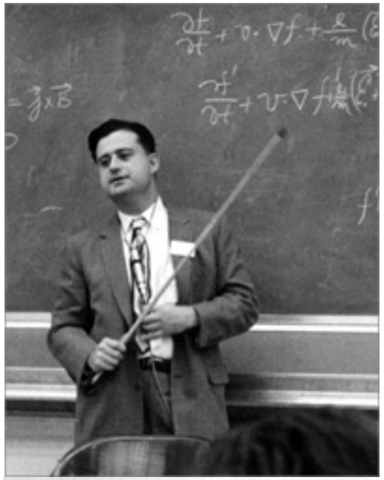
GEp experiment overview

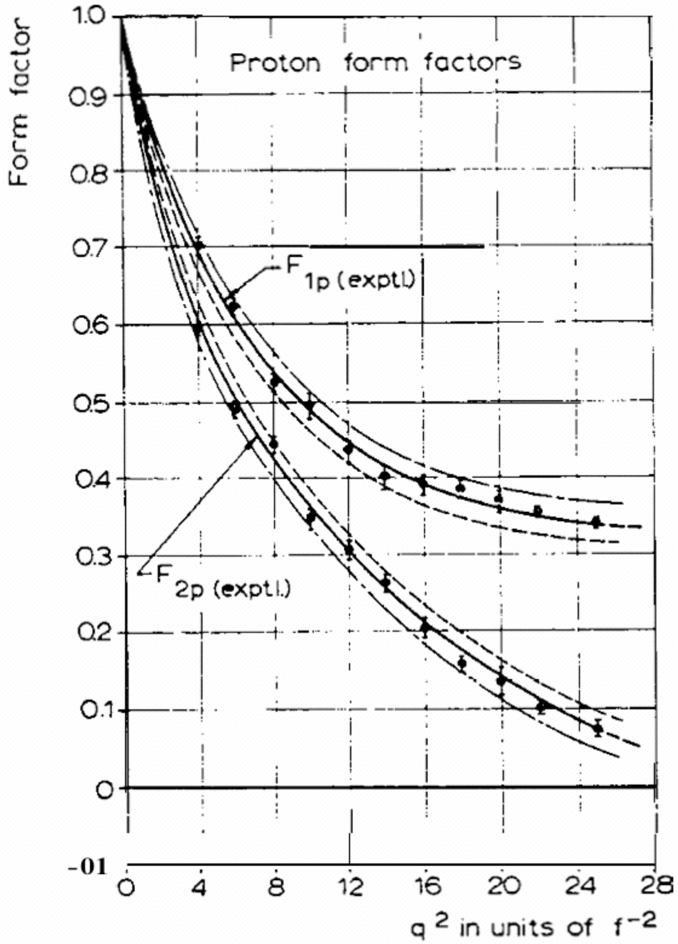
B. Wojtsekhowski, TJNAF

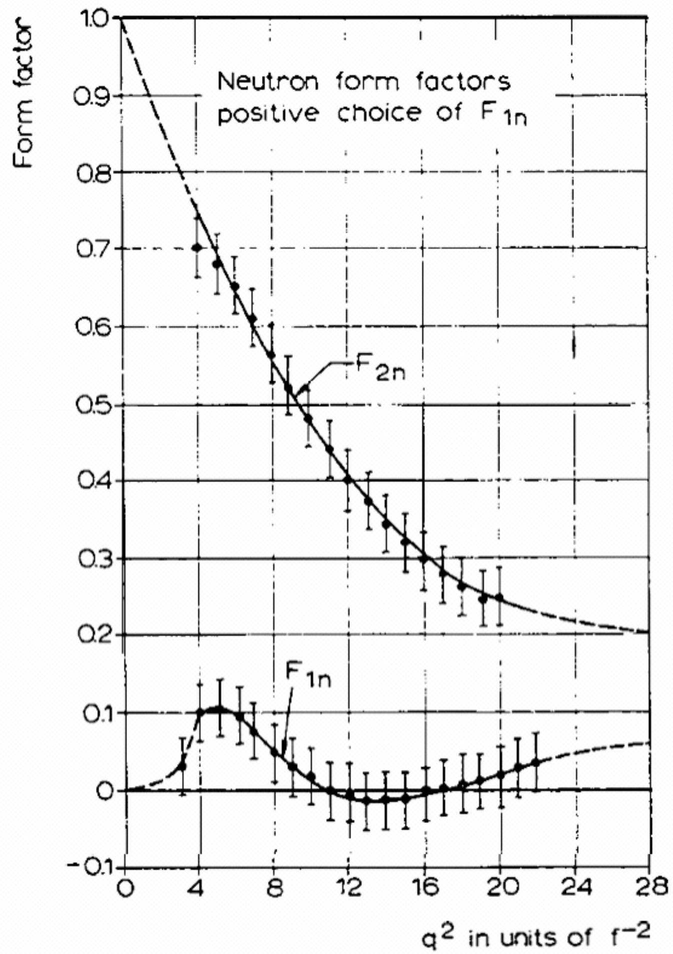
on behalf of the SBS collaboration

The story of nucleon structure

- 1933 Stern paper on anomalous magnetic moment of proton
- 1947 Fermi paper on pion-cloud role in e-n interaction
- 1950 Rosenbluth and 1956 Hofstadter nucleon Form Factors







