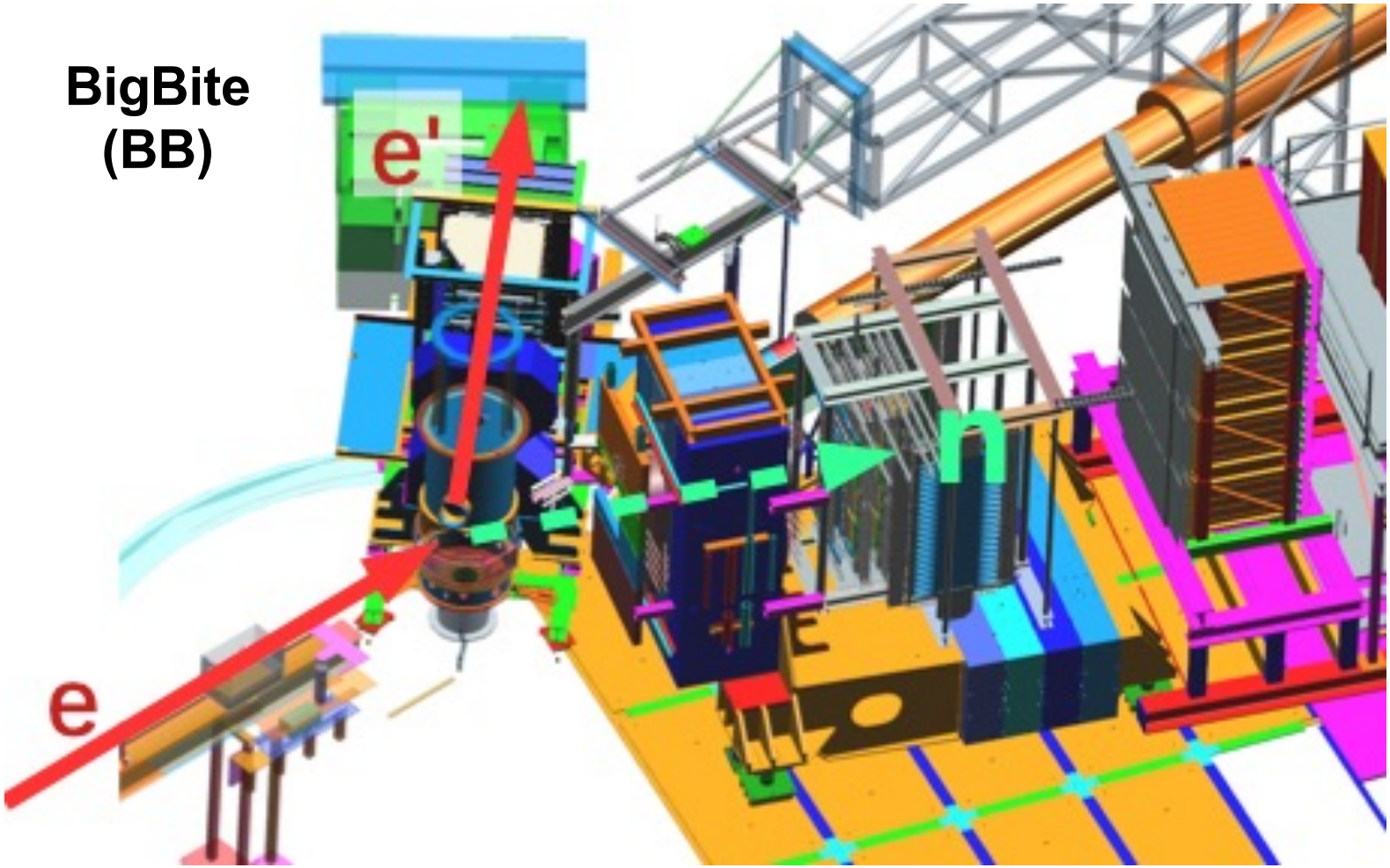
GEn-RP: Neutron recoil polarization exp.

E12-17-004: Measurement of G_{En}/G_{Mn} at $Q^2 = 4.5$ (GeV/c)^2

Unpolarized deuterium target: D(e,e'n) polarization transfer; neutron polarimetry

Completed data taking in May 2024, under analysis

BigBite (BB)



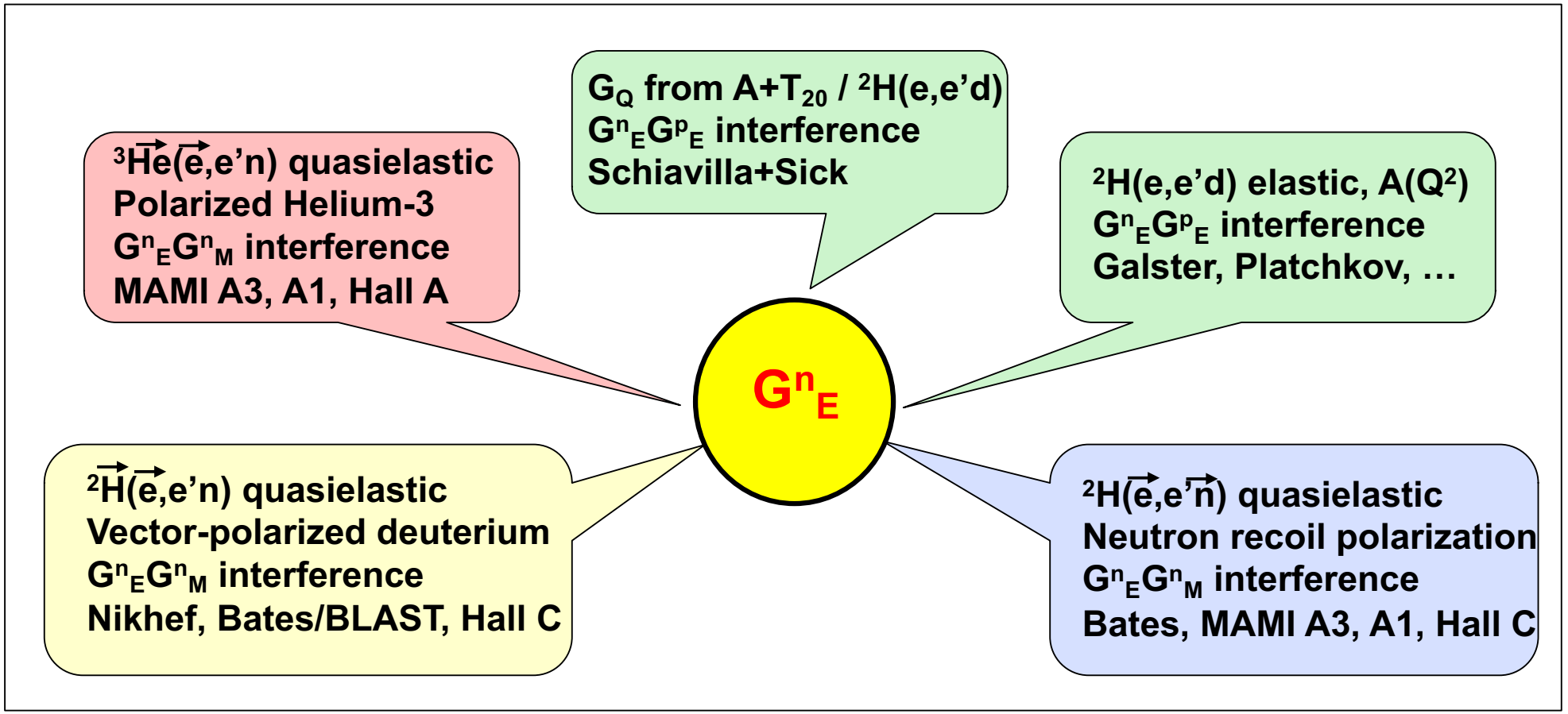
Super-BigBite (SBS)

G_{En} in absence of a free neutron target

No free neutron target → elastic and quasi-elastic scattering

Nuclear corrections (FSI, MEC, …)

Smallness of G^n_E has not allowed L-T sep. of d(e,e'n) or d(e,e')–d(e,e'p)



