Proton Form Factor Measurement Using Recoil Polarization Method

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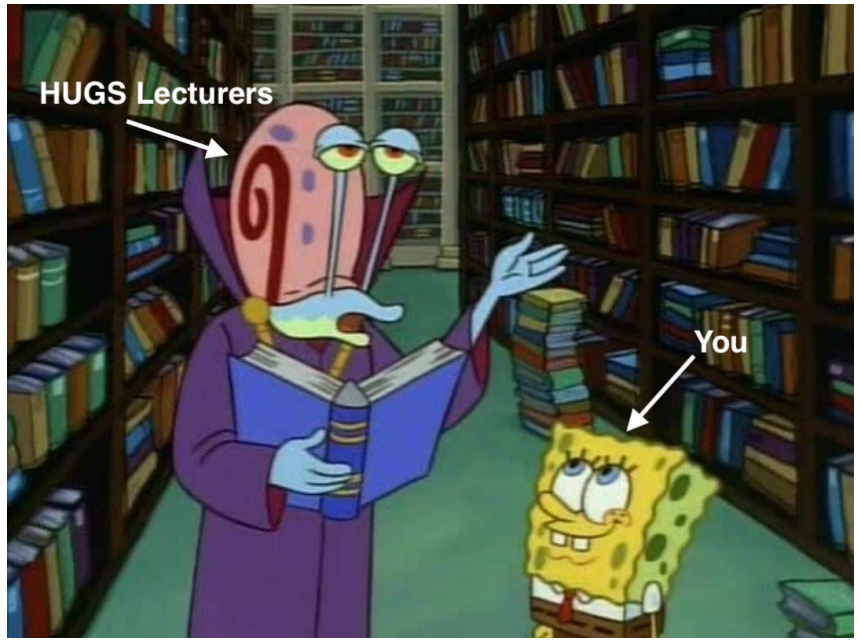
Outline

- Discussion of the proton electromagnetic form factor
  - Refresher from previous lectures
- The experiment
  - How will we make this measurement?
- The detectors
  - How do the polarimeter and tracking detectors work?

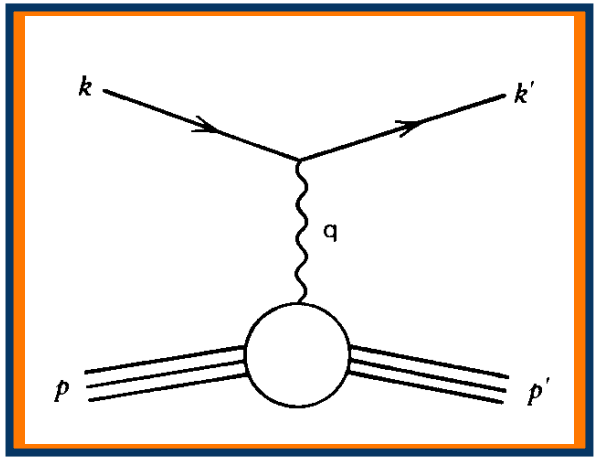
Previous Discussions

- [1] Y. Roblin, “A positron beam at Jlab”, Slides 5,6,7,8,11, May 28 2024
- [2] P. Rossi, ”JLab now and in the future”, Slides 21,22,23, May 29 2024



Nucleon Elastic Form Factors

- Form Factors describe internal structure of the nucleon
  - Elastic ⟹ Ground state structure
  - Charge and magnetization distributions ⟹ Nucleon Transition Current



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

- Use Sach's form factors:
  - Fourier transforms of the electric and magnetic moments distributions in the Breit frame

