Gas Electron Multiplier Detectors used in the SBS GMn Experiment

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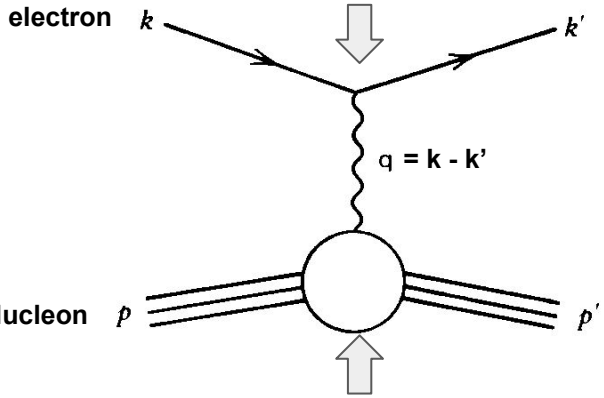
Electron-Nucleon Scattering

$$j^{\mu} = -e\bar{u}_e(k')\gamma^{\mu}u_e(k)$$



$$Q^2 = -q^2$$

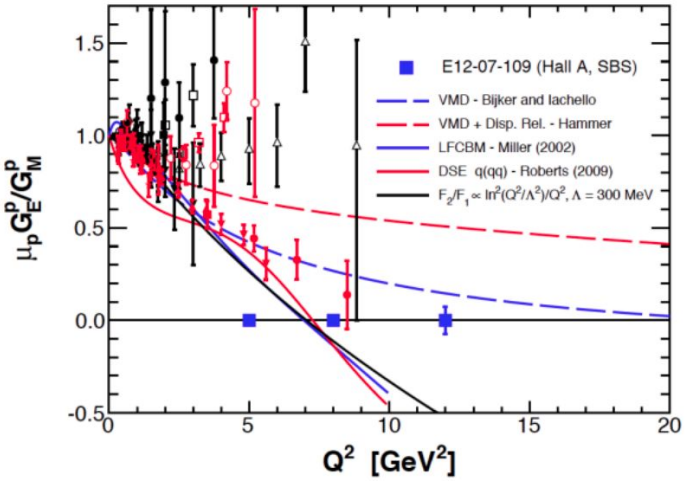
$$J^{\mu} = e\bar{u}_p(p')[F_1(Q^2)\gamma^{\mu} + \frac{i\kappa}{2M}F_2(Q^2)\sigma^{\mu\nu}q_{\nu}]u_p(p)$$

- Electron-nucleon scattering can be used to investigate the nucleon structure.
- $F_1(Q^2)$ and $F_2(Q^2)$ are Pauli and Dirac form factors.
- G_E and G_M, more commonly used, describe the electric and magnetic distributions.

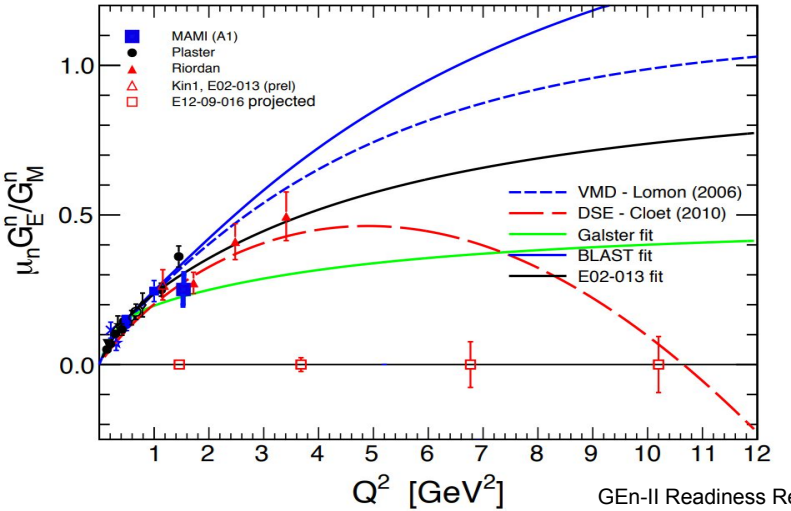
$$G_E = F_1 - \kappa\tau F_2 \qquad G_M = F_1 + \kappa F_2 \qquad \tau = \frac{Q^2}{4M^2}$$