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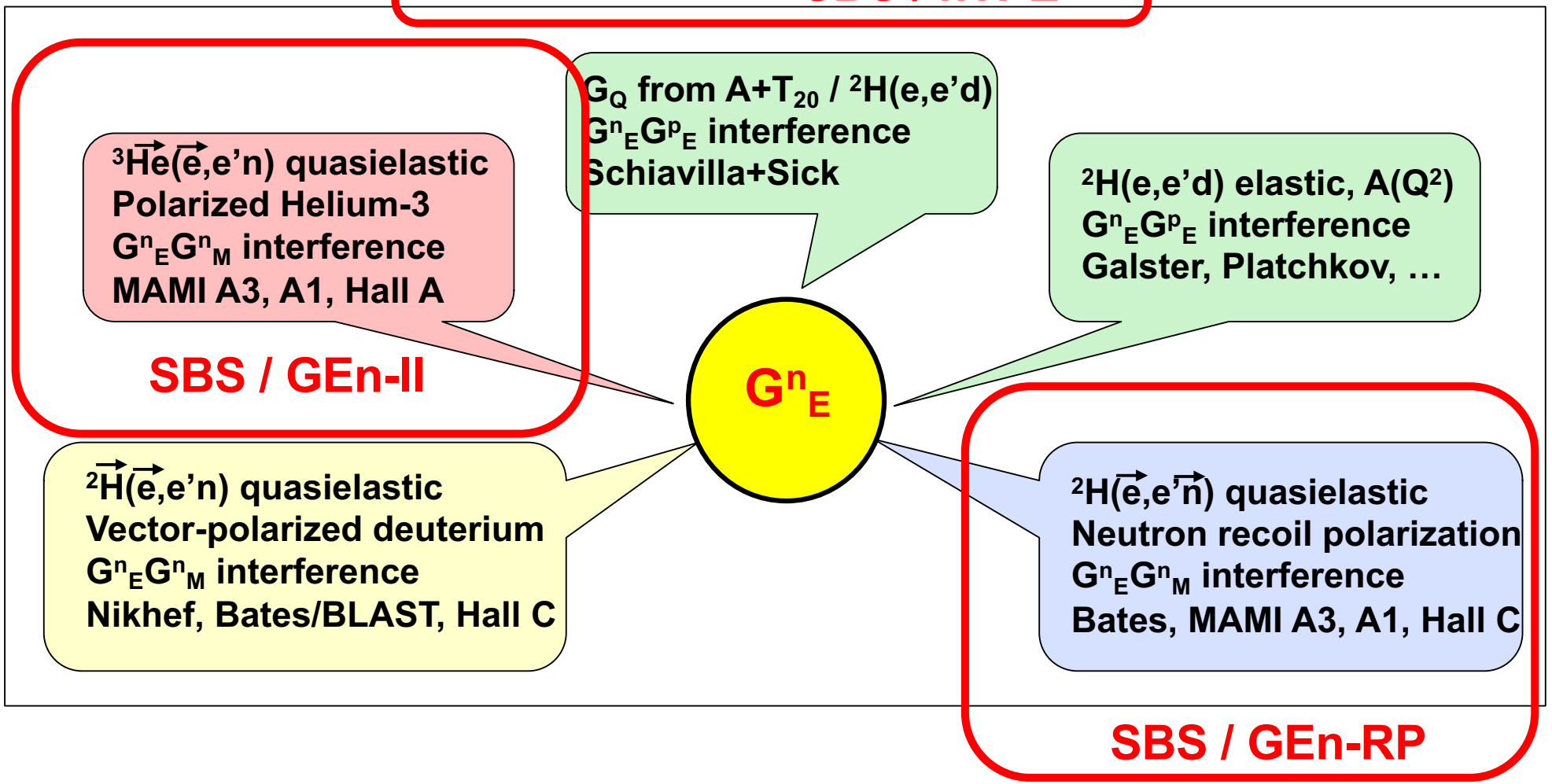
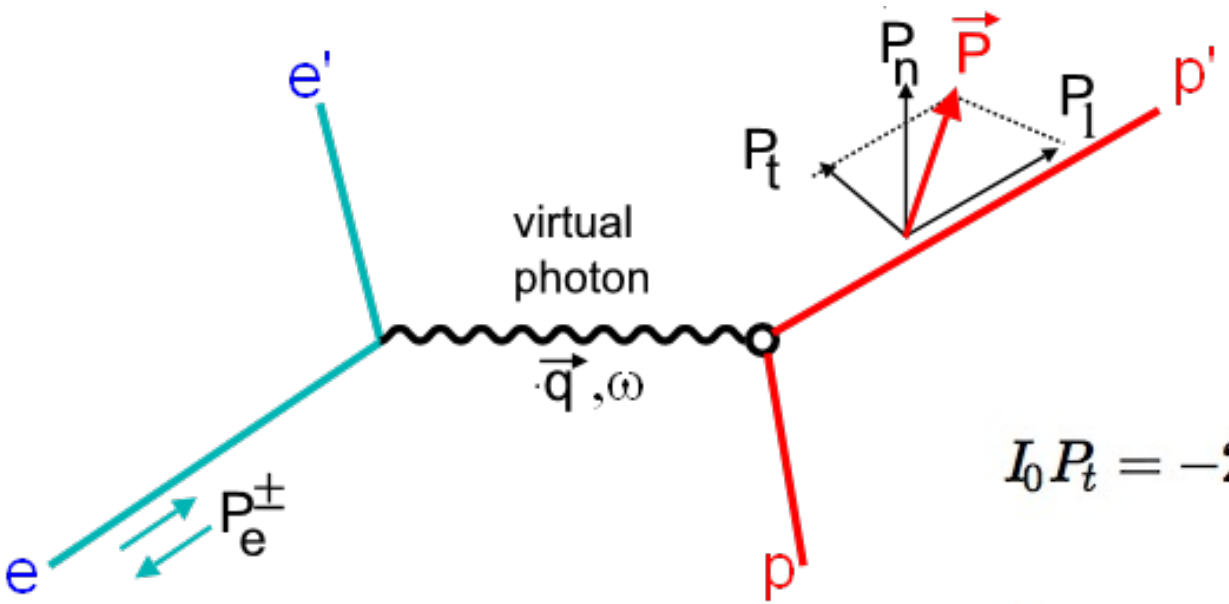
SBS / nTPE



Recoil polarization technique for G_E/G_M



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

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

$$I_0 P_\ell = \frac{1}{M}\left(E_e + E'_e\right)\sqrt{\tau(1+\tau)}G_M^2 \tan^2\frac{\theta_e}{2}$$

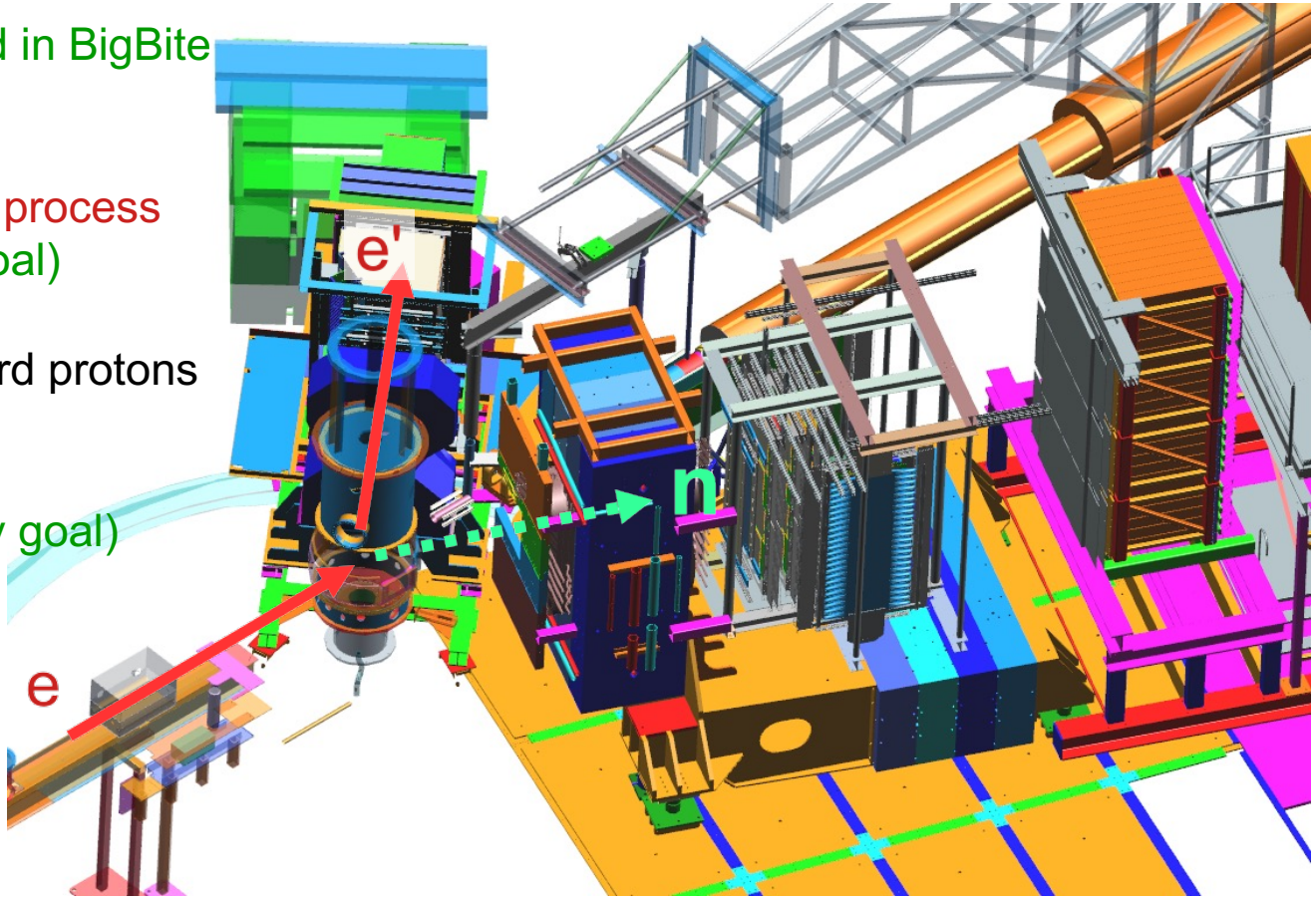
$$\frac{G_E}{G_M} = -\frac{P_t}{P_\ell}\frac{(E_e + E'_e)}{2M_p}\tan\left(\frac{\theta_e}{2}\right)$$