$$G_E(Q^2) = F_1(Q^2) - \tau F_2(Q^2)$$
$$G_M(Q^2) = F_1(Q^2) + F_2(Q^2)$$

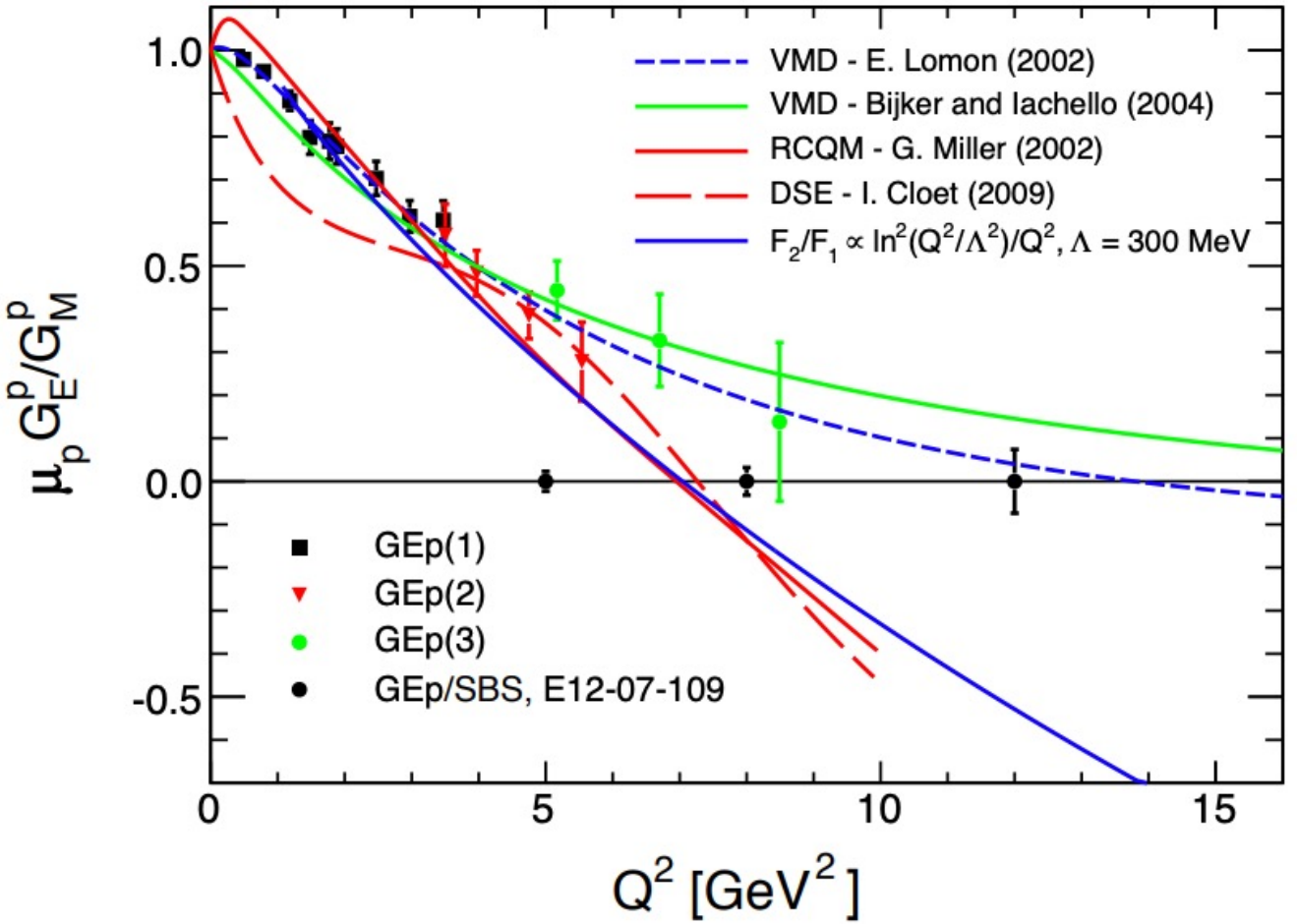
  - Scalar functions of Q^2 which parameterize the unknown nucleon structure

Brief Theoretical Background

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{\alpha^2 E' \cos^2(\frac{\theta}{2})}{4E^3 \sin^4(\frac{\theta}{2})}[(F_1^2 + \kappa^2 \tau F_2^2) + 2\tau(F_1 + \kappa F_2)^2 \tan^2(\frac{\theta}{2})]$$

