A novel neutron Polarimeter for the E12-17-004 Experiment (GEn-RP experiment)

Thir Gautam
Hampton University
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Virtual Hall A winter collaboration meeting

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Collaboration

- **PI-contact person**: B. Sawatzky (JLab)
- **Co-PIs**: V. Bellini (INFN), K. Gnanvo (UVA), D. Hamilton (U. Glasgow), M. Kohl (Hampton U), N. Piskunov (JINR), B. Wojtsekhowski (JLab)
- **GEM Systems:**

  INFN Group: E. Cisbani, P. Musico, R. Perrino, E. Wertz

  Hampton Group: T. Gautam, M. Rathnayake, and M. Suresh
- **UVa Group:** S. Ali, X. Bai, J. Boid, S. Jeffas, N, Liyanage, H. Nguyen, A. Rathnayake
- **Daq and readout electronics:** A. Camsonne, B. Raydo, B. Moffit, H. Szumila-Vance, H. Liu, C. Gosh
- **Analysis and software**: A. Puckett, E. Fuchey and W. Tireman

  and entire GEn-RP collaboration

Outline

- Introduction to neutron form factor
- GEn-RP experiment overview
- Analyzing power and figure of merit
- Projected goal of form factor and uncertainty
- Status UVa and INFN GEMs commissioning
- Status of the non-GEM detectors
- Conclusion

Important milestone of the GEn-RP experiment:

- **Formally cleared the ERR process in November 2020**
- **Beam request approved by the Lab in November 12**

Nucleon form factors

Electromagnetic current density of nucleon:

$$\mathcal{J}_{\text{proton}} = e\bar{N}(p')\left[\gamma^{\mu}F_1(Q^2) + \frac{i\sigma^{\mu\nu}q_{\nu}}{2M}F_2(Q^2)\right]N(p)$$

- Encode electric and magnetic structure of the nucleon
- Parametrize the properties of the quark and gluon
- Limited neutron measurements in terms the Q^2 range and the precision
- Better access to relatively small G_E
- No recoil polarimetry measurement above Q^2 of 1.5 GeV^2

$$G_E = F_1 - \tau F_2$$
$$G_M = F_1 + F_2$$

In High Q^2 range:

→ G_E measurement will sensitive to up and down quark distributions in quark core

→ Insight to the complete set of form factors in the region with small pion cloud contributions

→ Allows for flavor decomposition to distance scales deep inside the nucleon

Goals of GEn-RP experiment:

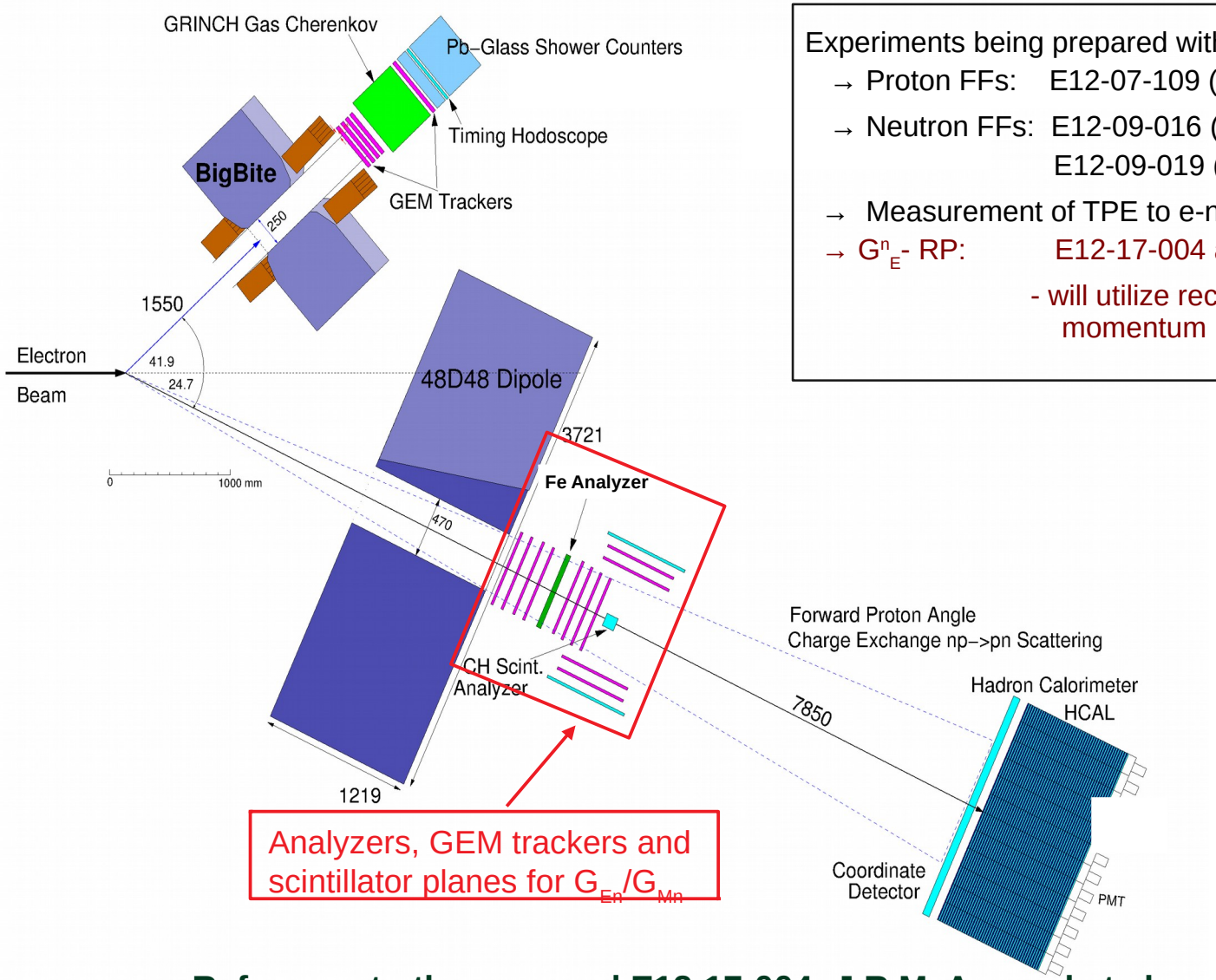
→ Measurement of $\mu G_E^n/G_M^n$ at Q^2 of 4.5 GeV^2 using recoil polarimetry technique

→ Establish how well the charge exchange method works which will layout the path forward for GEn at high Q^2 with C-GEN or with a future SBS/Hall-A version

The Super BigBite Program

- SBS is a 2.5 T*m dipole magnet with vertical bend, and a flexible configuration detectors
- A large solid angle, high luminosity (up to 10^{39} cm^{-2} s^{-1}) with large momentum bite

Schematic view of 4.5 (GeV/c)^2 kinematic setting



Experiments being prepared with SBS:

→ Proton FFs: E12-07-109 (G^p_E up to Q^2 =12 GeV^2)

→ Neutron FFs: E12-09-016 (G^n_E up to Q^2 = 13.5 GeV^2)
E12-09-019 (G^n_M up to Q^2 = 13.5 GeV^2)

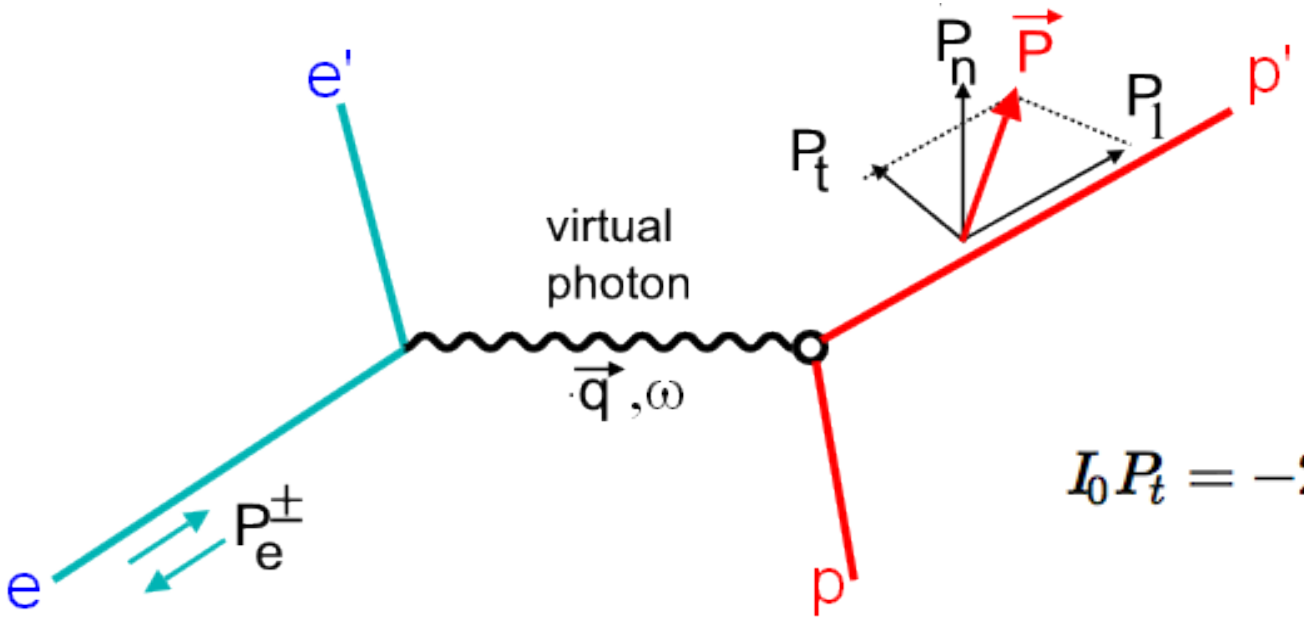
→ Measurement of TPE to e-n elastic scatt. at Q^2 = 4.5 GeV^2

→ G^n_E- RP: E12-17-004 at Q^2 = 4.5 GeV^2

- will utilize recoil neutron polarimetry at high momentum

Reference to the proposal E12-17-004: J.R.M. Annand et al.