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

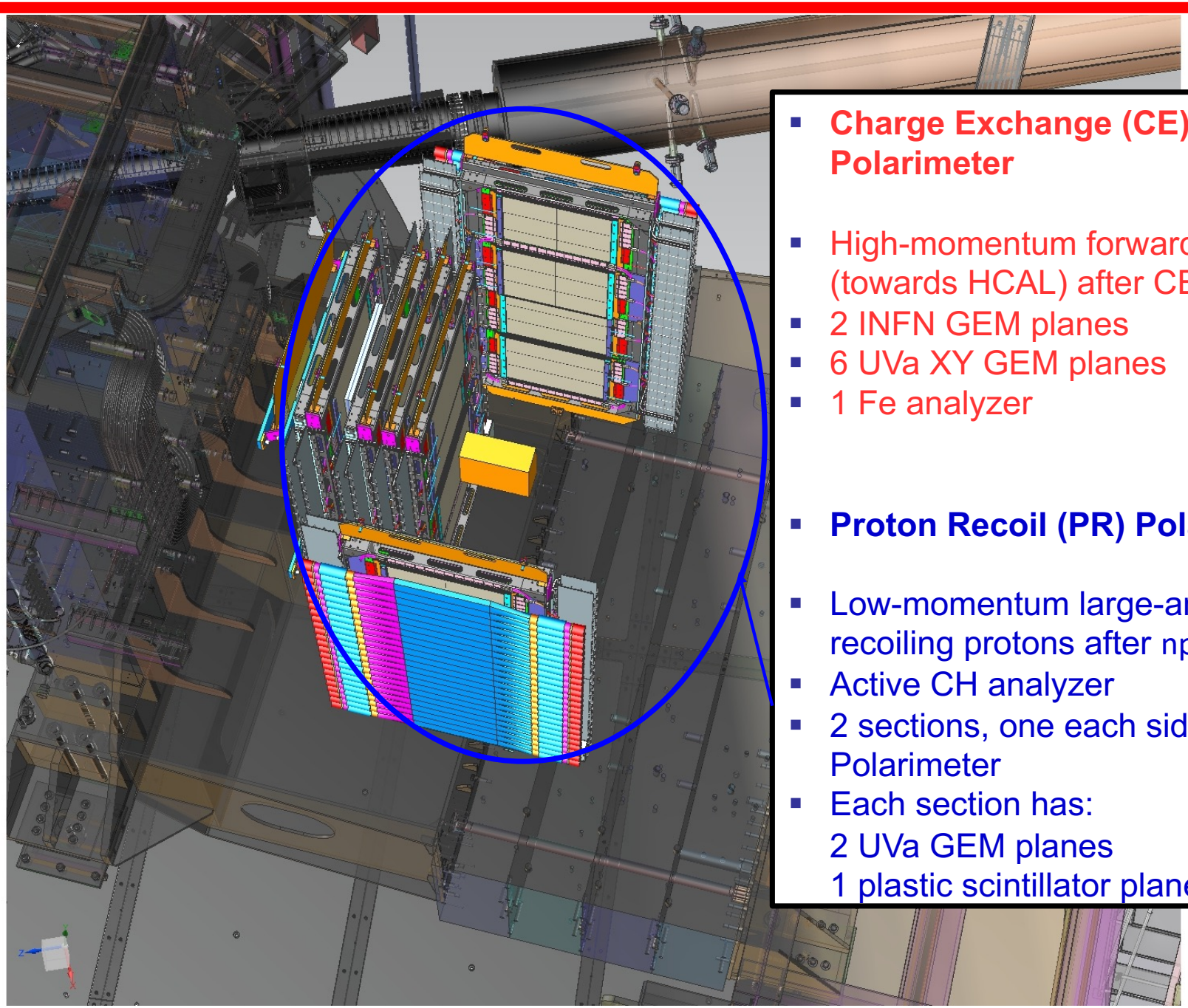
- **E12-17-004 (GEn-RP): Quasielastic $^2H(\vec{e},e'\vec{n})p$**
- **Dipole field for spin precession of P_l and P_n (P_t ~unaffected)**
- **Applicable to protons and neutrons**

Experimental technique of GEn-RP (SBS)

- E12-17-004 will measure GEn/GMn using two recoil pol. techniques at Q^2 = ~4.4 $(GeV/c)^2$
- "GMn" beam, beamline, target, BB
  Beam: ~4.3 GeV, ~30 μA, P_b = ~80%
  Target: 15 cm LD_2 (unpolarized)
  6% Cu radiator (KLL)
- Scattered electron measured in BigBite
  (π^- in case of KLL)
- Charge-exchange analyzing process
  np → pn channel (primary goal)
  Steel analyzer (passive)
  GEM tracking + HCAL forward protons
- Elastic analyzing process
  np → np channel (secondary goal)
  Plastic analyzer (active)
  Large-angle recoil protons
  → Side detectors
  (GEM + hodoscope)
  Forward neutron
  → HCAL
- Detector components also used in:
  Wide-angle Charged Photoproduction (KLL)
  SBS Inline GEM stack + Steel analyzer



SBS Neutron Polarimeter (orig. proposed)



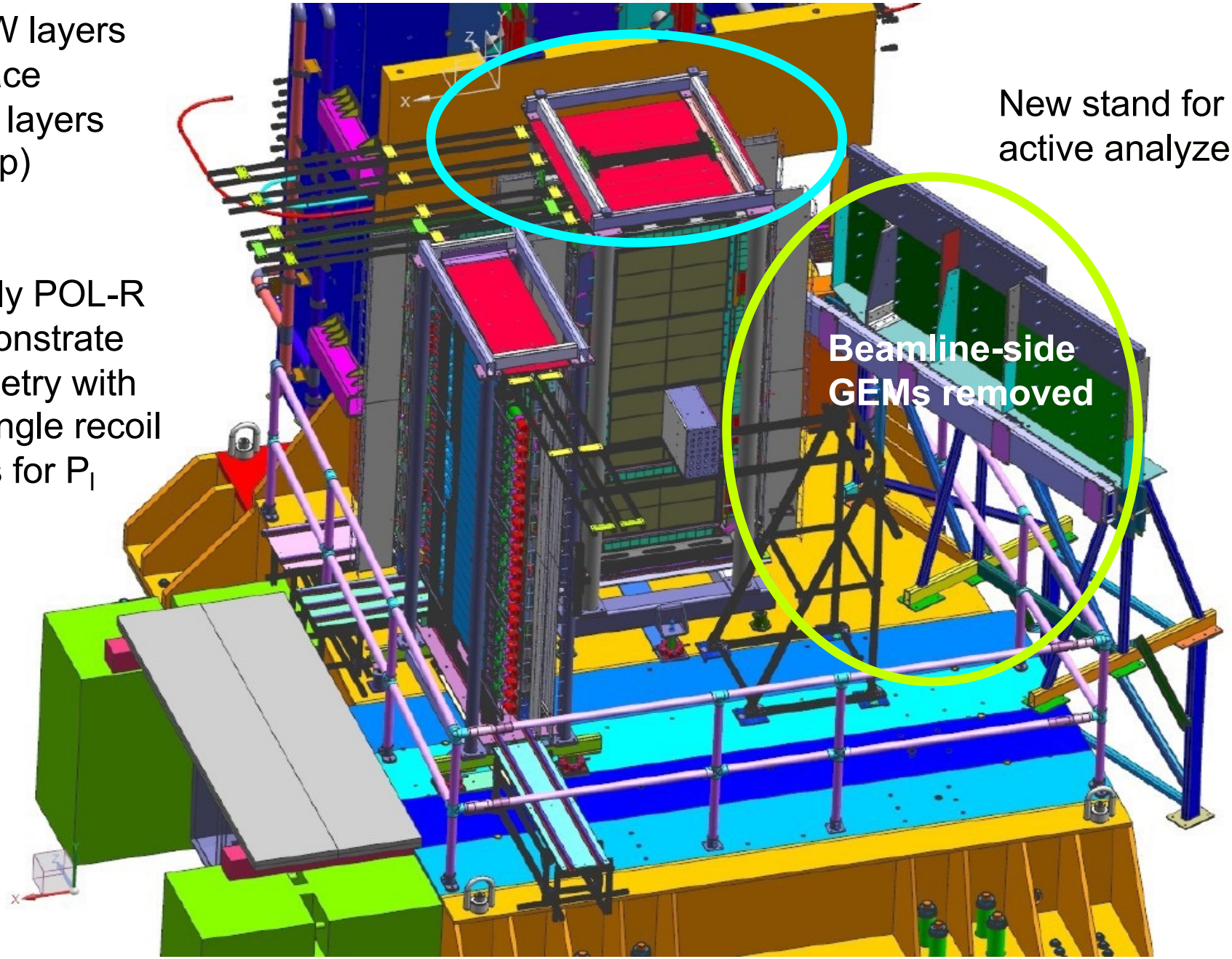
- **Charge Exchange (CE) Polarimeter**
- High-momentum forward protons (towards HCAL) after CE np → pn
- 2 INFN GEM planes
- 6 UVa XY GEM planes
- 1 Fe analyzer