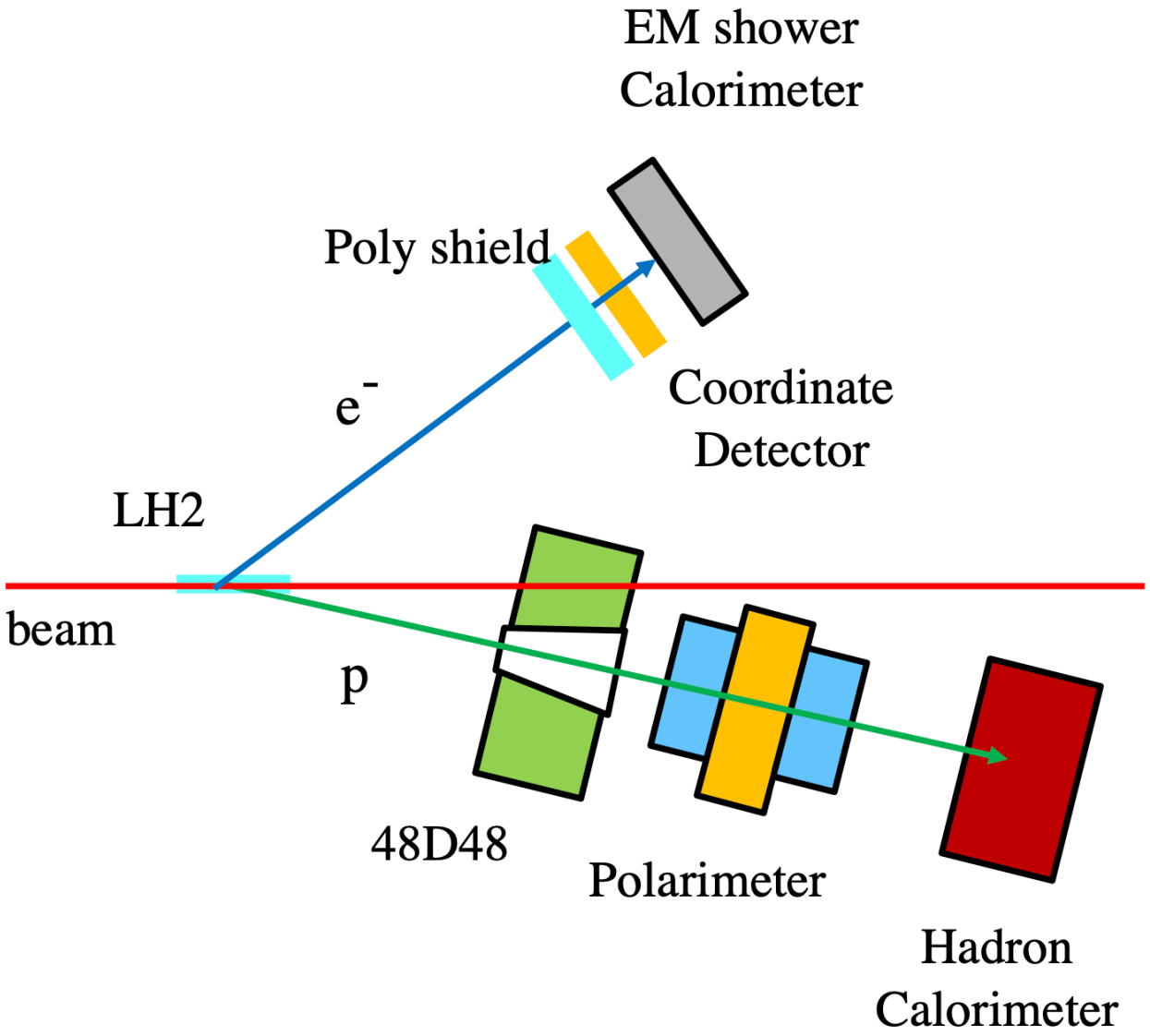
$$\frac{d\sigma}{d\Omega}(E,\theta) = \sigma_M[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2(\frac{\theta}{2})]$$

- Theory originally predicted $\frac{G_E}{G_M} = 1$
  - Instead dies off rapidly at high Q^2
- Models since differ greatly at high Q^2
  - Two-photon exchange likely culprit!
  - Cross sections don't account for this



[3] L. Pentchev (contact) et al., "Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 (GeV) Using Recoil Polarization Method." Jefferson Lab Experiment E12-07-109, 2007

The Experiment: E12-07-109 (GEp-V)



- The Bigbite Spectrometer
  - Poly shield
  - Scintillators
  - Calorimeter
- The Super Bigbite Spectrometer
  - Large dipole magnet
  - Polarimeter
    - GEM tracking layers
    - CH_2 polarimeter analyzer
    - GEM tracking layers
  - Hadron Calorimeter
- Both sides are on a track and can be rotated to different angles

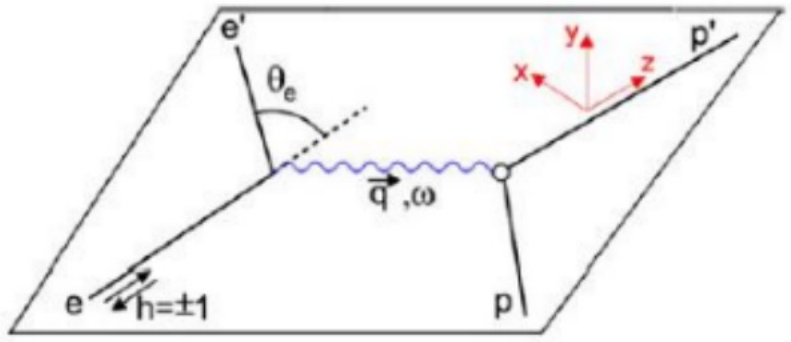
$$\frac{G_E^P}{G_M^P} = -\frac{P_t}{P_l}\sqrt{\frac{\tau(1+\epsilon)}{2\varepsilon}}$$