Neutron Electromagnetic Form Factor Ratio

- Previous experiments measured the proton ratio G_E^p/G_M^p up to Q^2 = 8 GeV^2 and the neutron ratio G_E^n/G_M^n up to Q^2 = 3.5 GeV^2.
- They found that G_E^p/G_M^p sharply declined after Q^2 ~ 1 GeV^2.
- It is suspected that G_E^n/G_M^n will exhibit the same behavior at higher Q^2.



Taken from Mark Jones, SBS Collaboration Meeting [1]



GEn-II Readiness Review [4]

Super BigBite Spectrometer (SBS) Program

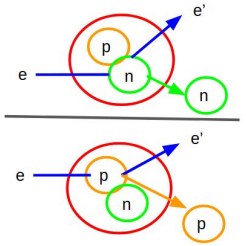
- **Precision Measurement of the Neutron Magnetic Form Factor up to Q^2 = 18.0 $(GeV/c)^2$ by the Ratio Method (GMn).**
- Measurement of the Neutron Electromagnetic Form Factor Ratio G_E^n/G_M^n at High Q^2 (GEn-II).
- Measurement of the Ratio G_E^n/G_M^n by the Double-polarized $^2\mathrm{H}(\vec{e}, e'\vec{n})$ Reaction (GEn-RP).
- Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 $(GeV/c)^2$ Using Recoil Polarization Method (GEp-V).

GMn “Ratio Method” Calculation

- Collide electron beam onto a deuterium target.
- Simultaneously measure the proton and neutron cross section.
- Many systematic errors cancel in the ratio.

Experimentally measured

$$R'' = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{d(e,e'n)}}{\left(\frac{d\sigma}{d\Omega}\right)_{d(e,e'p)}} =$$



Nuclear corrections

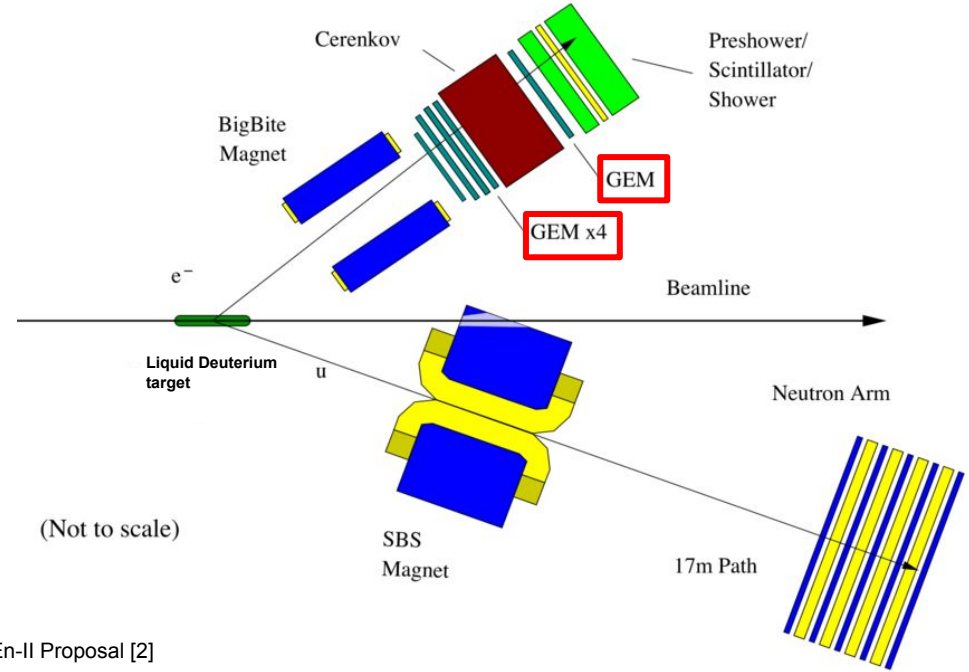
$$R' = \frac{R''}{1+\epsilon_{\text{nuc}}}$$