The story of nucleon structure

- SLAC high Q2 study of the nucleon FF and more in DIS
- Dipole fit from low Q2 up to 30 GeV2, Breit frame, VMD, pQCD
- From 1957 paper by Akhiezer to 1993 proposal by Perdrisat
- Recoil polarimetry at CERN/Dubna/Orsay
- Polarized electron beam from SLAC/Bates to CEBAF (85%)
- 1988/1993 proposals by Charles and Vina

ref. 4 disagree with both, indicating a constant ratio up to $Q^2=5$ GeV^2. This less than satisfactory situation illustrates the difficulty in separating G_{Ep} from cross section data, by the Rosenbluth separation method; at the risk of becoming unpopular, we would submit that the electric form factor of the proton is known at the present to $\pm 20\%$ above 2-3 GeV^2 if one takes into consideration the actual scatter of the data from these 3 experiments. The present experimental situation for G_{Ep} does strongly suggest that a new and independent technique should be used, and the recoil polarization technique proposed here is just the right one to resolve this ambiguity. The projected error bars we propose to obtain in this experiment up to $Q^2=4.5$ GeV^2 are in the range 1 to 2.5% if h=0.8 (and are shown as filled squares in figure 1), 1.5 to 4.5% with h=0.4. The systematics will be much better controlled because a measurement of G_{Ep}/G_{Mp} at a given Q^2 consists of a simultaneous determination of the transverse and longitudinal polarization components of the proton polarization.

The story of nucleon structure

- Recoil polarimetry at CERN/Dubna/Saclay
- Polarized electron beam from SLAC/Bates to CEBAF (85%)
- 1993 + 1999 proposals by Charles, Mark, Vina, Ed
- The 1998 GEp-I discovery that GEp/GMp falls with Q2

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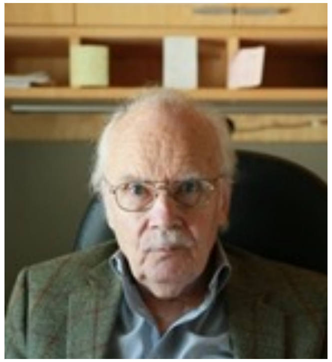
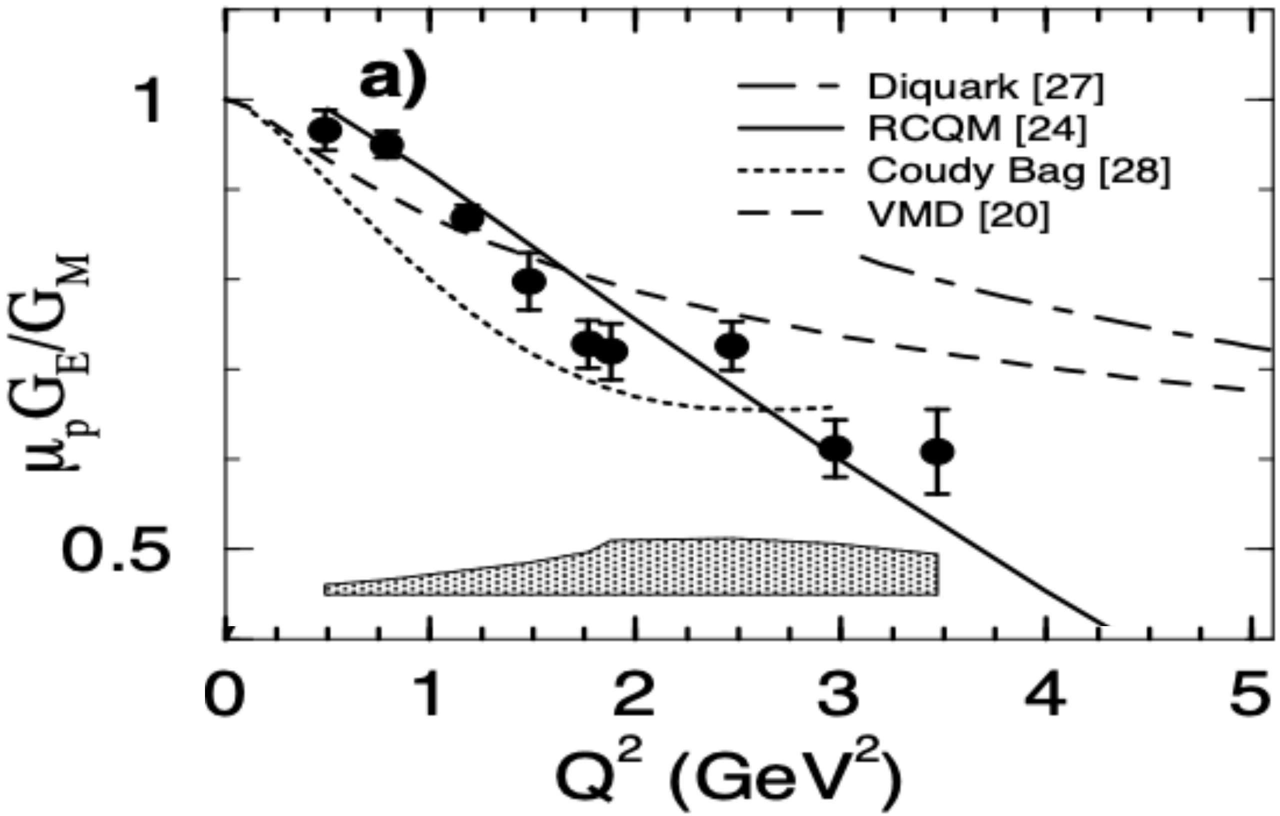