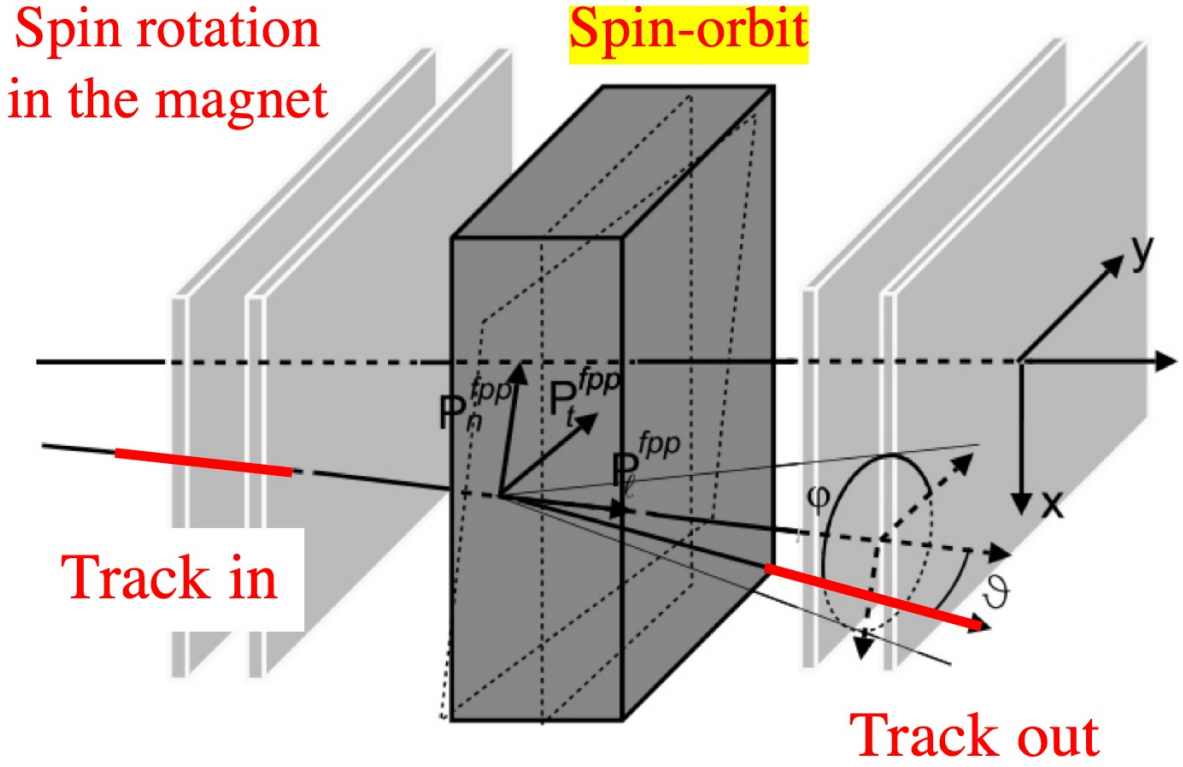
Experimental Measurement

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

$$\mu_p \frac{G_E^p}{G_M^p} = -\mu_p \frac{E_e + E'_e}{2M_p} \tan\frac{\theta_e}{2} \left(\frac{P_x^{fpp}}{P_y^{fpp}} \sin\chi_\theta + \gamma_p(\mu_p - 1)\Delta\phi \right)$$

- Experimentally we relate FF ratio to polarization ratio
- $P_x/P_t \Longrightarrow$ Polarization transverse to momentum
- $P_y/P_l \Longrightarrow$ Polarization longitudinal to momentum