Form factor extraction

$$R = R' - \frac{\eta \frac{\sigma_{\text{Mott}}}{1+\tau}(G_E^n)^2}{\frac{d\sigma}{d\Omega}\Big|_{p(e,e')}} = \frac{\eta\sigma_{\text{Mott}}\frac{\tau/\epsilon}{1+\tau}(G_M^n)^2}{\frac{d\sigma}{d\Omega}\Big|_{p(e,e')}}$$

SBS GMn Experiment

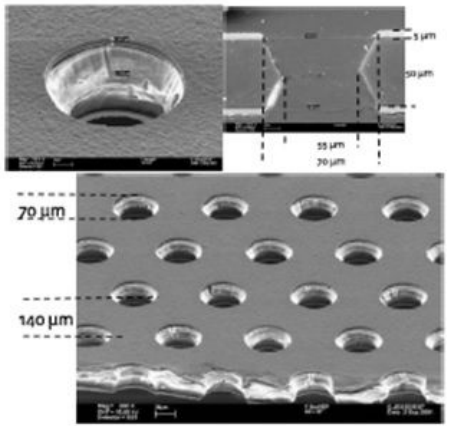
- GMn ran from October 2021 to February 2022.
- Measurements completed at Q^2 = 3.0, 4.5, 7.5, 10, and 13.6 GeV^2.

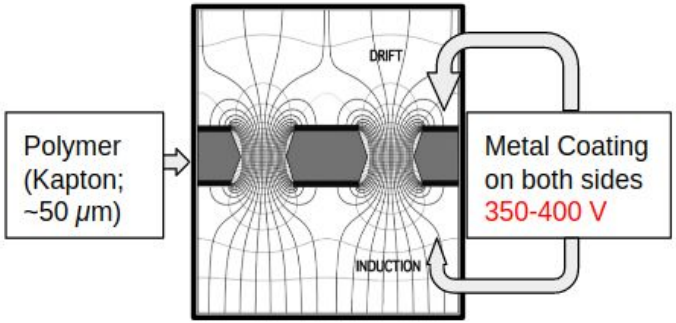


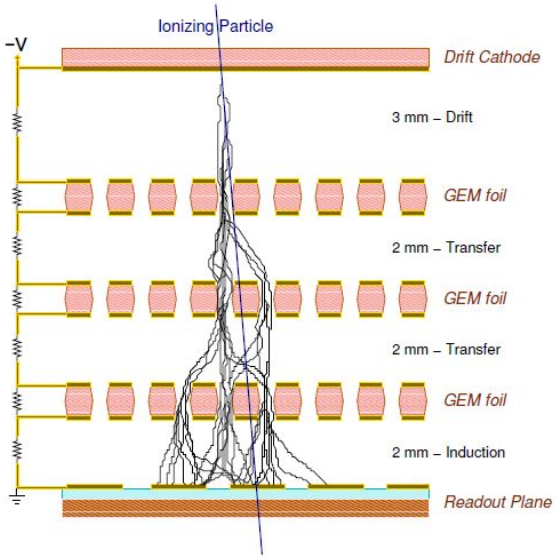
GEn-II Proposal [2]

Gas Electron Multiplier (GEM) Detectors

- The detector consists of three thin foils with micrometer size holes.
- Strong electric fields are created in a very small region.
- Incoming charged particles ionize the gas and shower through large electric fields.
- Resulting shower deposits charge onto copper readout strips.
- Electronics read out the position of the strips hit.