Bonner prize 2017

https://hallaweb.jlab.org/publications/AnnualReports/



The story of nucleon structure

- What is the nature of GEp reduction: 2-γ ? or other effects (Kuraev)
- Revival of form factor physics, Q2 is too low for pQCD, now GPDs
- Transverse distribution, u/d separation in the observables
- F1/F2 flavor decomposition for x_{Bj} = 1, PRL 106, 252003 (2011)

JIMP A, 18, 2, 173-207 (2003)
M.Burkhardt

184 *M. Burkardt*

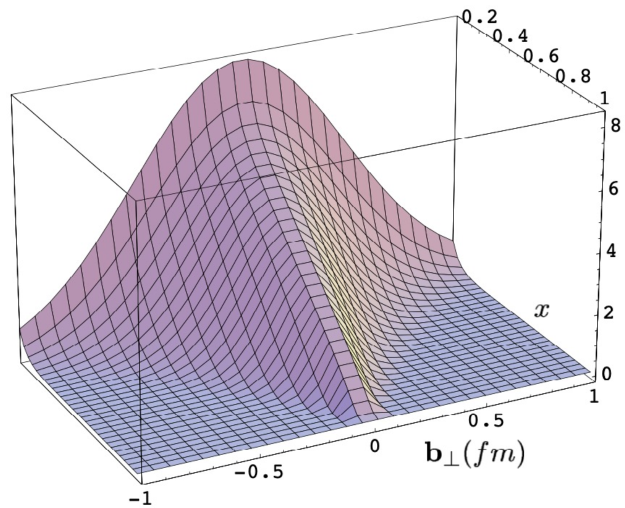
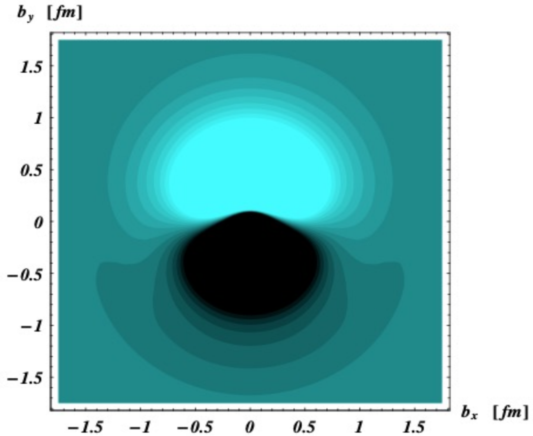
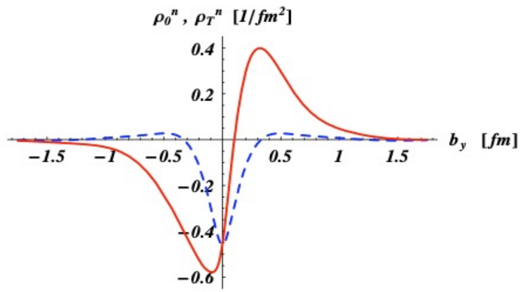


Fig. 1. Impact parameter dependent parton distribution $u(x, \mathbf{b}_\perp)$ for the simple model (31).