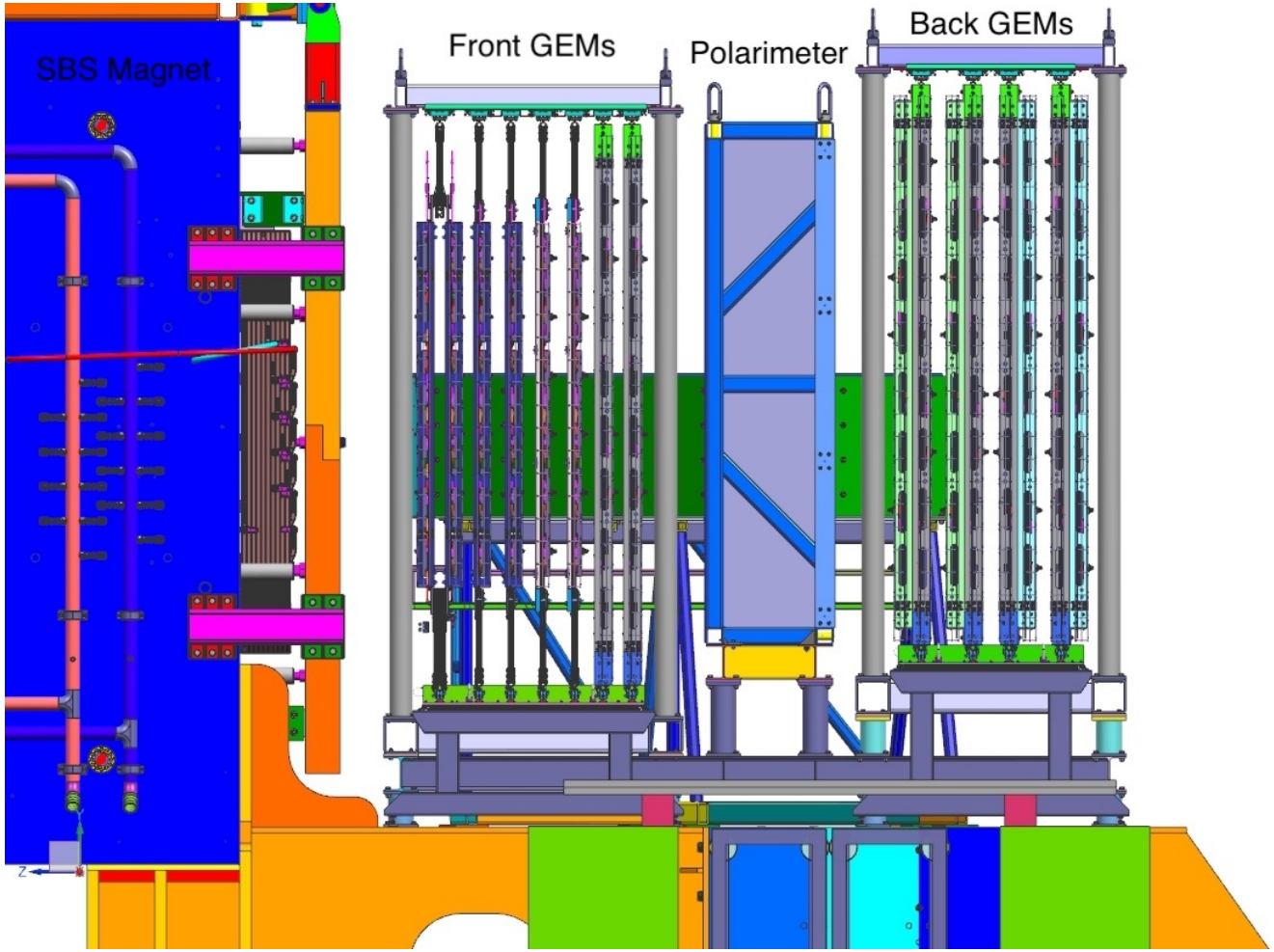


$$\frac{G_E^P}{G_M^P} = -\frac{P_t}{P_l}\sqrt{\frac{\tau(1+\epsilon)}{2\varepsilon}}$$

[4] B. Wojtsekhowski et al., "GEp Experimental Readiness Review 2023." https://hallaweb.jlab.org/wiki/index.php/ERR#Agenda, 2023

The Hadron Arm

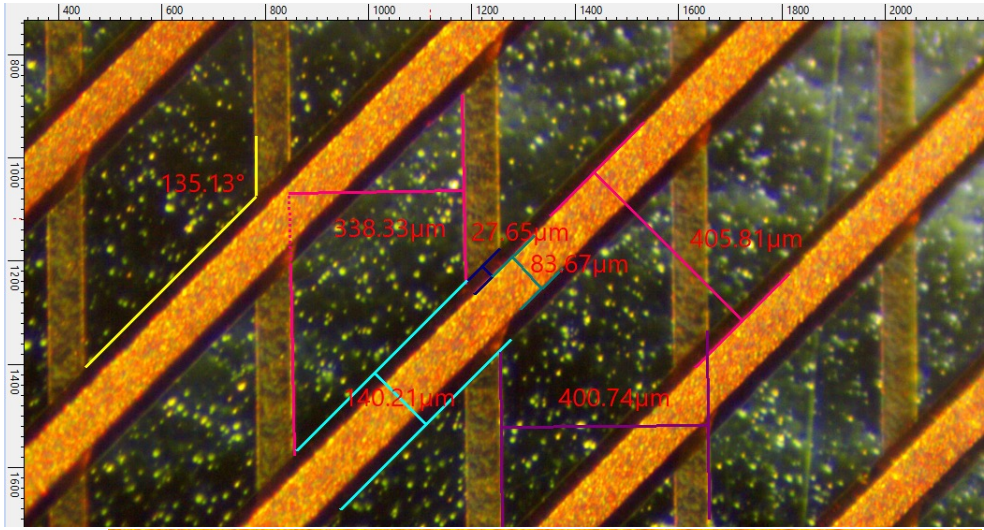
- GEM tracking detectors
  - Scattering angle, position, direction, etc.
- 8 GEM layers in forward and back trackers
  - Front – 4 UV, 2 XW, 2 XY
  - Back – 8 XY
- All built by UVa group