Recoil polarization technique



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

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

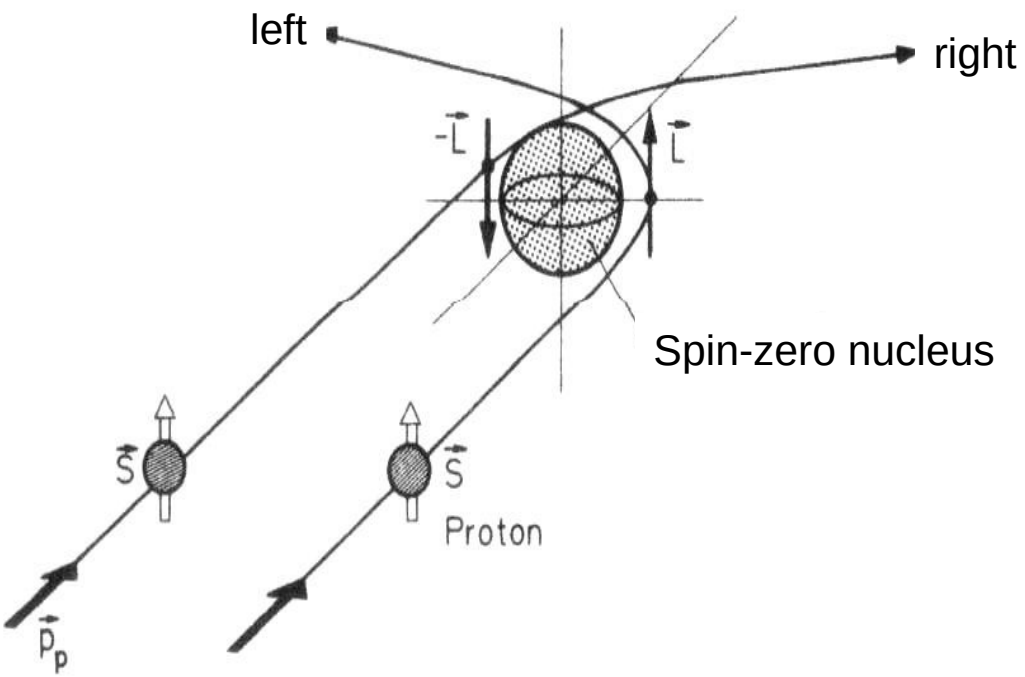
$$I_0 P_\ell = \frac{1}{M}\left(E_e + E'_e\right)\sqrt{\tau(1+\tau)}G_M^2 \tan^2\frac{\theta_e}{2}$$

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

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

- **Use dipole field for spin precession to rotate P_t and P_n**
- **Applicable to protons and neutrons**

Polarimetry



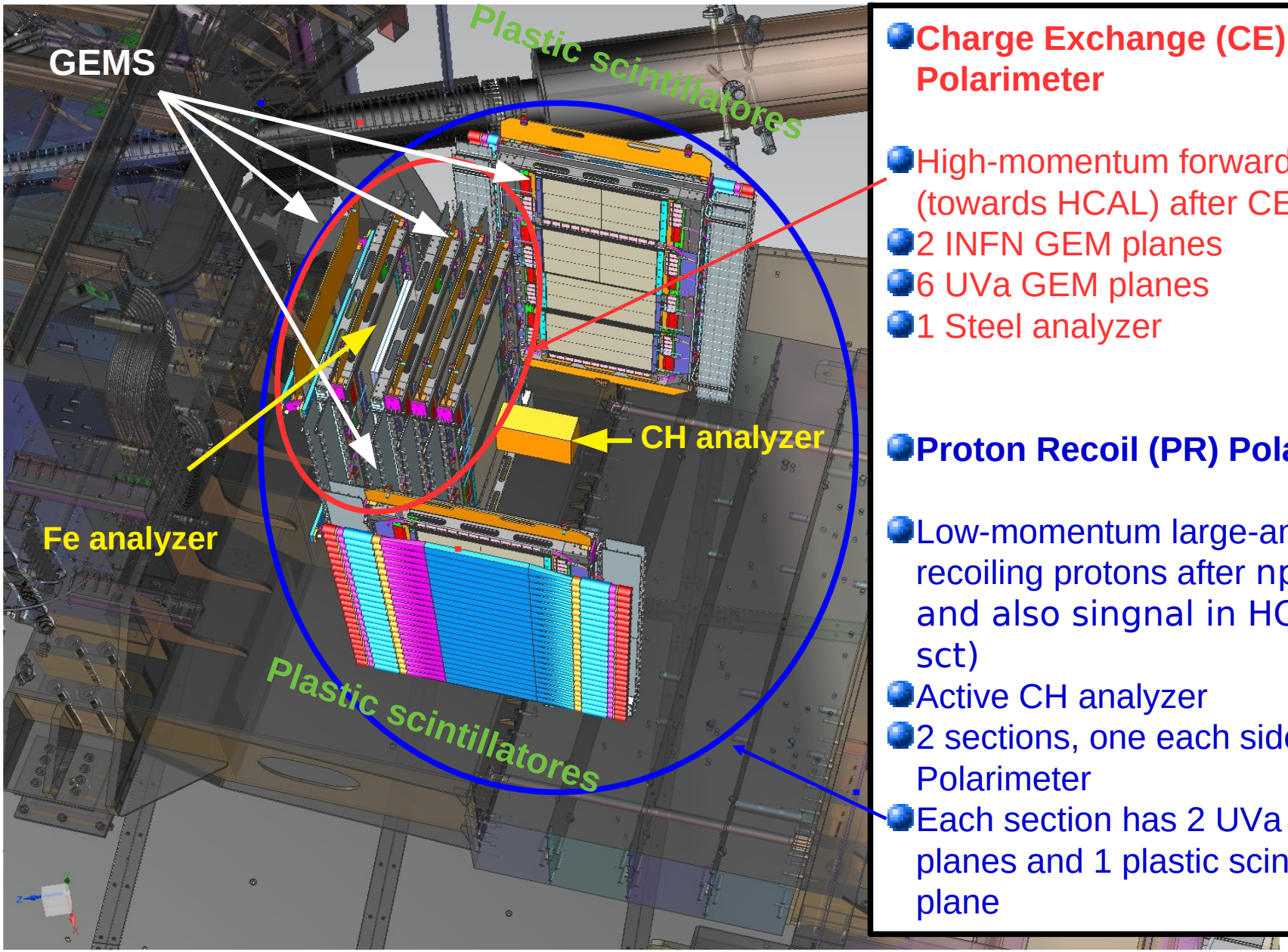
- **Strong LS interaction energy allows hadron polarization measurements with large analyzing powers**
- **Analyzing power forward-peaked and decreasing with higher energy**
- **Normal polarization causes left-right asymmetry**
- **Sideways polarization causes top-bottom asymmetry**

Neutron polarimetry:

Elastic / Proton-Recoil (PR): np → np

Charge Exchange (CE) np → pn

SBS Neutron Polarimeter



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

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

Figure of merit: elastic vs. charge exchange

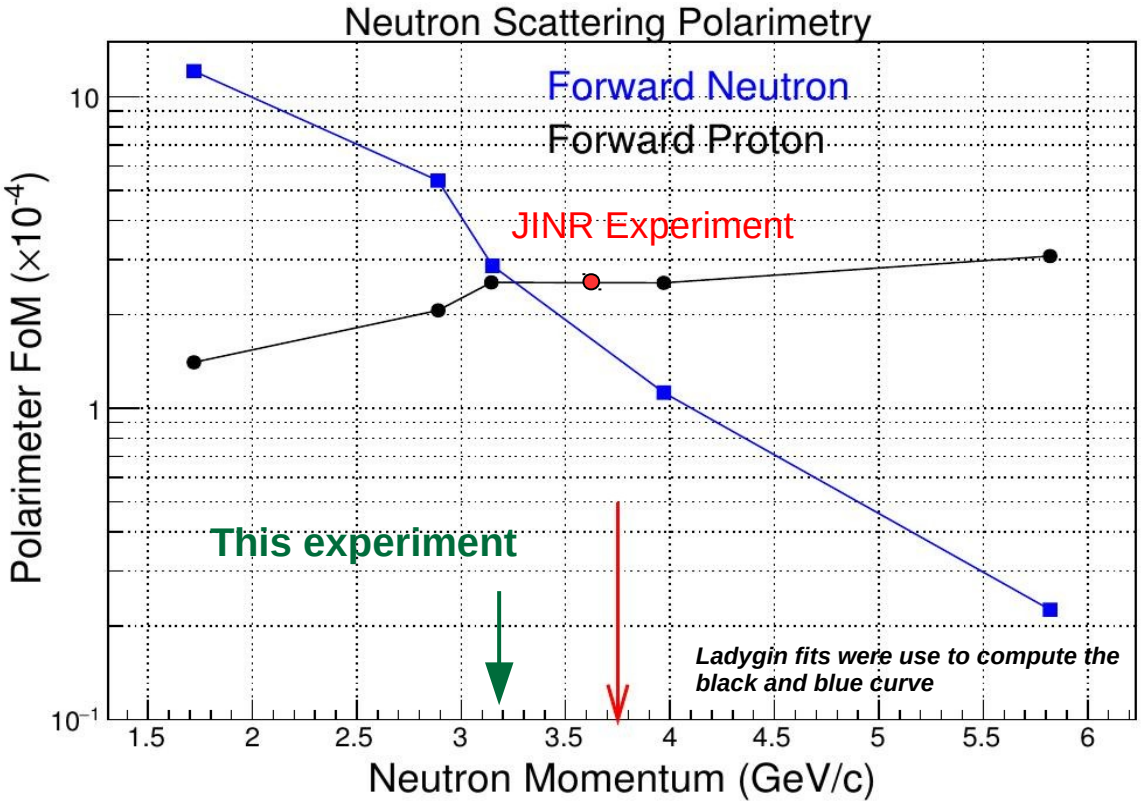
Azimuthal modulation of cross section:

$$\sigma(\theta_n^{'},\phi_n^{'}) = \sigma(\theta_n^{'})\left[1 + A_y(\theta_n^{'})\left\{P_x^n \sin\phi_n^{'} + P_y^n \cos\phi_n^{'}\right\}\right]$$

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

- Standard n-p elastic scattering from CH scintillator
- np → np (forward neutron)

- Charge exchange n-p scattering from Cu
- np → pn (forward proton)



- A_y for np → pn on Cu: new 2016-17 measurement from JINR indicated by a red arrow

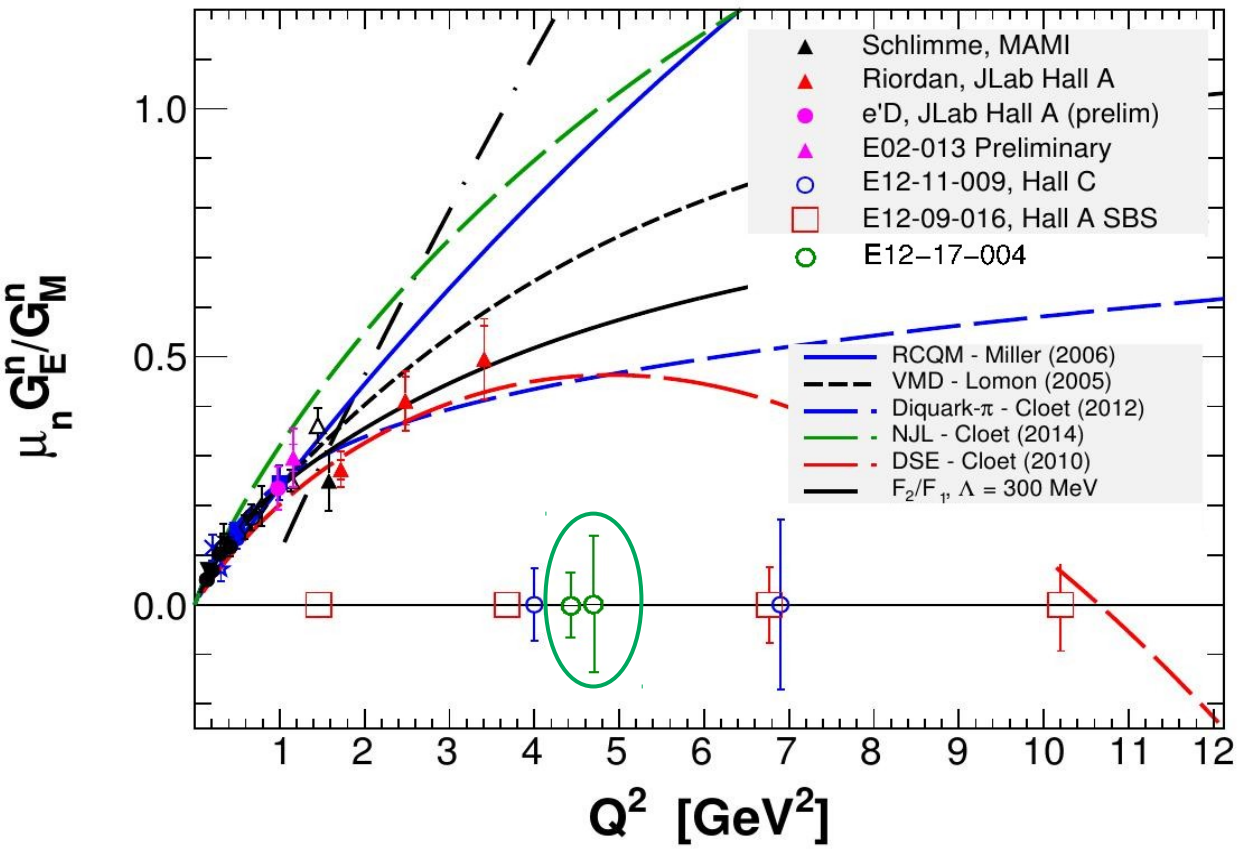
→ GEn-RP is placed right at 3.15 GeV/c near cross over which is Q^2 of 4.5 GeV²

Reference to the proposal E12-17-004: J.R.M. Annand et al.

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 $\xi 10^{-4}$	δP (absolute)	δR (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

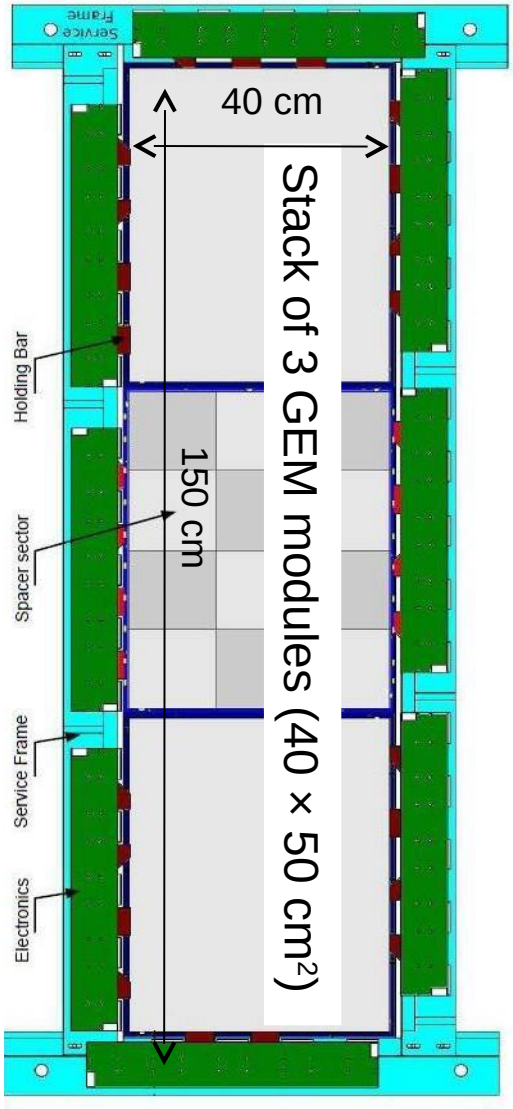


Expect overall systematic error to be ~3.0%

Reference to the proposal E12-17-004: J.R.M. Annand et al.