- **Proton Recoil (PR) Polarimeter**
- Low-momentum large-angle recoiling protons after np → np
- Active CH analyzer
- 2 sections, one each side of CE Polarimeter
- Each section has:
  2 UVa GEM planes
  1 plastic scintillator plane

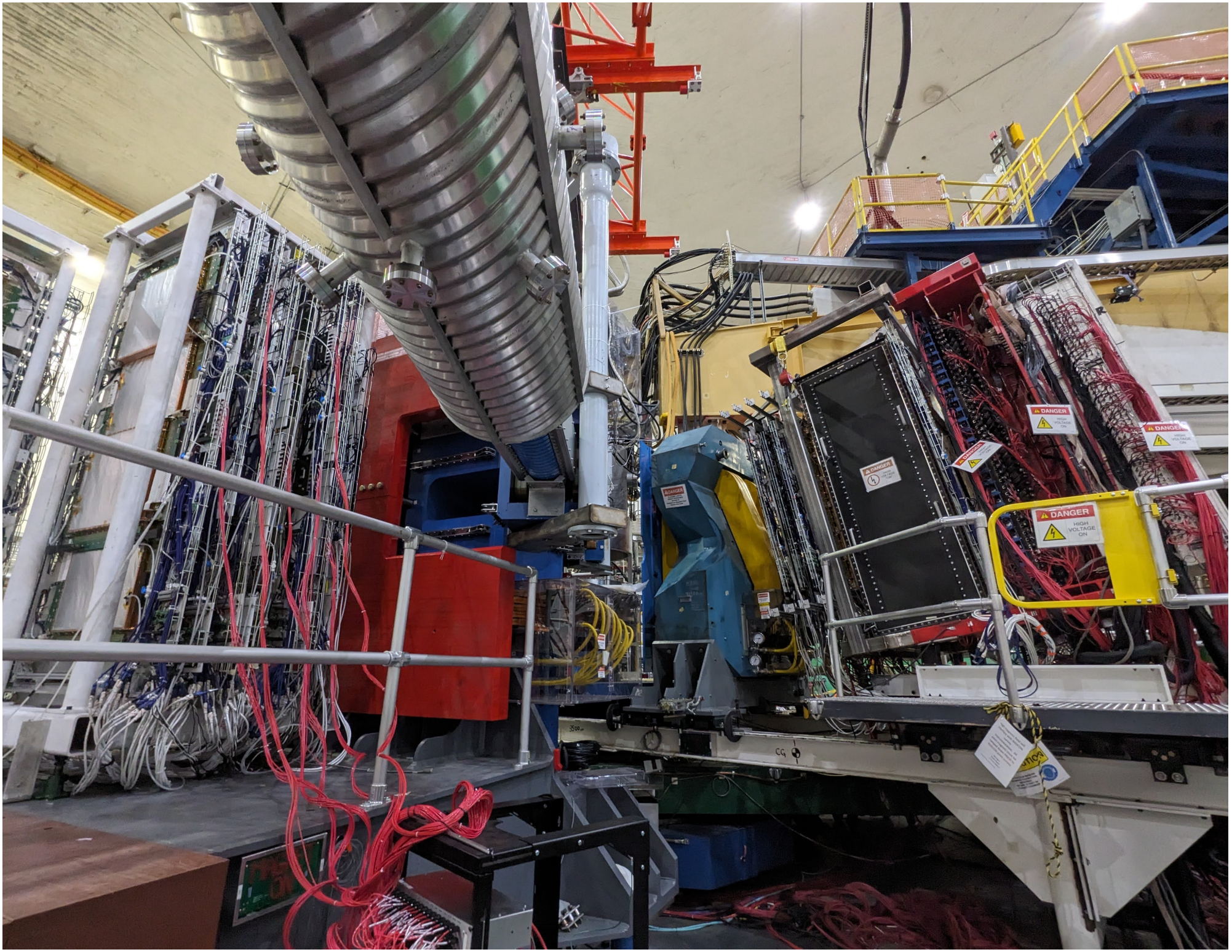
Descoping of beamline-side RP arm

UVa XW layers
to replace
2 INFN layers
(for GEp)

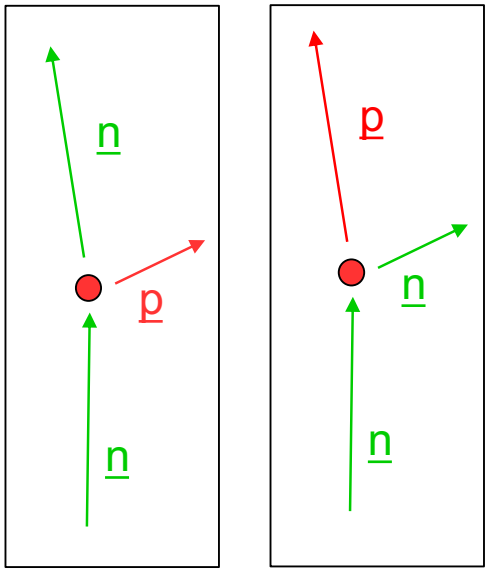
Use only POL-R
to demonstrate
polarimetry with
large-angle recoil
protons for P_l



New stand for
active analyzer


DANGER
HIGH VOLTAGE ON

Analyzing power for elastic n-p scattering



- A_y for n-p (or p-n) falling rapidly with increasing neutron momentum
- A_y for charge-exchange n-p large at sufficiently large t (θ_p ~ few deg.)
- No apparent strong incident momentum dependence for charge-exchange A_y
- $\sigma_{np\to np}$ factor ~10 higher than $\sigma_{np\to pn}$

Diebold et al., PRL 35,(1975),632
Fits: Ladygin JINR E13-99-123 (1999)