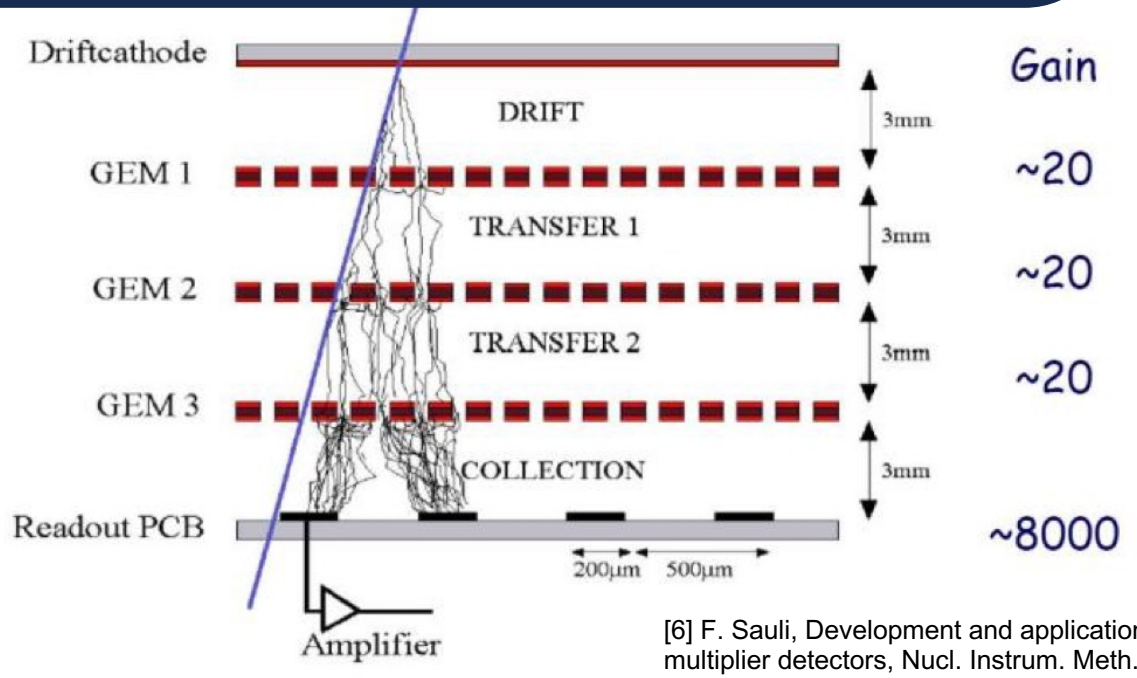


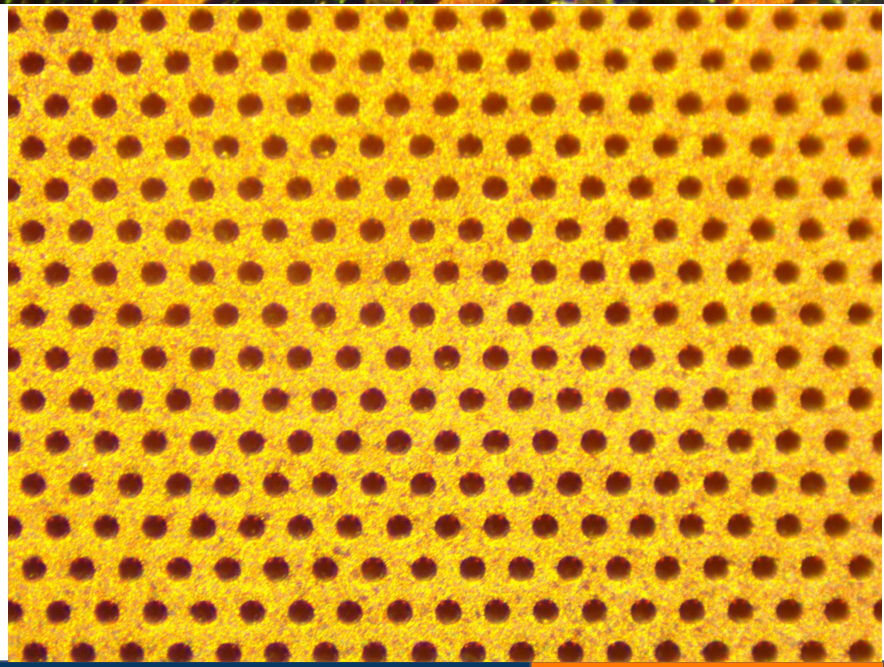
[5] H. Szumila-Valnce et al., “GEp Experimental Readiness Review 2023.” https://hallaweb.jlab.org/wiki/index.php/ERR#Agenda, 2023