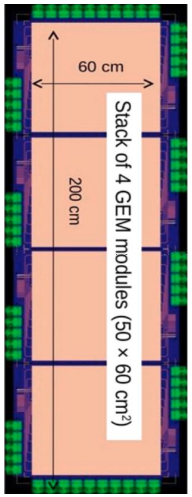




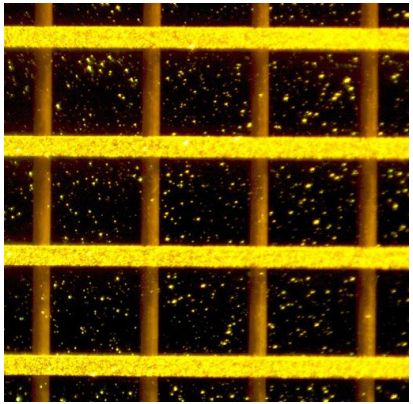
U-V GEM Readout

- UVa group has produced 50 X-Y and 4 U-V GEMs for the SBS experiments.
- National Institute for Nuclear Physics (INFN) in Italy has produced 12 X-Y GEMs.
- Technological improvements have made U-V orientation GEMs possible.
- U-V GEMs can be larger ⇒ Reduce size of dead areas.
- U-V GEMs provide extra coordinate information ⇒ Improved tracking results.