SBS GEM trackers

2 INFN GEM layers



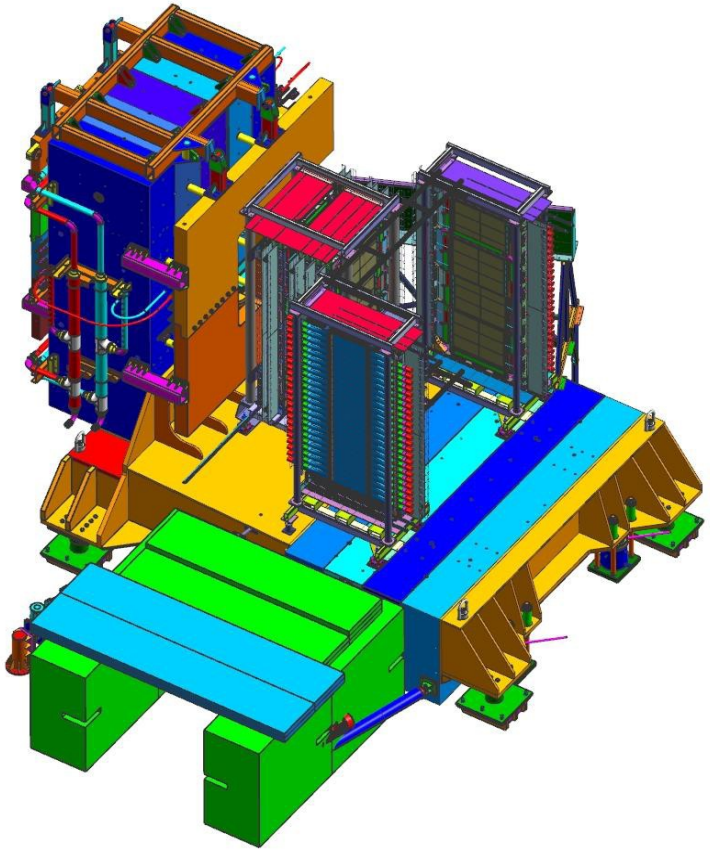
Charge-Exchange (CE) Polarimeter:

⇨ 2 INFN + 2 UVa layers, in front of Fe analyzer

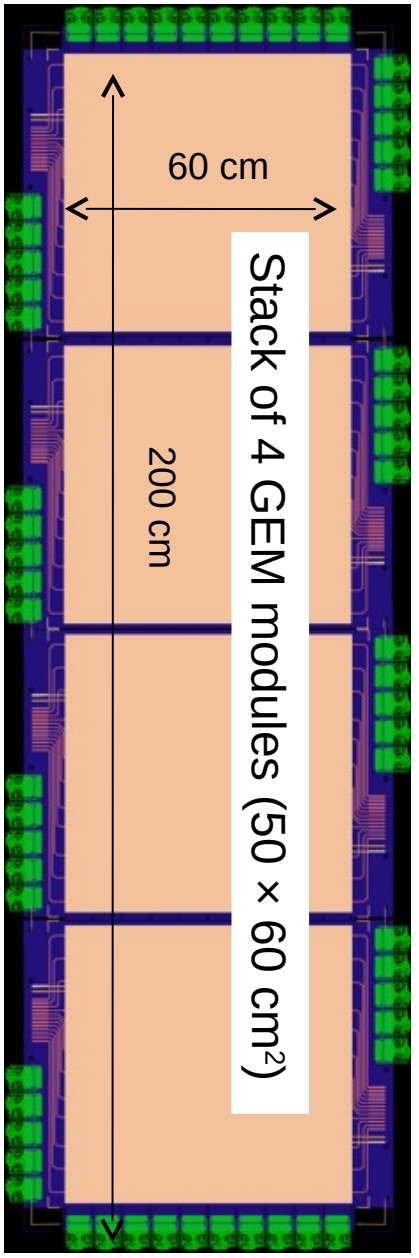
⇨ 4 UVa layers behind the Fe analyzer

Proton-Recoil (PR) Polarimeter:

⇨ 2 Identical arms, 2 UVa GEM layers in each arm

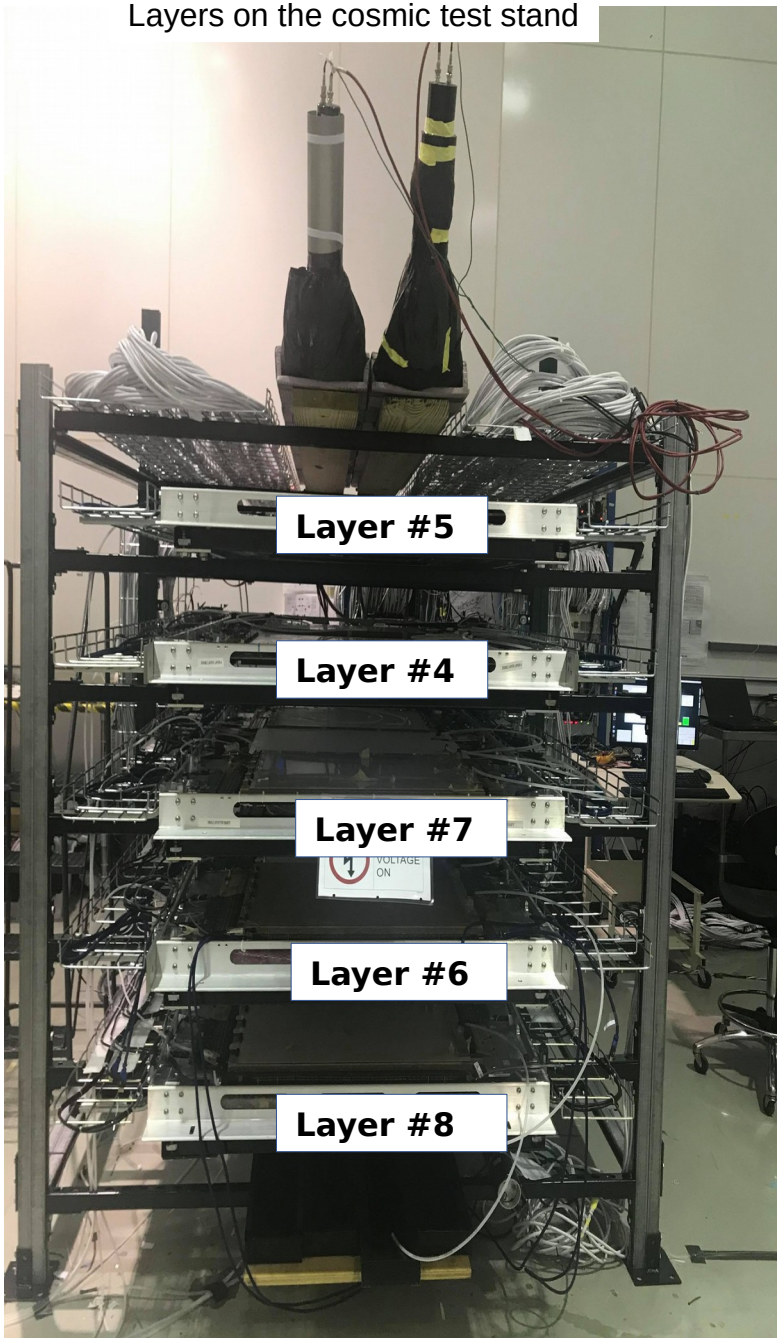


10 UVA GEM layers

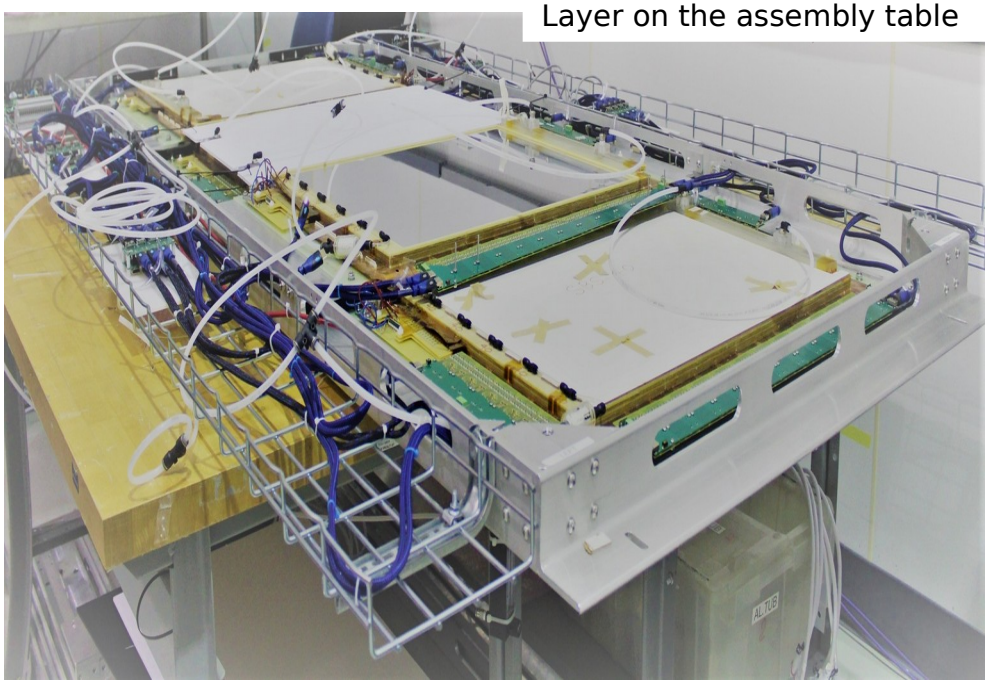


Status of the UVa GEM layers assembly in EEL 124

Layers on the cosmic test stand



Layer on the assembly table



→ 8 out of 11 layers have been assembled

- One layer now installed in BB detector stand
- Two layers have been disassembled for some modifications in frames: being re-assembled now
- Remaining five layers currently on cosmic test stand