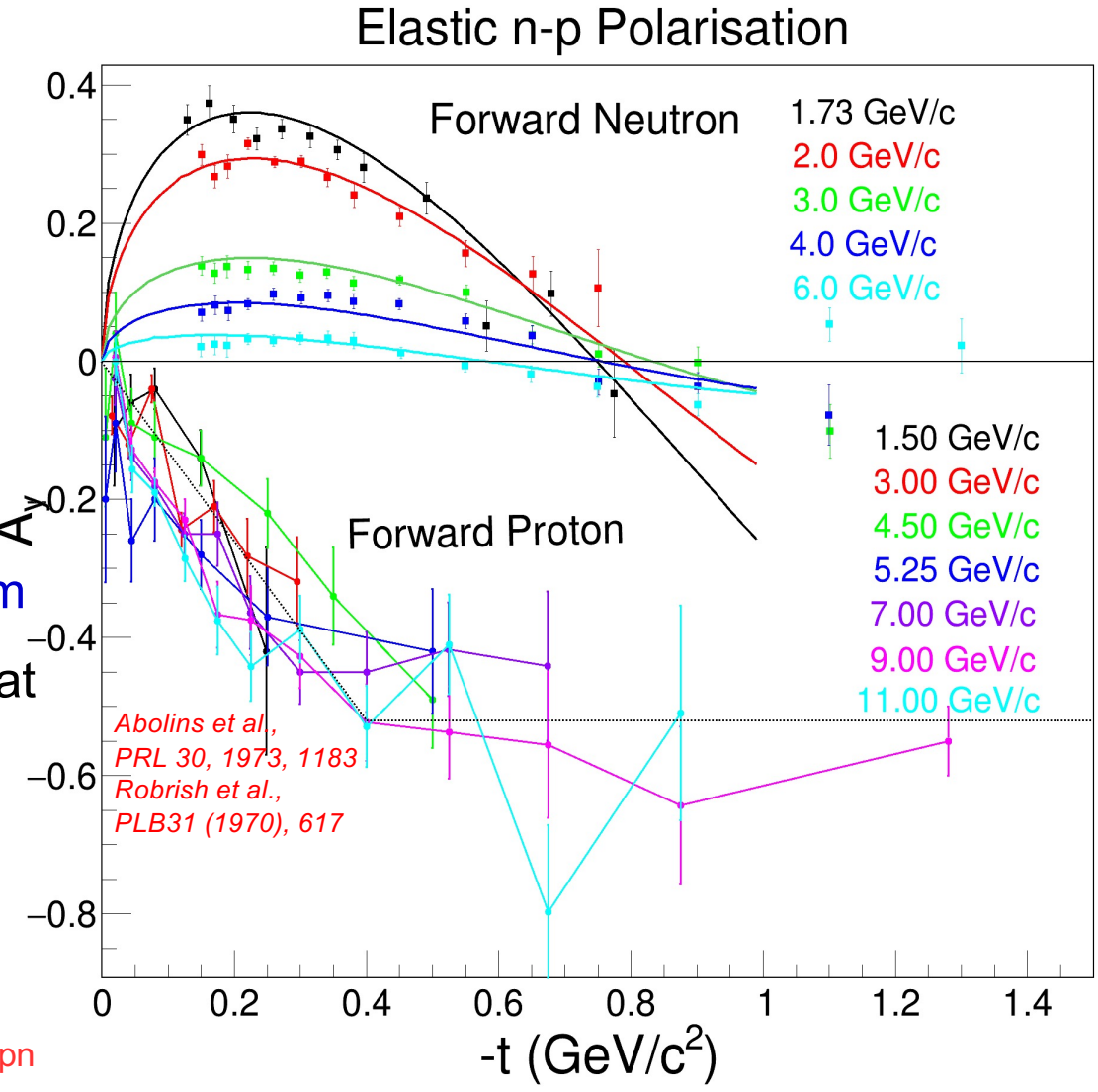
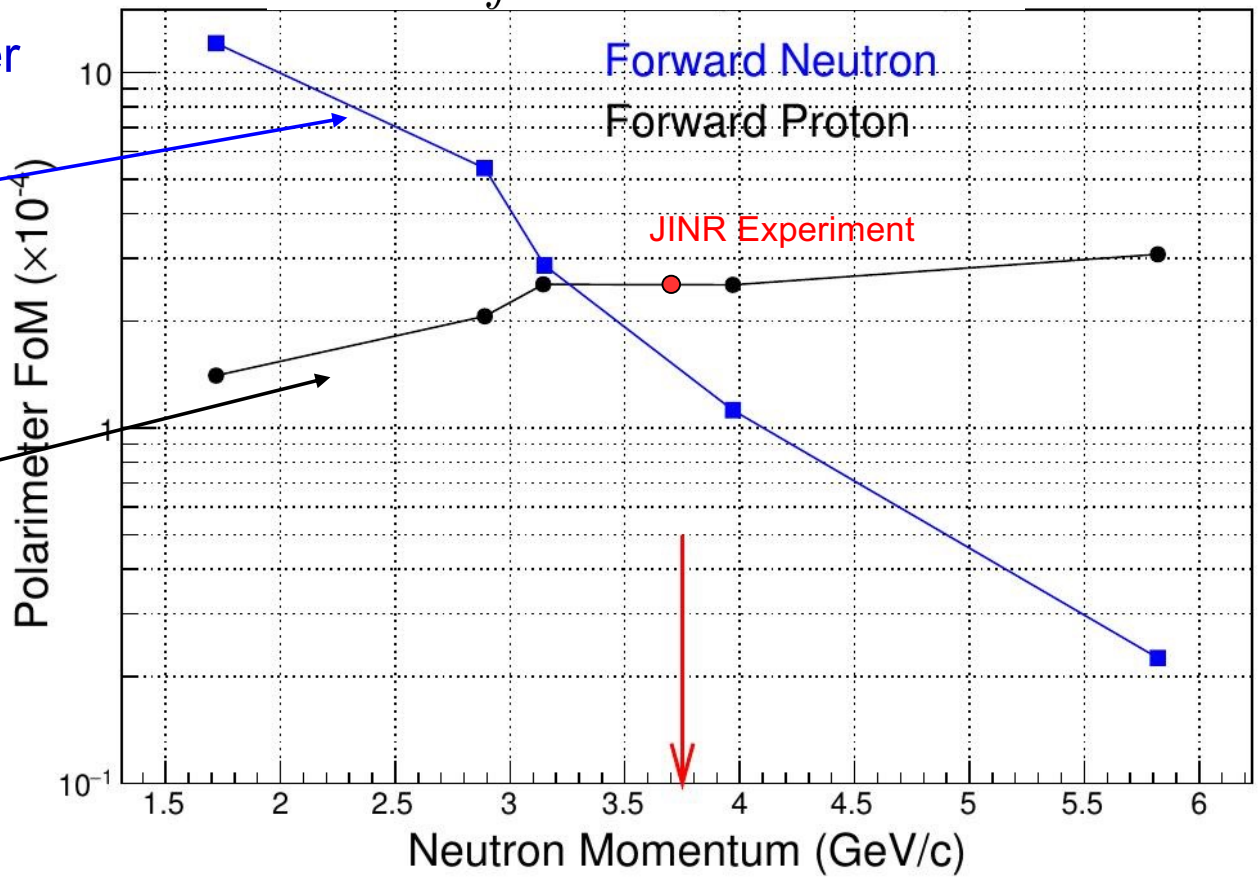


Figure of merit: elastic vs. charge exchange

$$\mathcal{F}^2(p_n) = \int \varepsilon(p_n, \theta'_n)\, A_y^2(p_n, \theta'_n) d\theta'_n$$

- Plastic scintillator analyzer
- np→np (forward neutron)



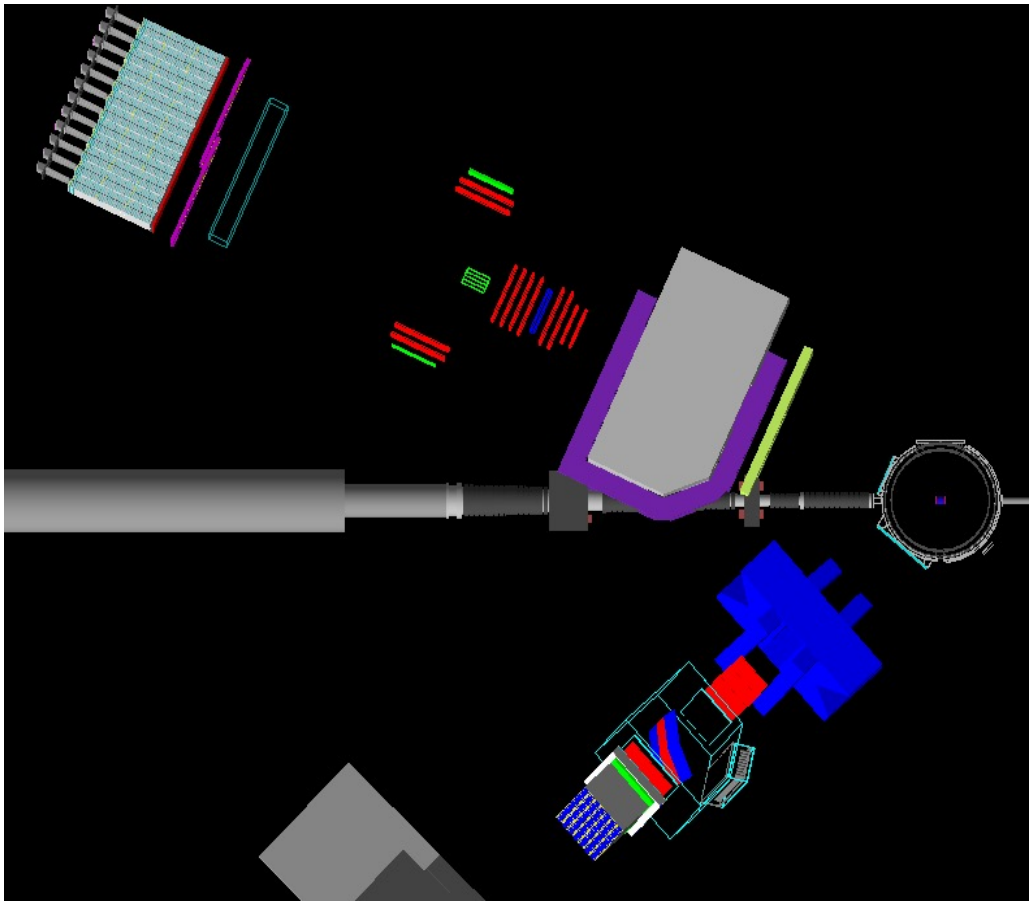
- Fe analyzer
- np→pn (forward proton)

- A_y for np→pn on Cu: new 2016-17 measurement from JINR

S.N. Basillev et al.
EPJ A 56, 26 (2020)

- Calculate efficiency of polarimeter as function of θ_n by Monte Carlo
- A_y for free np→np: JINR fit to p_n and θ_n dependence, scale A_y by 0.5 for ^{12}C scattering (agrees with JINR 2016-17 data)

Geant4 Monte Carlo simulation



g4sbs framework: A. Puckett (U. Connecticut)

FOM study: D. Hamilton (U. of Glasgow)