GEM Detectors

- Gas Electron Multiplication
  - Incident particles ionize gas
  - Electrons accelerated across Drift field
  - Avalanche Multiplication in GEM regions
  - Charge deposited on readout board (crossing wire strips or sometimes pixels)
  - APV25 cards read signals and provide ADC values
- Mixture of Argon (70-75%) and CO2 (30-25%)



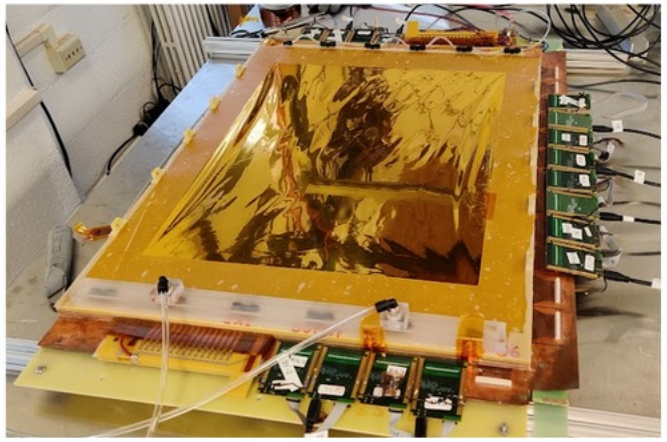


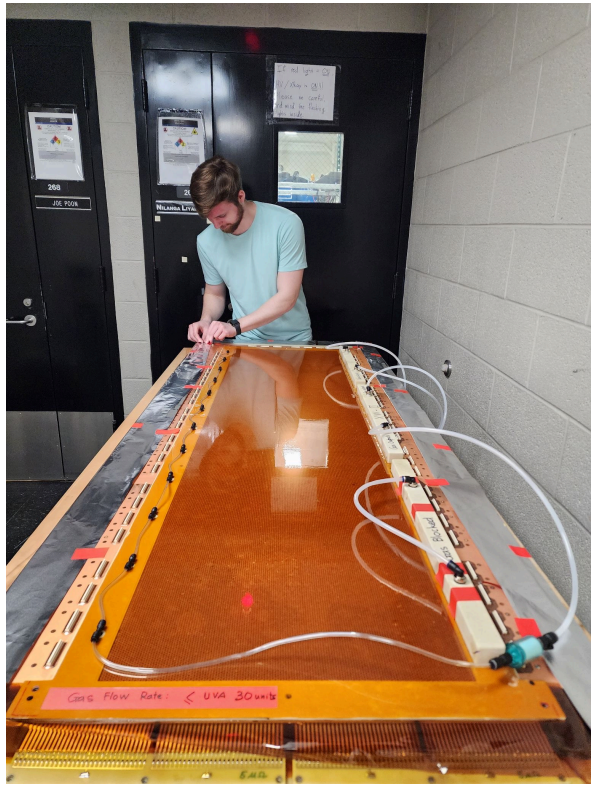


[6] F. Sauli, Development and applications of gas electron multiplier detectors, Nucl. Instrum. Meth. A 505 (2003) 195–198.

GEM Characteristics

- 3 mm spaced triple GEMs
- GEM hole diameter/pitch: 70/140 µm
- Readout wire spacing:
  - Resolution: 70 µm
- Wire Pitch:
  - XW: 35°
  - UV: 45°
  - XY: 90°
- Active Area:
  - XW/UV: 150x40 cm²
  - XY: 50x60 cm²





Summary and Outlook

- SBS experiment E12-17-004 (GEn-RP) completed May 2024
- SBS currently being reconfigured for GEp-V
- Nominal start date of October 24th, 2024
  - Completion in April 2025 with subsequent analysis

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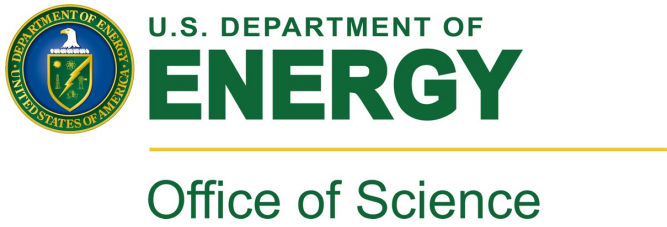
- The SBS Collaboration
- JLab Staff who have helped and contributed to the program
- US Department of Energy, Office of science, Office of Nuclear physics award number DE-FG02-03ER41240
- HUGS Program & Coordinators!



References

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[2] P. Rossi, ”JLab now and in the future”, Slides 21,22,23, May 29 2024

[3] E. Cisbani, N. Liyanage, L. Pentchev (contact), A. Puckett, M. Jones and B. Wojtsekhowski (spokespersons), “Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 (GeV) Using Recoil Polarization Method.” Jefferson Lab Experiment E12-07-109, 2007 with 2019 update.