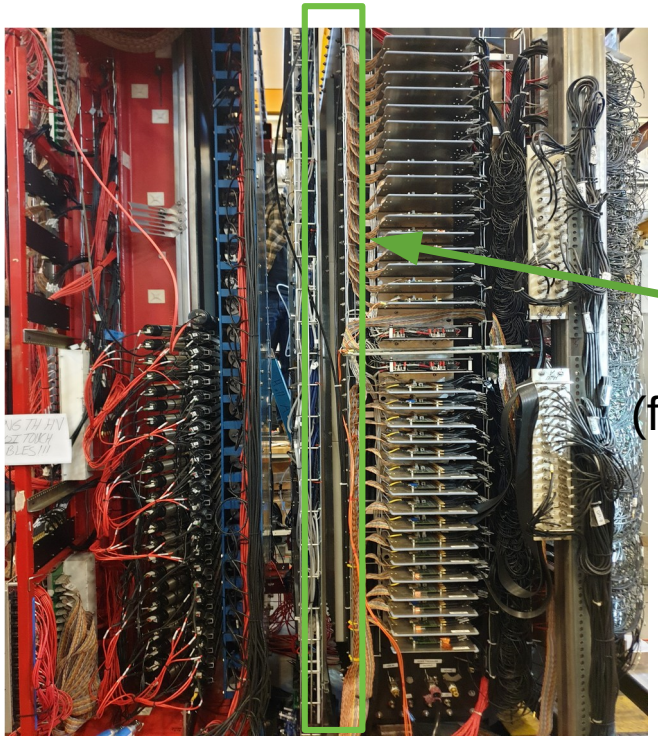
→ Expect to complete the assembly and testing of the remaining layers in the next 2-3 months

Installation of Layer 3 into the Bigbite setup


Sitting outside the EEL clean room


Lifted up using a crane in TEDF

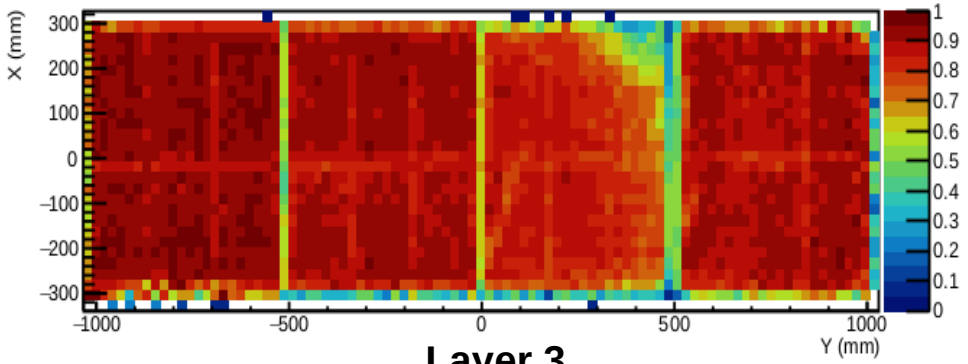

Inserted into the Bigbite frame


UVa layer
(from the side)

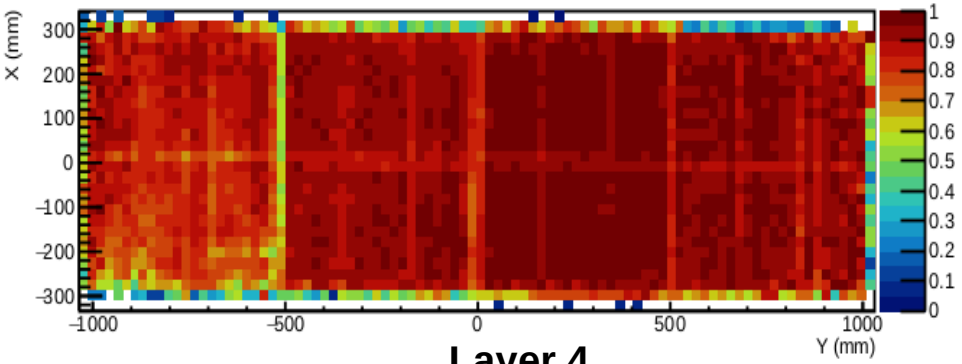
→ Connected HDMI cables and LV power supply
→ Completed Daq and readout set up

Cosmic test results-Track based efficiency

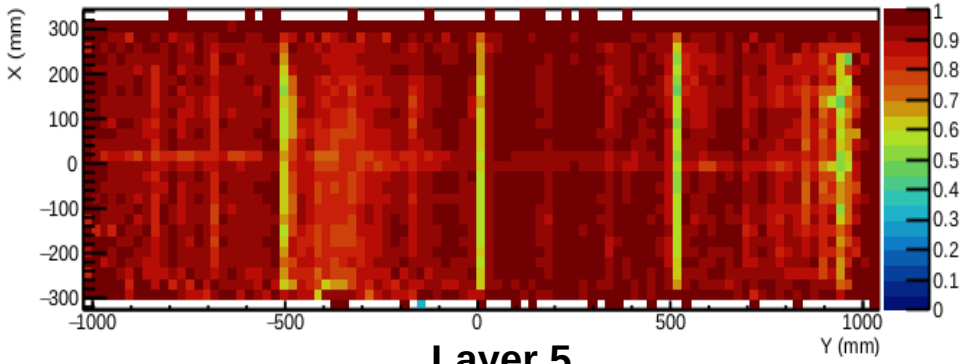
Layer 1



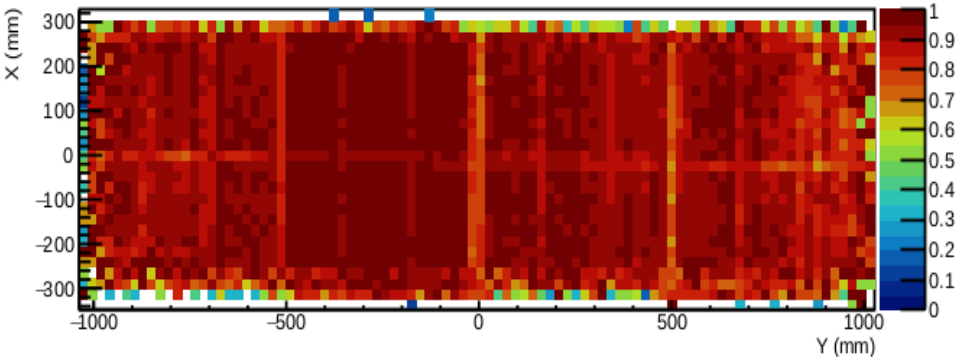
Layer 2



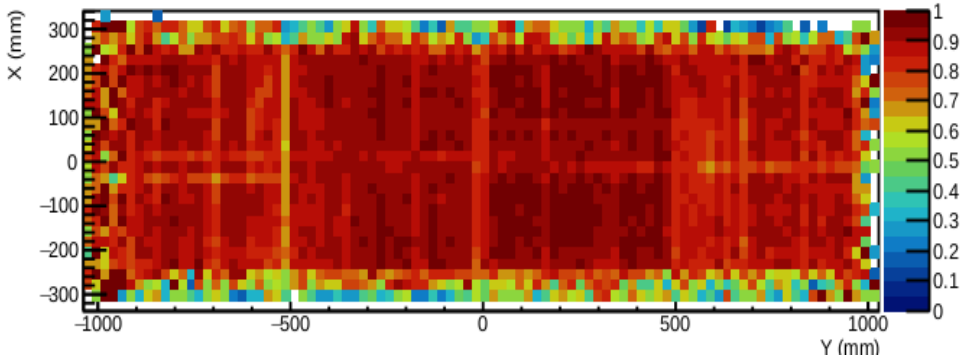
Layer 3



Layer 4



Layer 5



→ Divide each layer into coarse XY binning so that we have on average few hundred bins