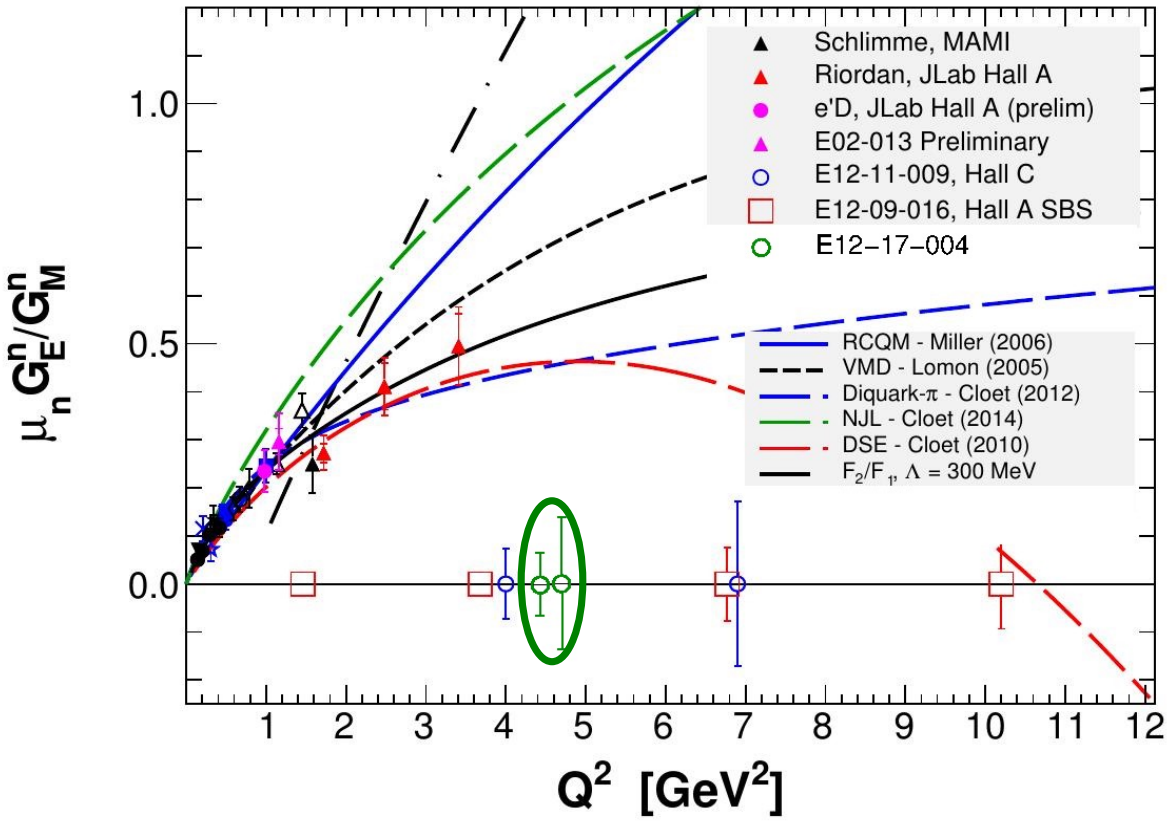
Rate studies: W. Tireman (Northern Michigan)

- Realistic description of polarimeter components in g4sbs
- Included spin-dependent hadronic processes and precession
- Full quasi-elastic pseudo-data set simulated for expected luminosity
- Two-arm data analysis performed for both CE and PR polarimeter with realistic detector efficiencies and resolutions
- Analyzing power parametrizations based on Ladygin (x0.5) for PR and Dubna results for CE
- Extracted effective analyzing power (due to depolarization), overall efficiency, FOM and statistical uncertainty on polarization components and form factor ratio

Projected form factor ratio uncertainty

$$\delta P = \sqrt{\frac{2}{N_{inc}\mathcal{F}^2}} \qquad R = \mu_n G_E^n / G_M^n \qquad \left(\frac{\delta R}{R}\right)^2 = \left(\frac{\delta P_x}{P_x}\right)^2 + \left(\frac{\delta P_z}{P_z}\right)^2$$

E_{beam} (GeV)	Q^2 (GeV/c)^2	p_n (GeV/c)	Rate (Hz)	Time (hours)	FOM x10^{-4}	dP (absolute)	dR (absolute)
4.4	4.5	3.15	48.8	120	2.6 (CE)	0.019	0.078
					0.8 (PR)	0.034	0.140
					3.4 (Total)	0.017	0.070



- Estimates from g4sbs agree very well with proposal
- *dR* based on Galster G_{En} and Kelly G_{Mn} parametrizations
- Expect overall systematic error to be ~3.0%

Run summary

- Completed data taking during April 16 - May 14, 2024
- 10-12 μA beam current on LD2 target
- 82% polarized beam
- BB (750 A), SBS (2,100 A) magnets at 100%
- BB, SBS Spectrometer angels at 42.5° and 24.7°
- 3 hours of LH2 data per day
- 11.8 C total LD2 data collected
- 3-4 kHz data acquisition rate (~1.2 GB/s)

Manpower update

Glasgow: David Hamilton (+ students and postdoc):
Oliver Jevons (Glasgow postdoc)
Andrew Cheyne (PhD student on GEn-RP)
Gary Penman (Glasgow grad, GEn-II)

N. Michigan: Will Tireman (+ UG students)

Hampton: M.K. (+ students and postdocs):
Sarashowati (Saru) Dhital (PhD student on GEn-RP)
Ryan Richards, Dulitha Jayakodige (HU postdocs, 0.5 FTE combined

JLAB: Jiwan Poudel, Arun Tadepalli, Holly Szumila-Vance, Bill Henry,
B. Wojtsekhowski (+staff & tech. team)

UVA: Nilanga Liyanage (+scientists, postdocs, students, and tech)
Huong Nguyen, Xinzhan Bai (research scientists), Asar Ahmed (postdoc)
Vimukthi Gamage (grad), Bhasitha Dharmasena (PhD student on GEn-RP)
Jacob McMurty (grad student), Minh Dao (UG), Eric Fernandez (tech)

UConn: Andrew Puckett (+ students and postdoc)

CNU: Ed Brash (+ UG students)

William & Mary: D. Armstrong, T. Averett (+ students and postdocs)

GEnRP status

Calibrations and tuning:
Timing, GEM clusters, geometry, event selection (event topologies), magnetic field calibration, proton deflection, spin transfer

Electron arm: same configuration as GMn and GEn-II (He-3)
Hadron arm: neutrons, protons. Proton deflection. Spin precession.
Inline GEMs: Front tracker, Steel analyzer, Back tracker
Active Analyzer, HCAL
PR side arm: 2 GEMs + Hodoscope

Physics:
Elastic H(e,e'p) → known proton ff+polarizations, validate p-polarimetry
Quasiel. D(e,e'p) → p-polarimetry, pp→pp, passive analyzer, front+back tracker

Quasielastic D(e,e'n) → neutron polarimetry

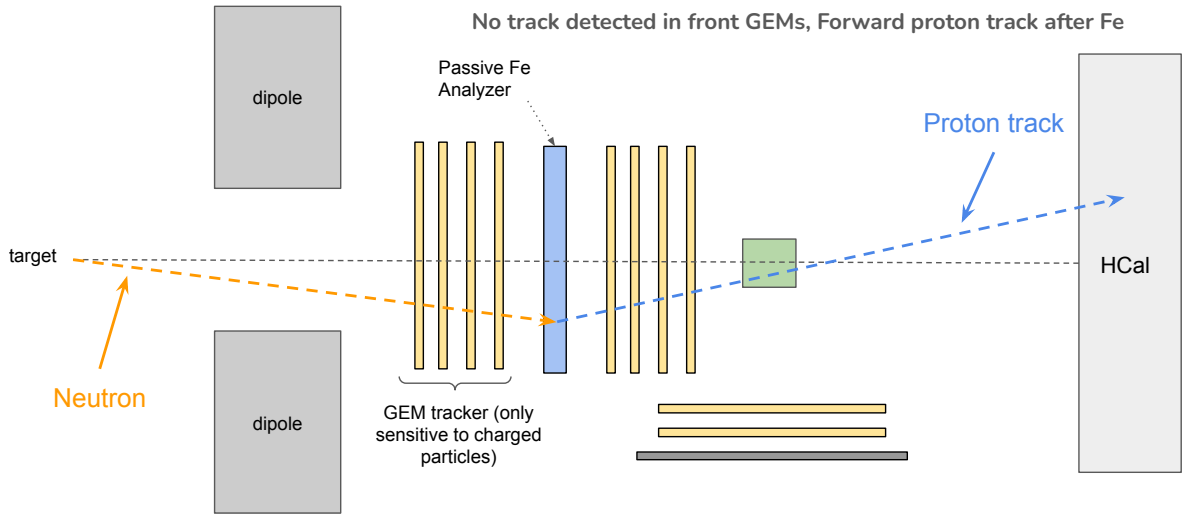
np→pn (fwd-p)	np→np (fwd-n)	np→np (bkw-p)
passive analyzer	active analyzer	active analyzer
only back track	no front, no back track	large-angle proton "track"
Best FOM → GEn/GMn	Ok FOM → GEn/GMn	Low FOM → P_l only