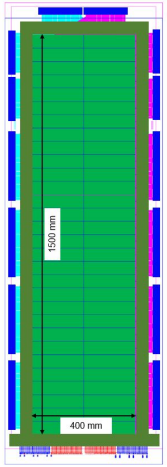
UVa X-Y



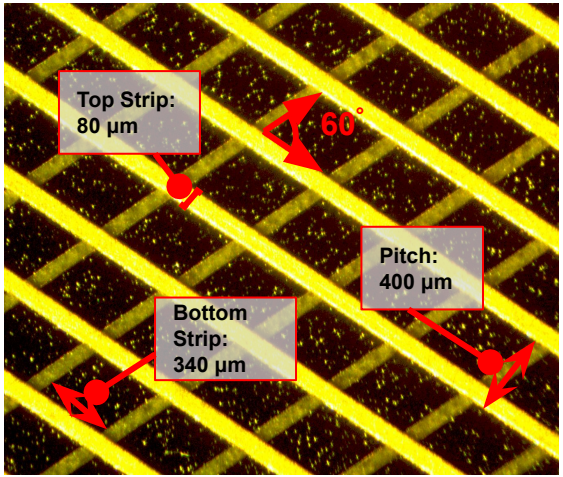
X-Y Readout Strips



UVa U-V

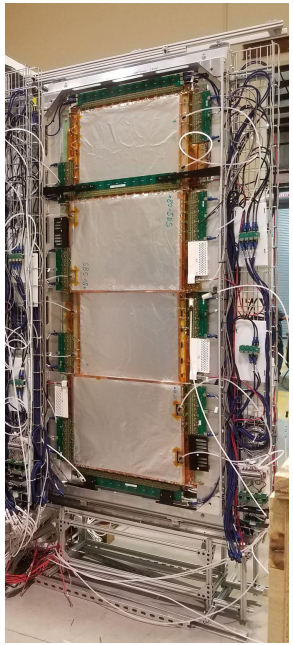


U-V Readout Strips

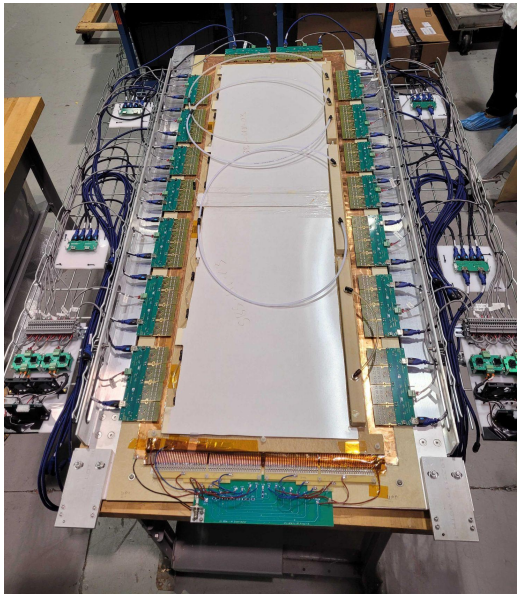


SBS GEM Types

UVa X-Y



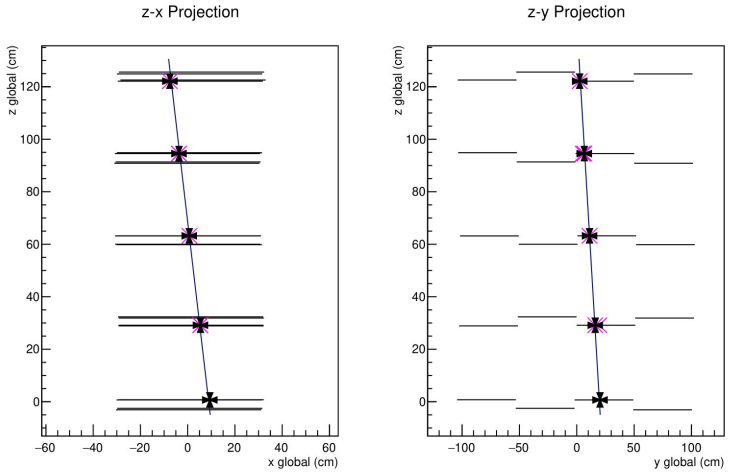
UVa U-V

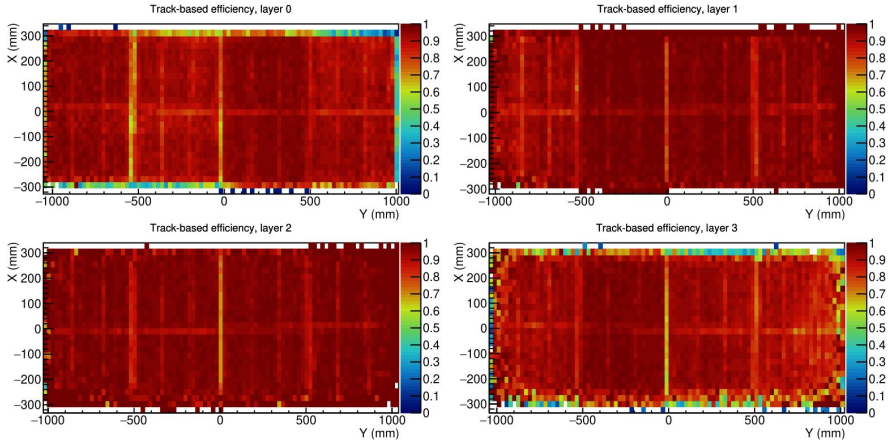


GEM Commissioning at JLab

- Layers stacked together on a large cosmic stand.
- Multiple layers with hits can be used to form tracks.
- Tracks are projected through all layers to look for real hits.

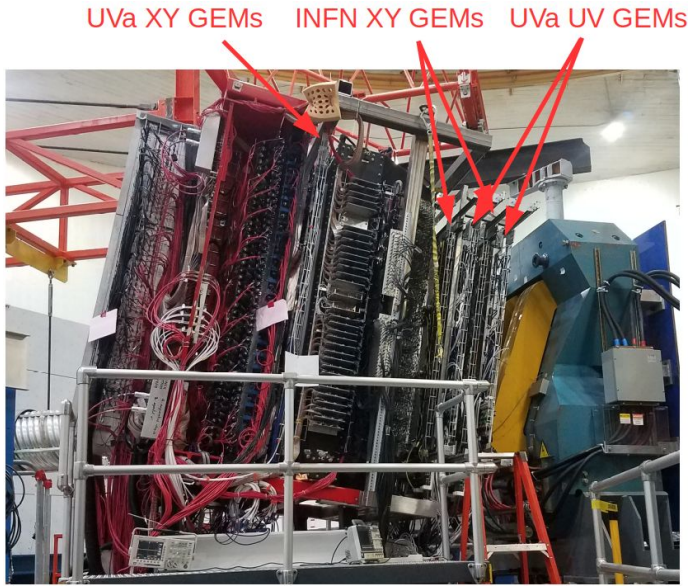
$$\text{Efficieny} = \frac{\text{\# of hits found}}{\text{\# of tracks that should hit}}$$