[4] B. Wojtsekhowski et al., “GEp Experimental Readiness Review 2023.” https://hallaweb.jlab.org/wiki/index.php/ERR#Agenda, 2023

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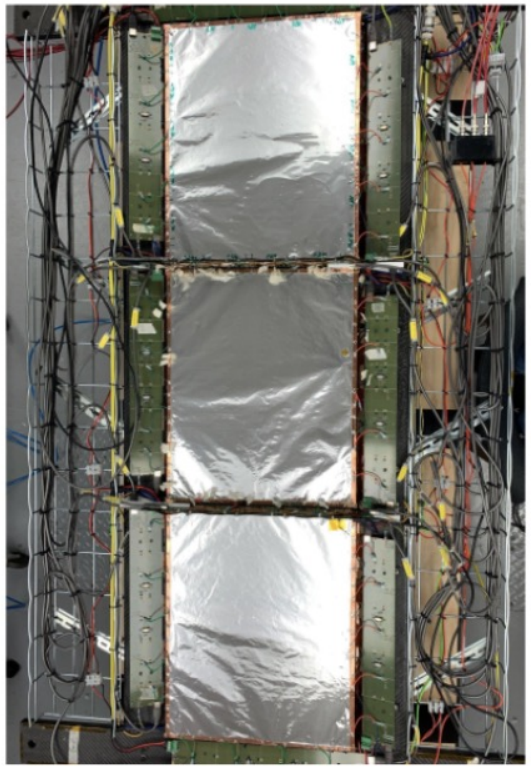
[6] F. Sauli, Development and applications of gas electron multiplier detectors, Nucl. Instrum. Meth. A 505 (2003) 195–198.

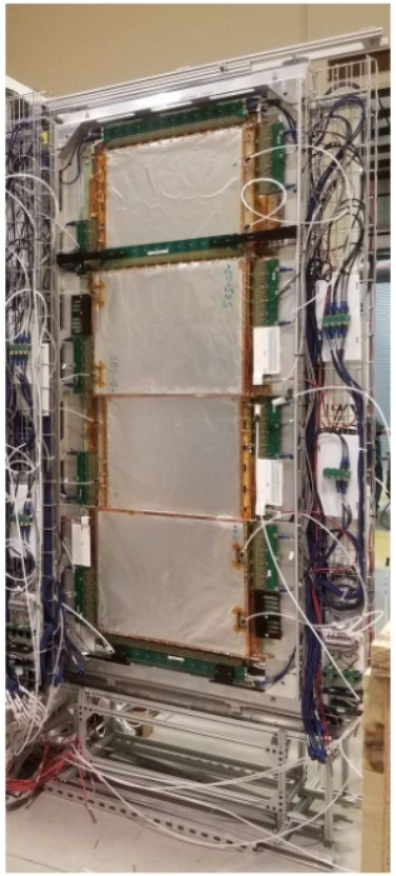
Backup Slides

SBS GEM Types

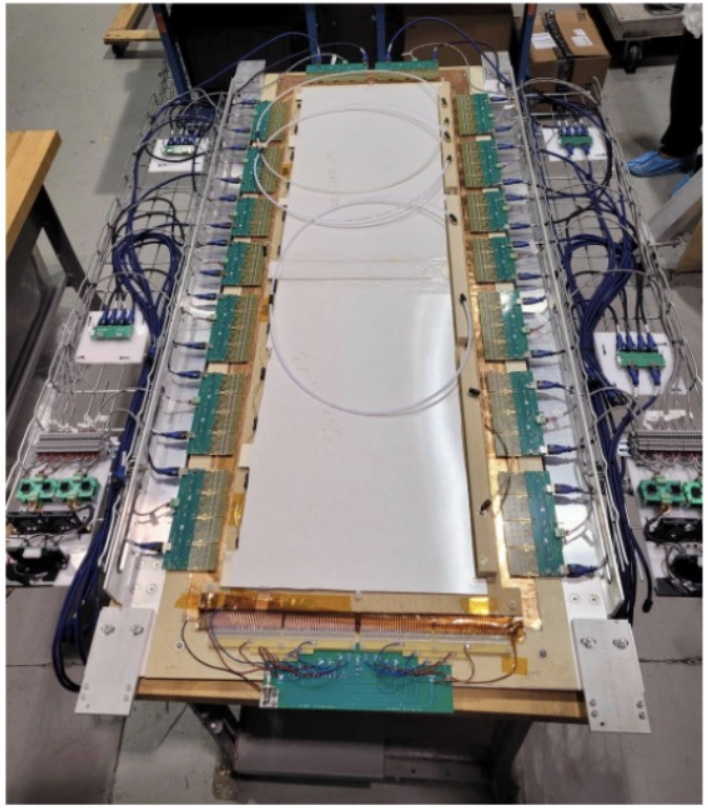
INFN X-Y



UVa X-Y



UVa U-V



UV GEM