Event topologies

Charge-Exchange

(TOP VIEW)

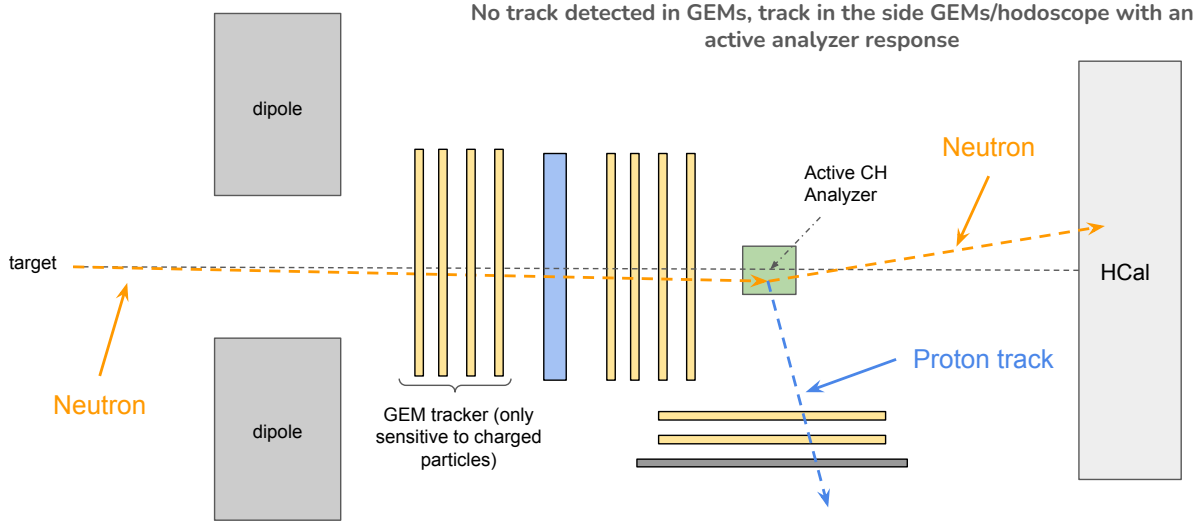
np → pn (fwd-p)



Conventional Scattering

(TOP VIEW)

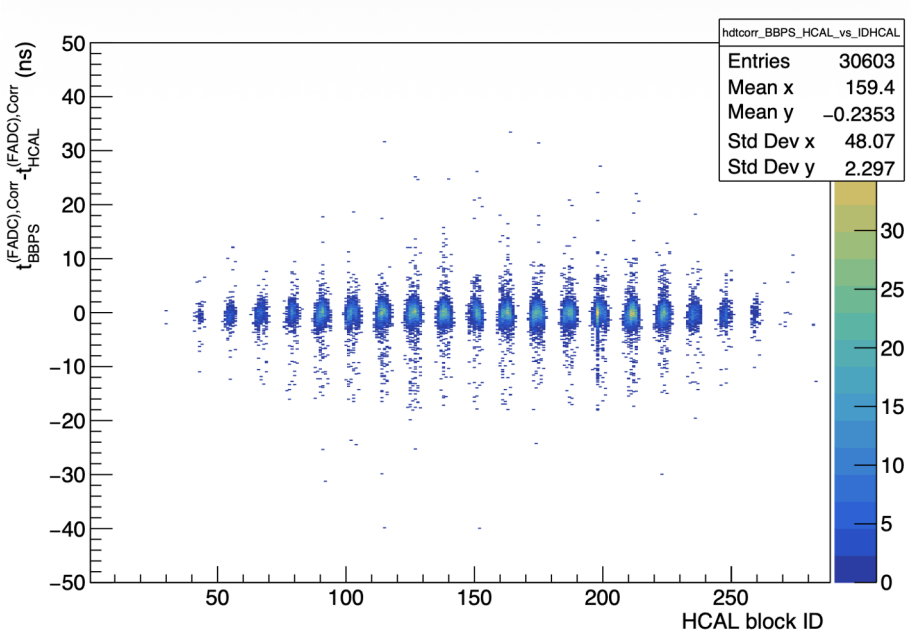
np → np (fwd-n + bwd-p)

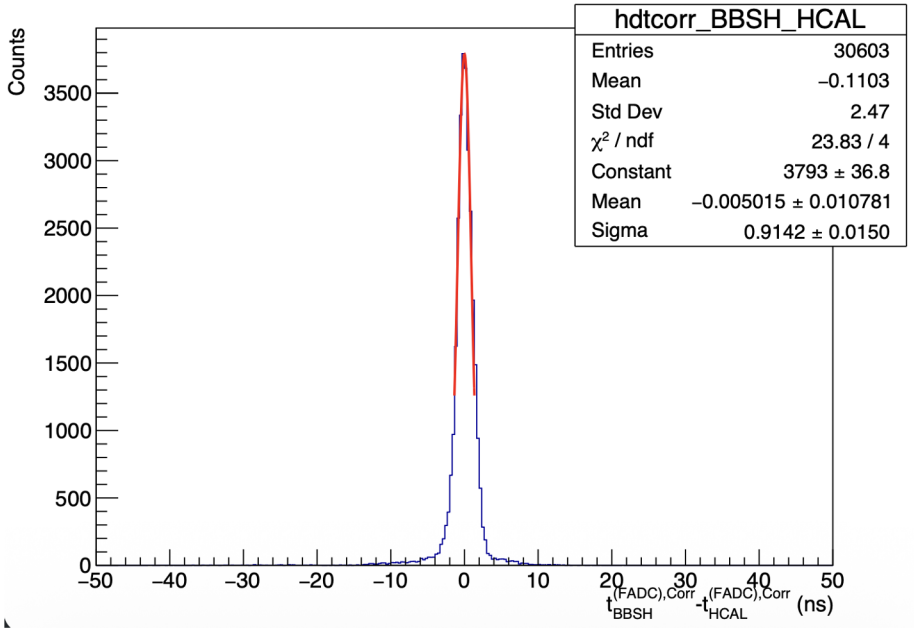


Bhasitha Dharmasena (UVa)

Timing Calibration

- Accidental timing background can be removed using the a coincidence time cut between the two spectrometer arms. A good timing resolution is important
- Recent developments in timing using the BB Hodoscope by Andrew Puckett and others
- These calibrations were implemented for GEn-RP
- Improvements in coincidence timing resolution from ~2.1ns to ~1.0ns