→ Then for each track falling in that bin, ask

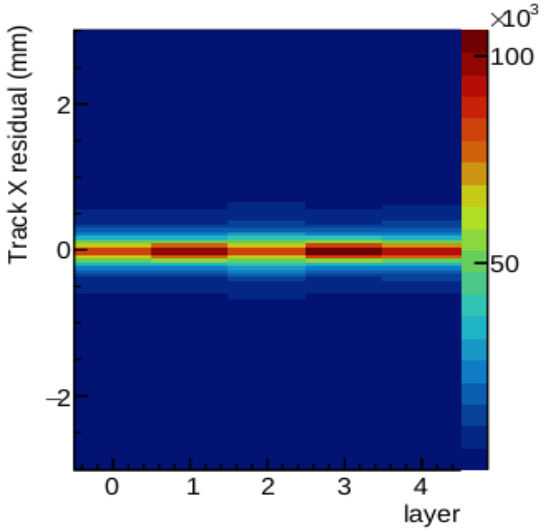
If there was a hit on that track in that bin

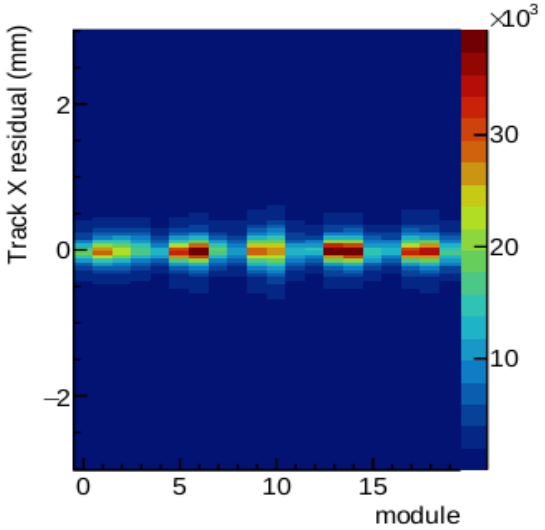
→ Ratio of did hit to should hit gives local efficiency

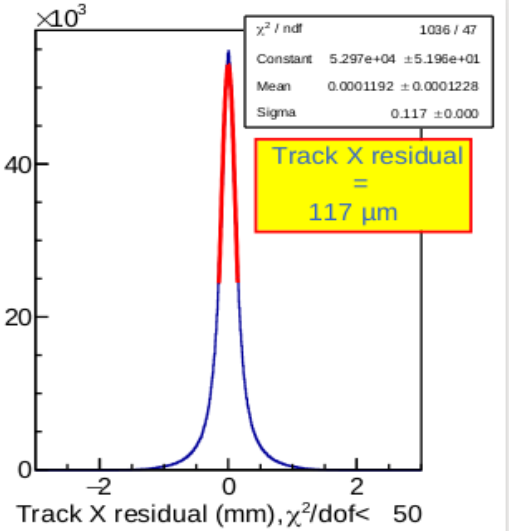
Cosmic results and residual plots

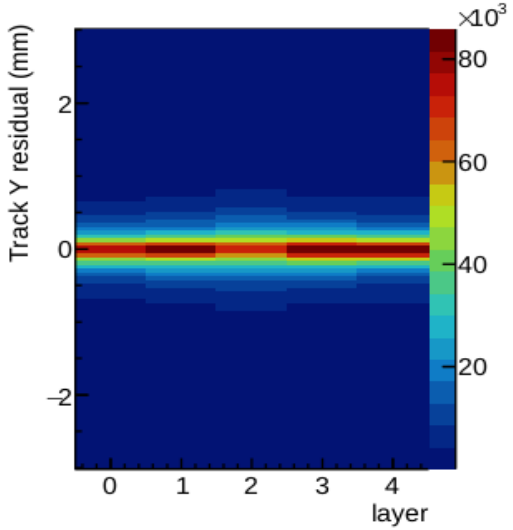
→ Difference between projected track location and actual cluster location

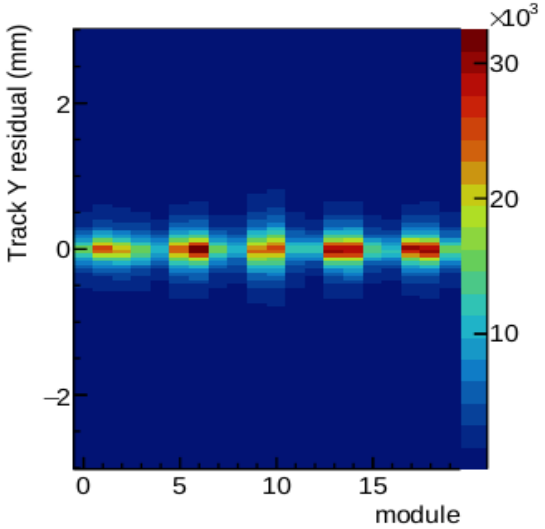
→ Spatial resolution as measured by tracking residuals $(\sigma_x, \sigma_y) = (117\ \mu m, 133\ \mu m)$