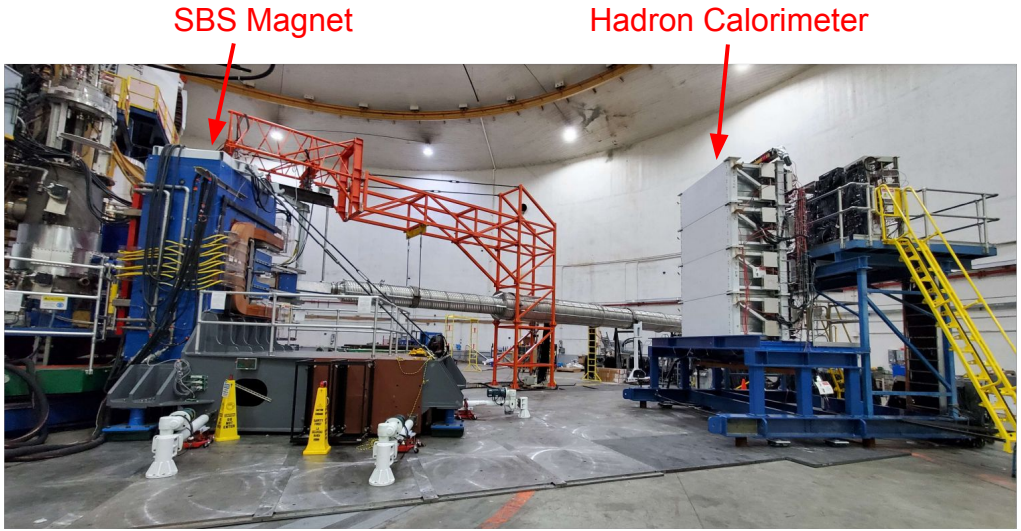


SBS GMn/GEn Spectrometers

BigBite Spectrometer (Electron Arm)