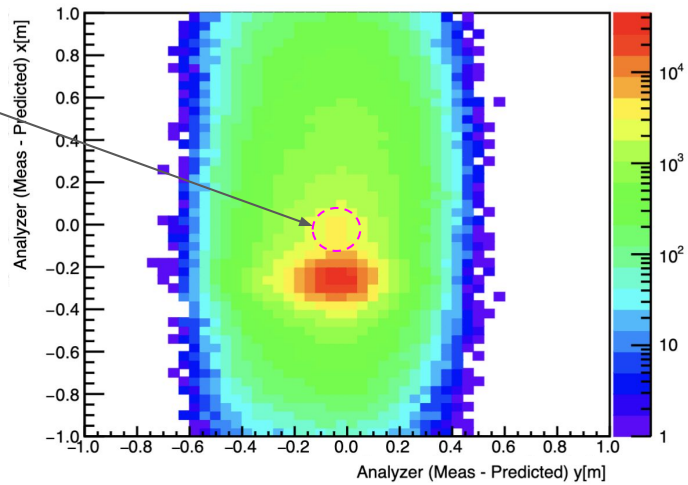


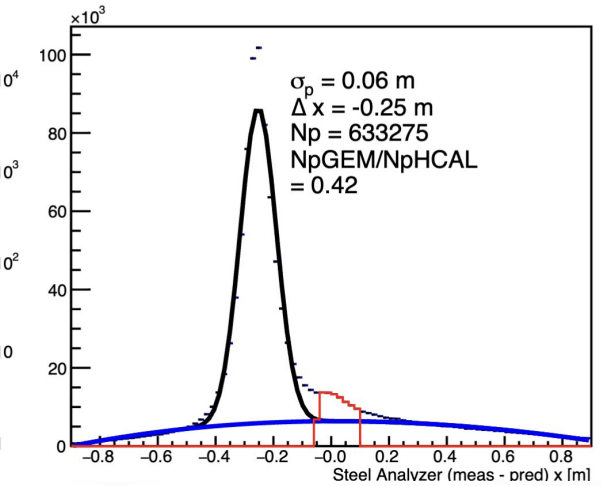
BBPS – HCAL **BBSH – HCAL**

time differences

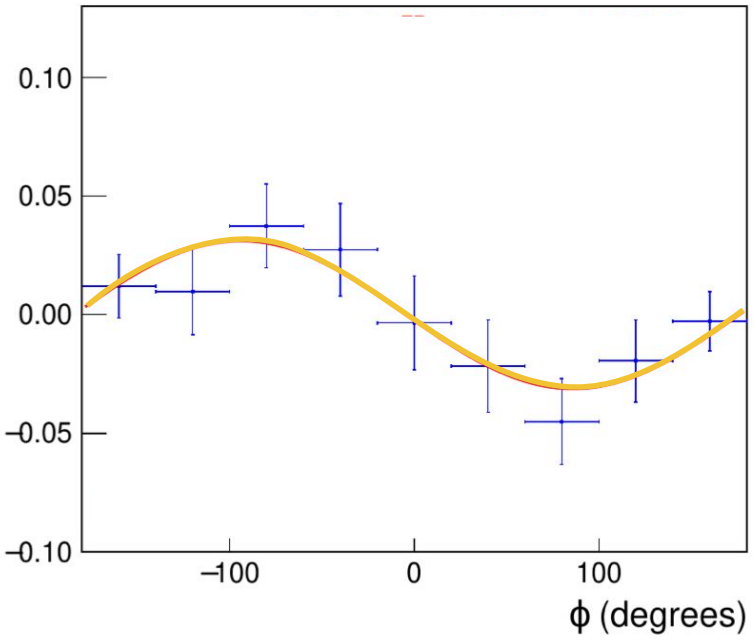
Andrew Cheyne (Glasgow)

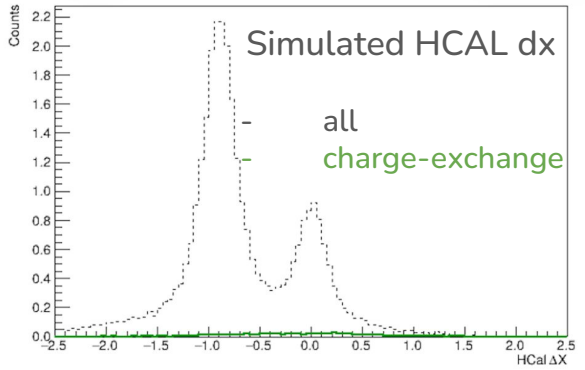
Charge-Exchange region of interest at (0, 0) in dx, dy

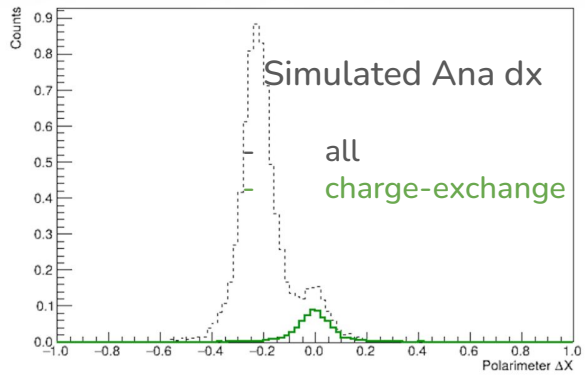




CHX polarimetry: Evidence for asymmetry







More work needs to be done for better isolation of the charge-exchange channel

Credits: David Hamilton

Simulations: Andrew Cheyne

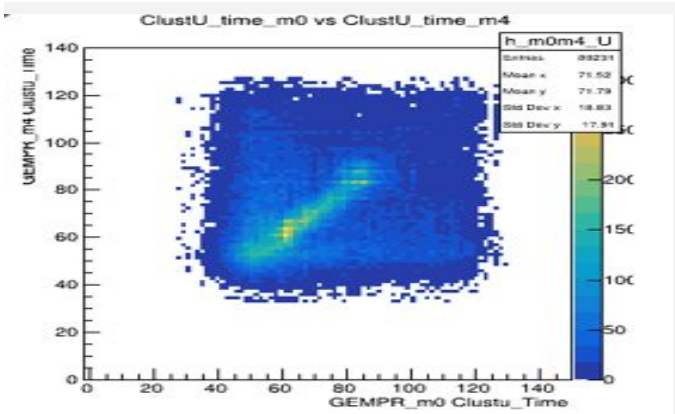
Sarashowati Dhital (Hampton U)

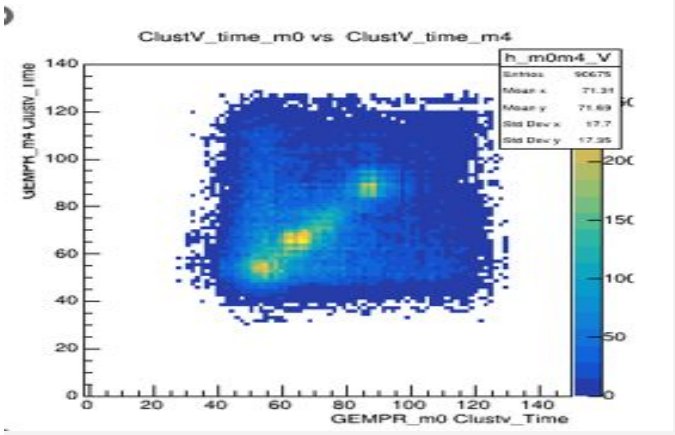
2025 DOE SCGSR Fellow since Jan 2026, stationed at Jlab

Attempting to establish evidence for large-angle proton recoils in PR system

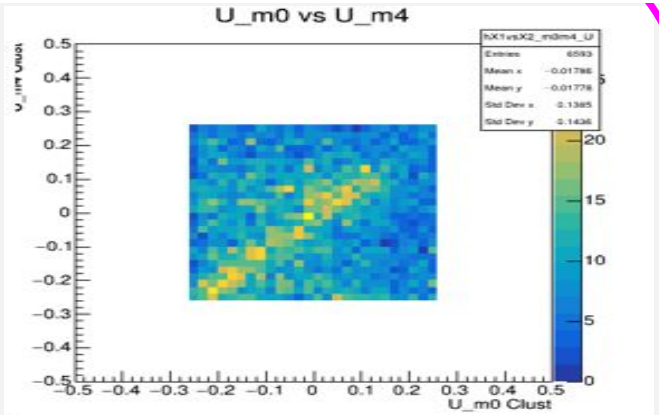
Correlations between 2 GEM layers

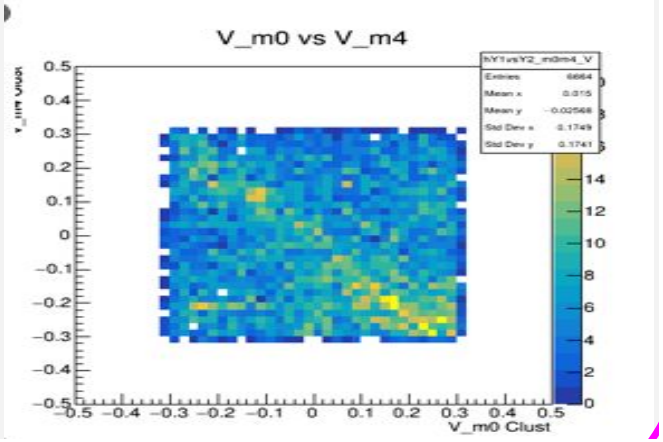
Time vs Time





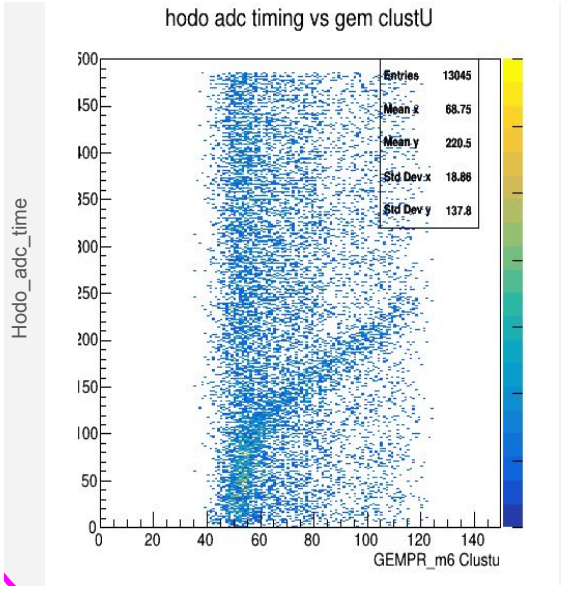
Position vs Position





Time correlations

Hodoscope vs GEM



GEnRP Future

- Proof of principle (E12-17-004)
  - Demonstrate CHX neutron polarimetry (fwd-p)
  - Demonstrate large-angle proton recoil (PR) polarimetry

- Letter of Intent (LOI)
  - In preparation for PAC54 (2026)
  - Present GEnRP spokespeople expressed interest

- If E12-17-004 results are promising: Full proposal at PAC55 (2027)
  - FOM
  - Backgrounds

- Similar, but at that time established concept
  - Hall C
  - BB large acceptance spectrometer for electron arm
  - SBS with GEM front tracker used as software veto, passive analyzer, GEM back tracker for forward protons; HCAL

Thank you!