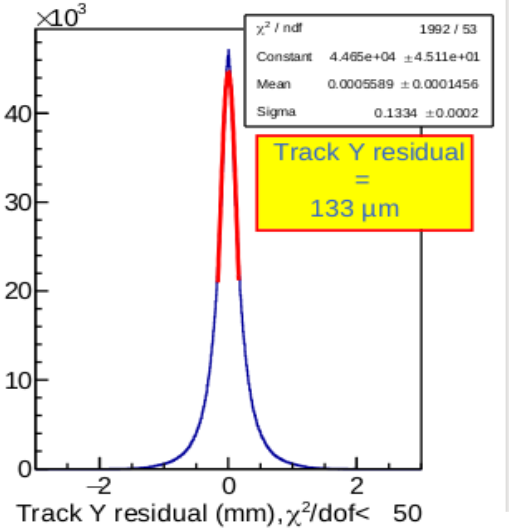




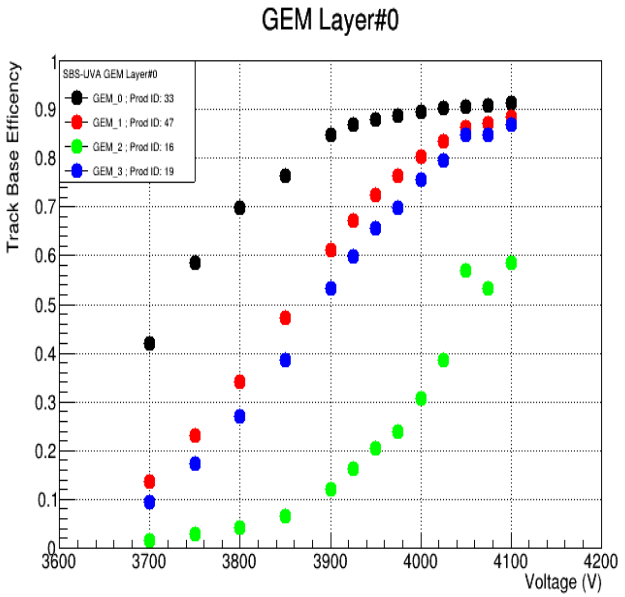


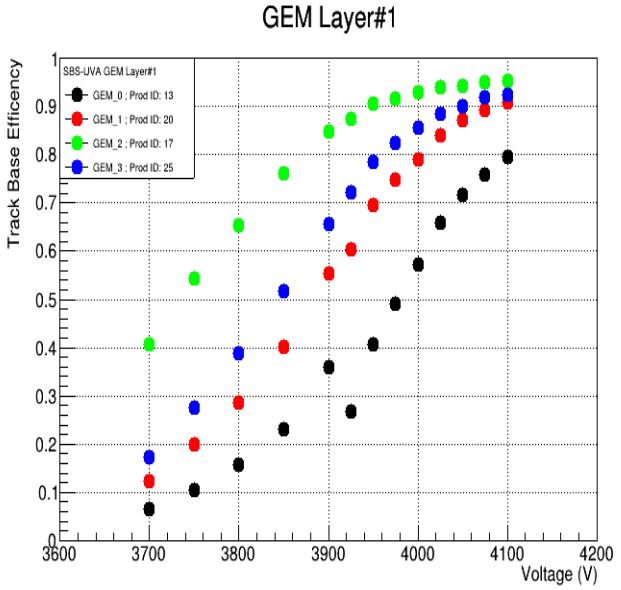


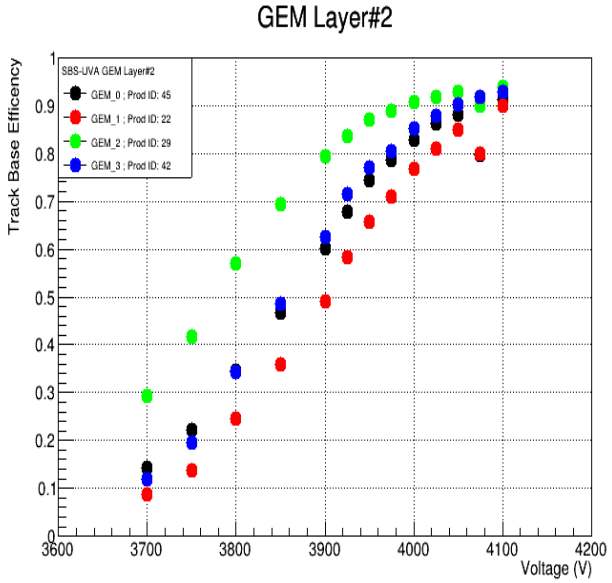


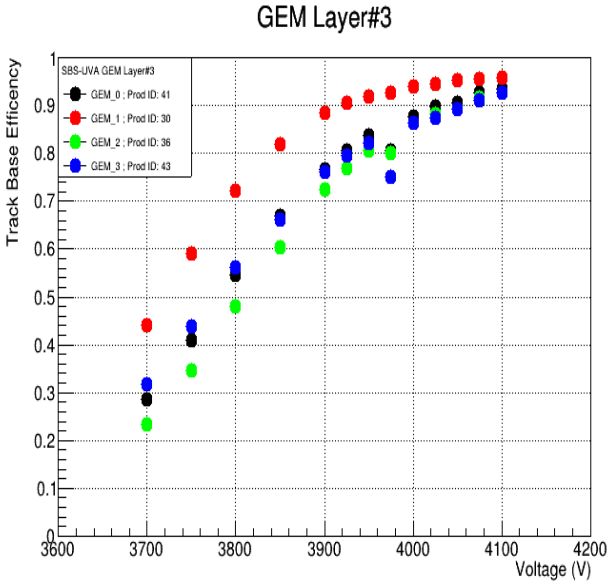


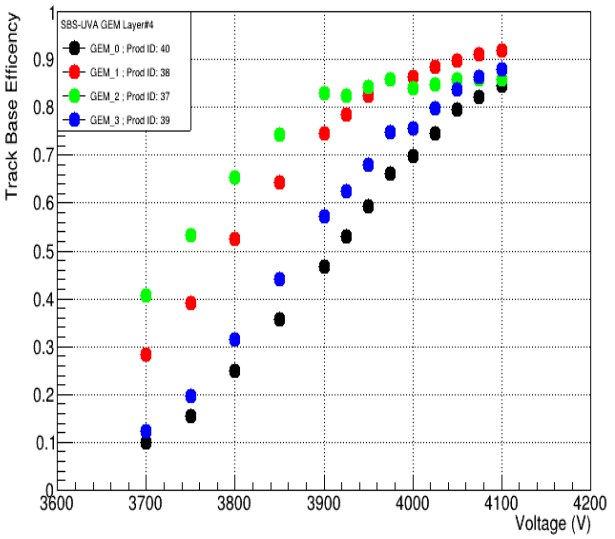
HV scan for Efficiency plateau studies









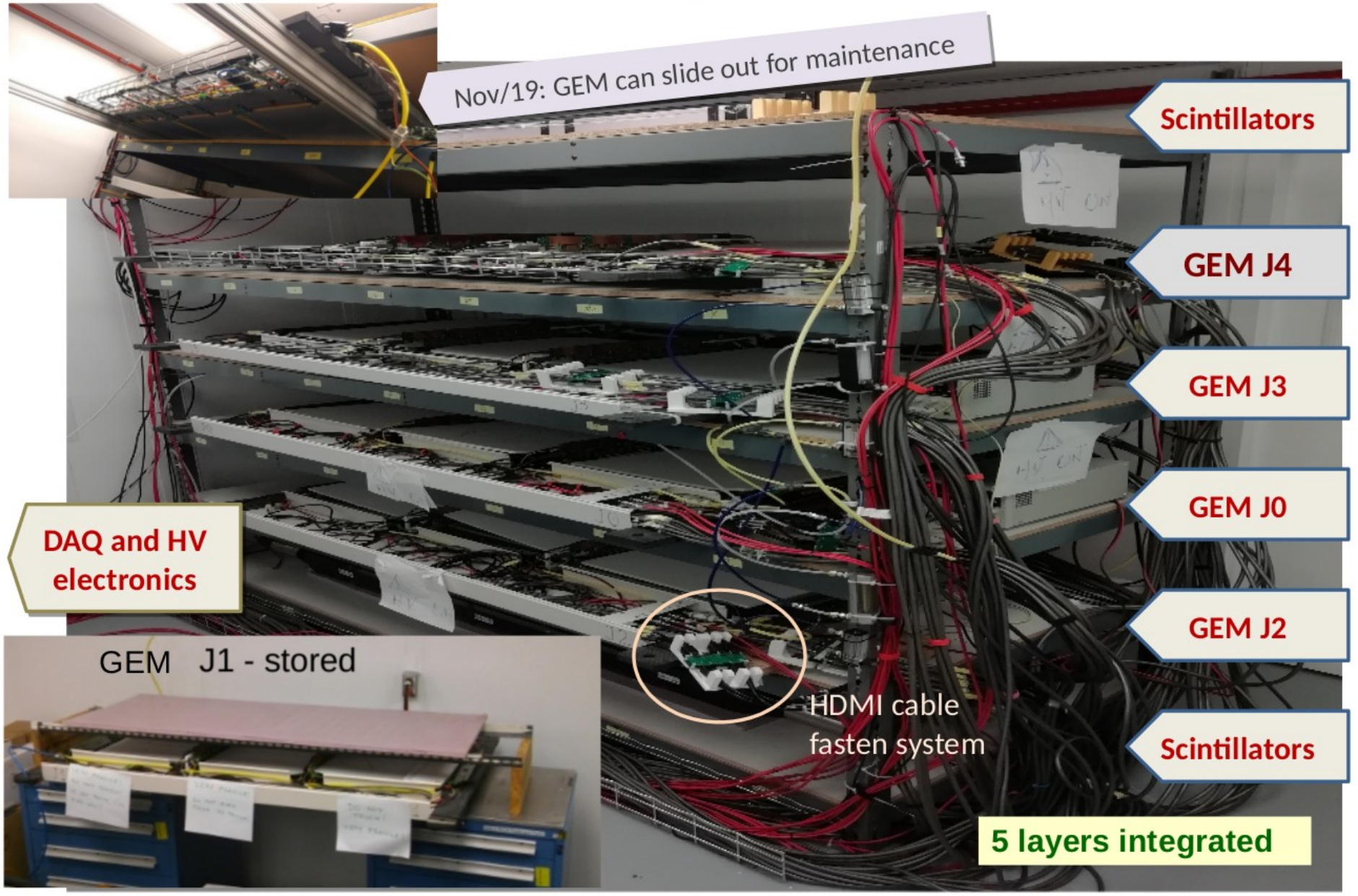


- Voltage scan from 3700V to 4100V to find efficiency plateau for an individual module

- Scan was performed for four modules of one layer at a time by keeping the voltage at 4100V for the other four layers

- Ratio of "number of tracks did hit " /"number of tracks should hit" gives the average track base efficiency value for a module.

INFN GEM setup at JLab



INFN GEM – Main Activities

- Taken cosmic data (at different HVs) → analysis underway (thanks also to Andrew); upgraded to CODA3; fixed different cabling and other electronics/DAQ issues; one module tripped at 4150 – not recovered!
- Replaced plastic cable trays, with metallic ones on the two layers expected to be installed in BB;
- Performed test on mechanical structure of the carbon frame

➔ Short carbon frame modification in progress (2 holes on each bar) to fix extensions for the BB frame rails