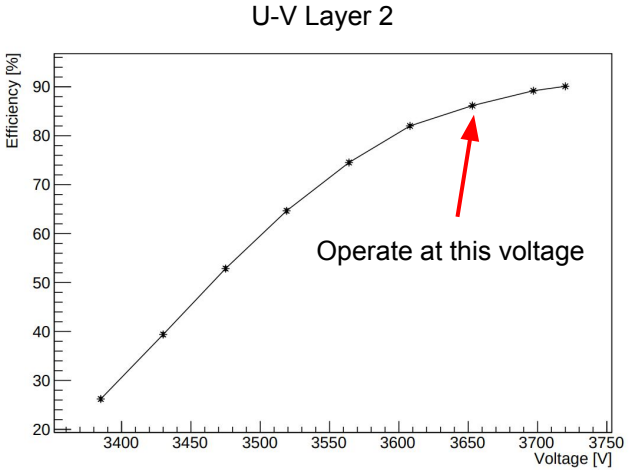


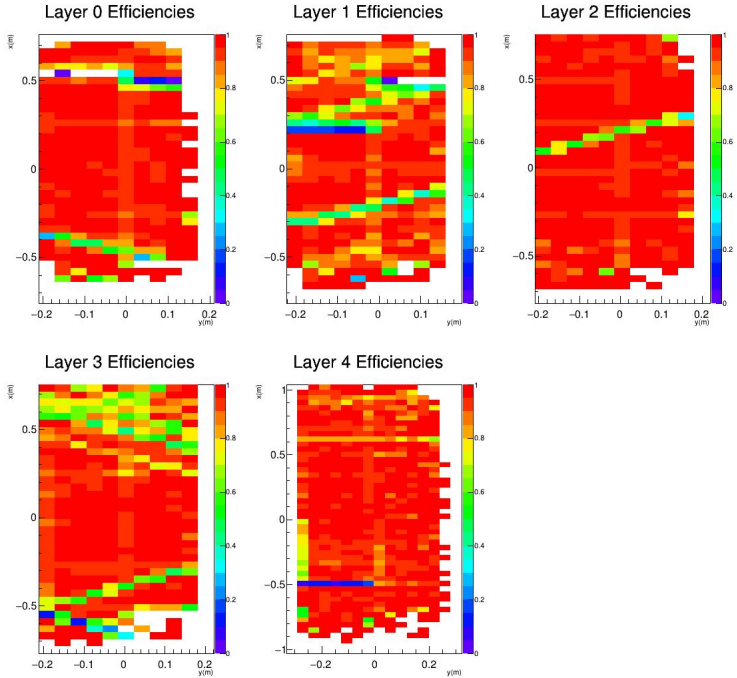
Super BigBite Spectrometer (Neutron/Proton Arm)



GEM Commissioning with Beam

- Under low beam current we varied the GEM voltage and measured the resulting efficiency curve.
- Set operating voltages to the onset of the efficiency plateau.
- This process was completed for all GEM modules.
- Overall 85+% efficiency, except for some worse areas.





High Rate Tracking

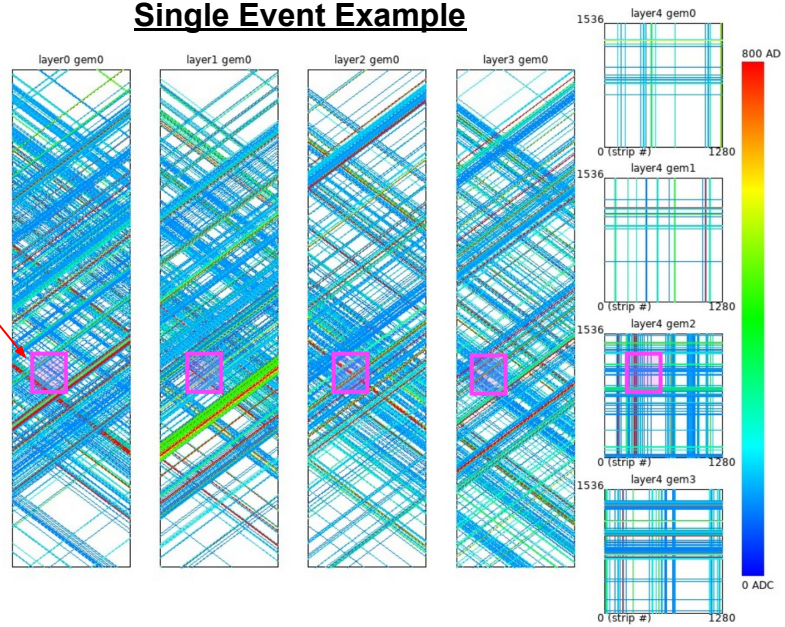
- Large number of possible of 2D hit combinations.
- “Fake hits” from noise would artificially reduce the tracking efficiency.
- Signal on top of a large background could be lost, reducing the efficiency.

Tracking Procedure

- Form all 2D hit combinations from strips.
- Filter hits using a variety of thresholds
  - Cluster ADC
  - Correlation coefficients
  - ADC asymmetry
  - Timing cuts
- Form all possible tracks through hits on layers
  - Cut on calorimeter region
  - Cut on projection back to target