➔ Helping finalizing BB frame

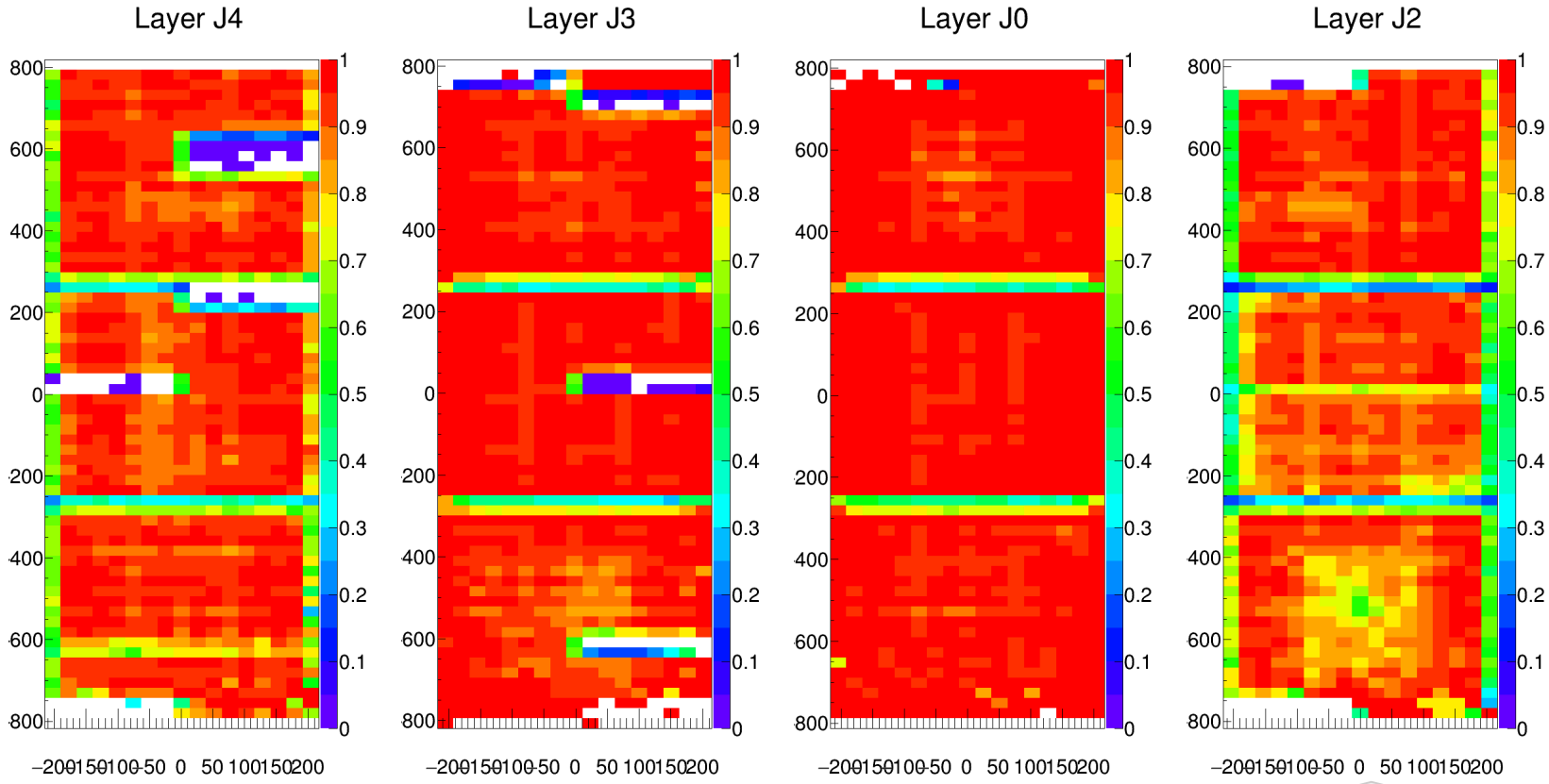
➔ Working on noisy cards (either improve noise or remove card)

- Immediate future: repeat cosmic data taking before final integration

Layer Cosmic Efficiency - Preliminary

Software alignment by Andrew

Cosmic Run 147
HV = 4100 V
Gas Flow ~ ½ of nominal



Layer J0 and J2 + 2 U/V layer will be installed in BB Frame.

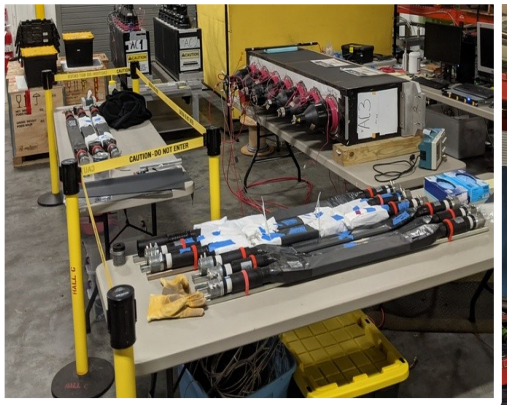
The other INFN layers can be used for the RP

(including J1 and one additional layer not assembled yet)

Lower Efficiency due to wrong latency setting (This layer has 10 m digital cable instead of 20 m)

Status of the non-GEM detectors

- GEn-RP scintillator hw is being commissioned in the ESB
  - → Minor repairs, gain matching nearly complete and ready for assembly into frames
  - → Production FADC based readout (CODA3; F250s, 1190, etc) being assembled now
    - » Existing FB based test stand will be used in parallel
- Hardware for Frames/Stands is procurred and on-site in ESB
  - → Assembly of large-angle side detectors (hodoscopes + UVa GEM layer) will be done in ESB
  - → “Inline” GEM stack + Fe Analzyer assembly done in Hall (TBD?)



Nucleon form factors

- The SBS program in the Jefferson lab Hall A will measure the nucleon form factors at the highest Q^2 to the date
- E12-17-004 will measure the ratio of neutron electric to magnetic form factors by quasi-elastic electron-deuteron scattering with neutron recoil polarimetry
- GEM tracker commissioning is continuously moving forward
- Expected to run this experiment starting Jun 21, 2021

Thank you all!

Analyzing power for elastic n-p scattering

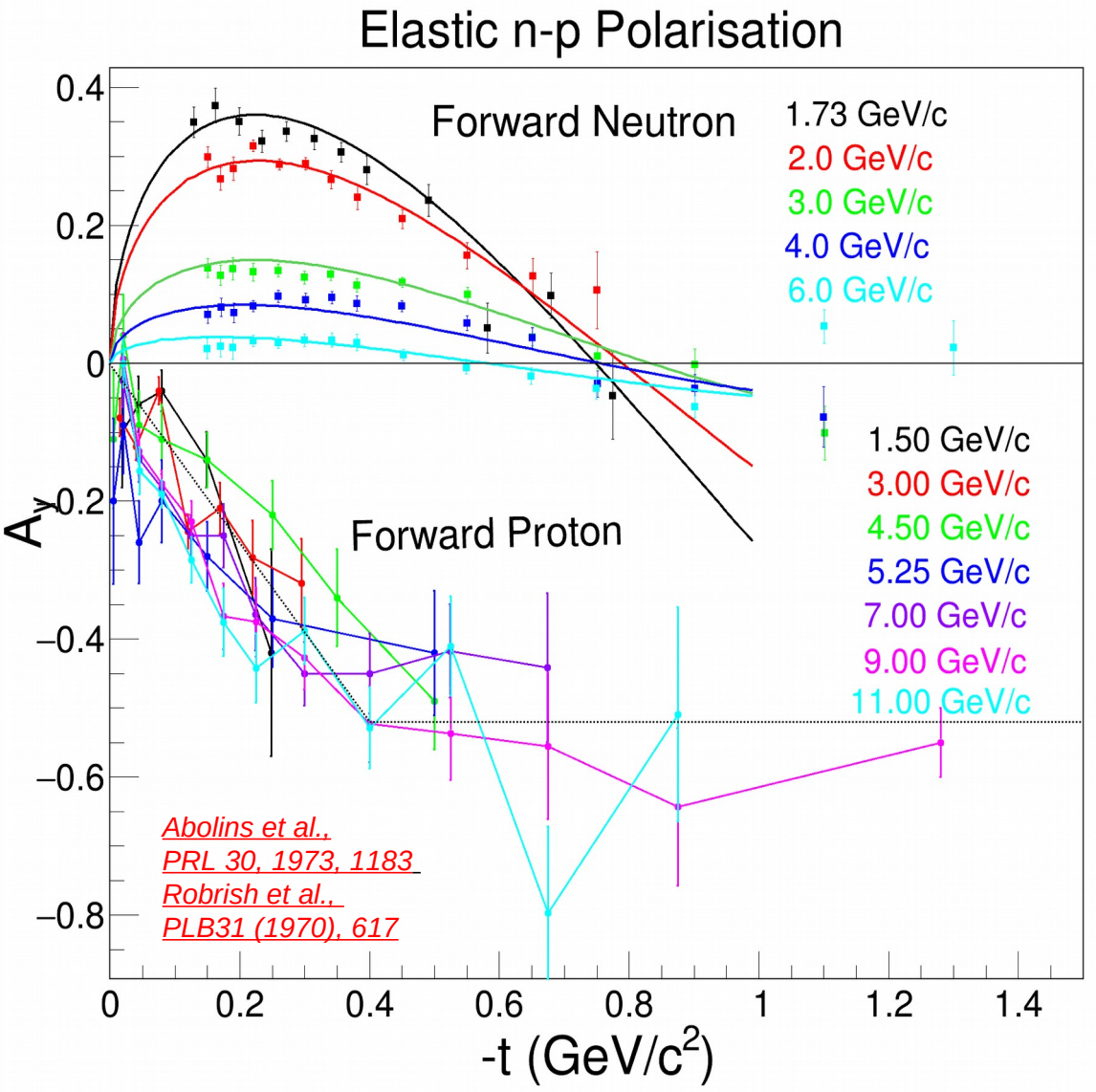
Azimuthal modulation of cross section:

$$\sigma(\theta_n^{'},\phi_n^{'}) = \sigma(\theta_n^{'})\left[1 + A_y(\theta_n^{'})\left\{P_x^n \sin\phi_n^{'} + P_y^n \cos\phi_n^{'}\right\}\right]$$

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

- 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

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



Reference to the proposal E12-17-004: J.R.M. Annand et al.