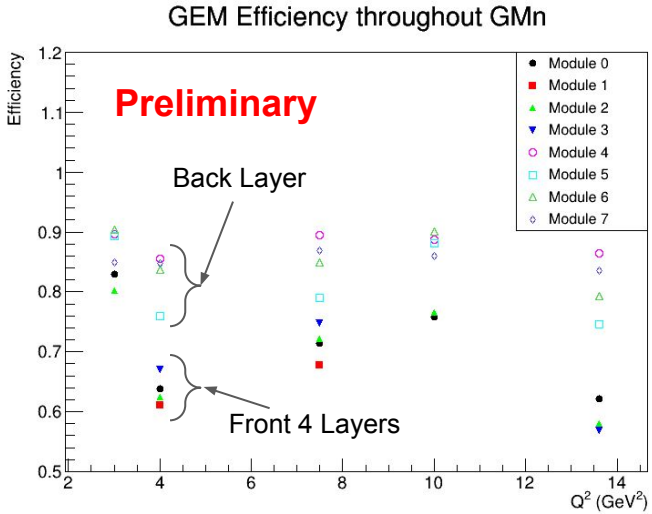
Calorimeter search region

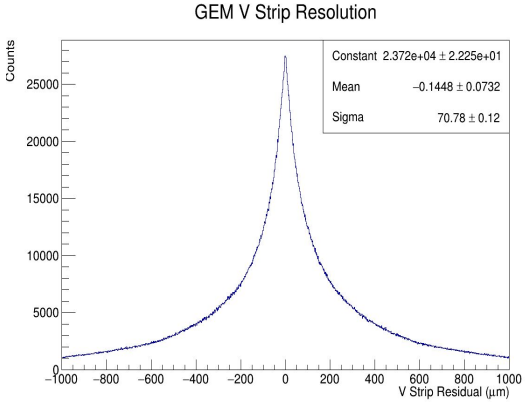
Single Event Example



GEM Overall Performance

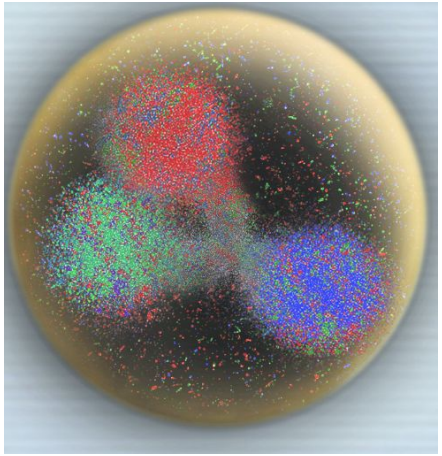
- Due to high rates the back tracker performed consistently better than the front layers.
  - After analysis improvements, real efficiencies will likely be at least 5% better.
- Good position resolutions of 70 μm





Summary

- GMn was completed in February 2022.
- Learned a lot about GEM performances and solutions for future experiments.
  - Many fixes currently being implemented.
- GEn-II will run in the September of 2022.
- FF measurement will provides tests for various hadronic structure models.



References

[1] SBS Collaboration Meeting, Feb 17 - 18 2021: https://indico.jlab.org/event/430/contributions/7832/attachments/6493/8711/mkjones_sbs_ecal_feb_2021.pdf

[2] B. Wojtsekhowski, T. Averett, G. Cates, S. Riordan (spokespersons), Jefferson Lab experiment E12-09-016 - GEn(2): https://misportal.jlab.org/mis/physics/experiments/viewProposal.cfm?paperId=617

[3] B. Sawatzky, V. Bellini, K. Gnanvo, D. Hamilton, M. Kohl, N. Piskunov, B. Wojtsekhowski (spokespersons), Jefferson Lab experiment E2-17-004 (GEn-RP): https://misportal.jlab.org/mis/physics/experiments/viewProposal.cfm?paperId=919

[4] Gordon Cates, GEn 2020 Experimental Readiness Review: https://hallaweb.jlab.org/wiki/images/0/0f/Cates_err_oct_2020_v4-compressed.pdf

[5] S. Gadomski, G. Hall, T. Høgh, P. Jalocha, E.Nygårdd, P.Weilhammer, *The deconvolution method of fast pulse shaping at hadron colliders*, Nucl. Instr. Meth. Phys. Res A, 320 (1992)

[6] G.D. Cates, C.W. de Jager, S. Riordan, B. Wojtsekhowski, Phys. Rev. Lett. **106** 252003 (2011)