Nucl. Phys. A 805 (2008) 210
M.Vanderhaeghen





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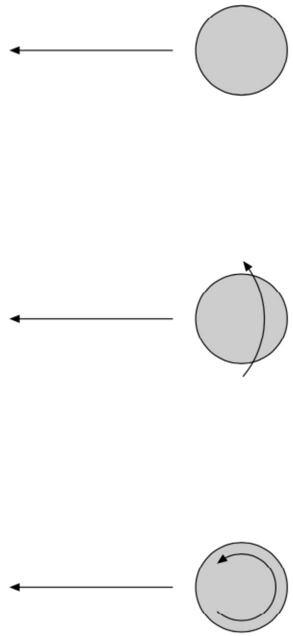

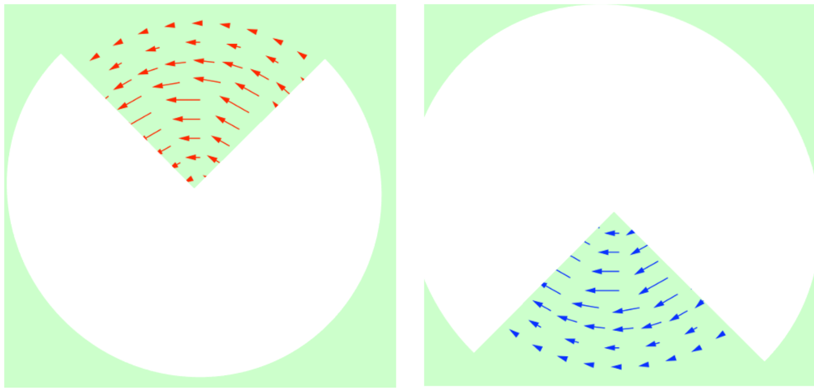

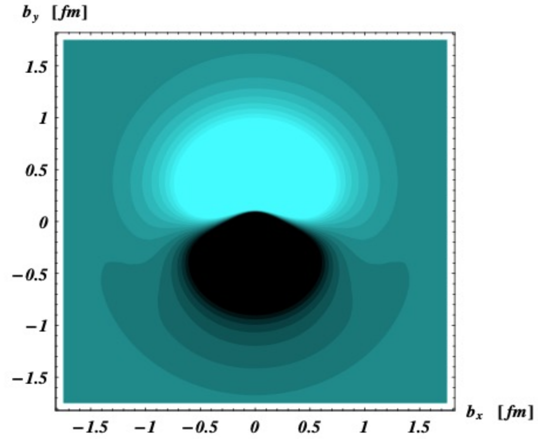

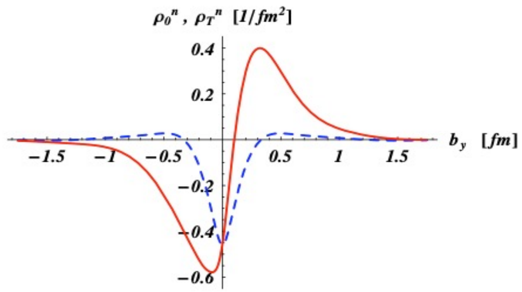

γ*-q interaction selects the side

The story of nucleon structure

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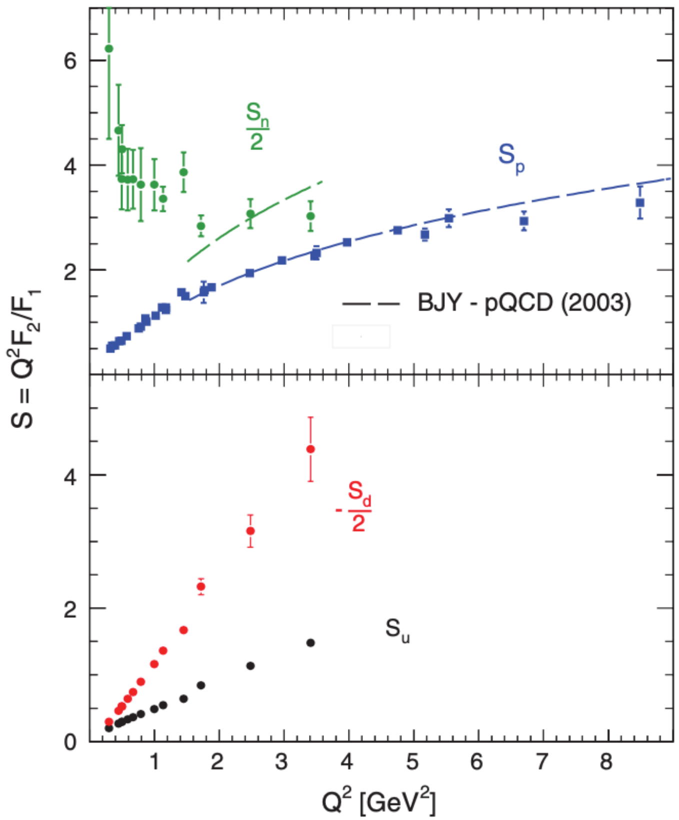
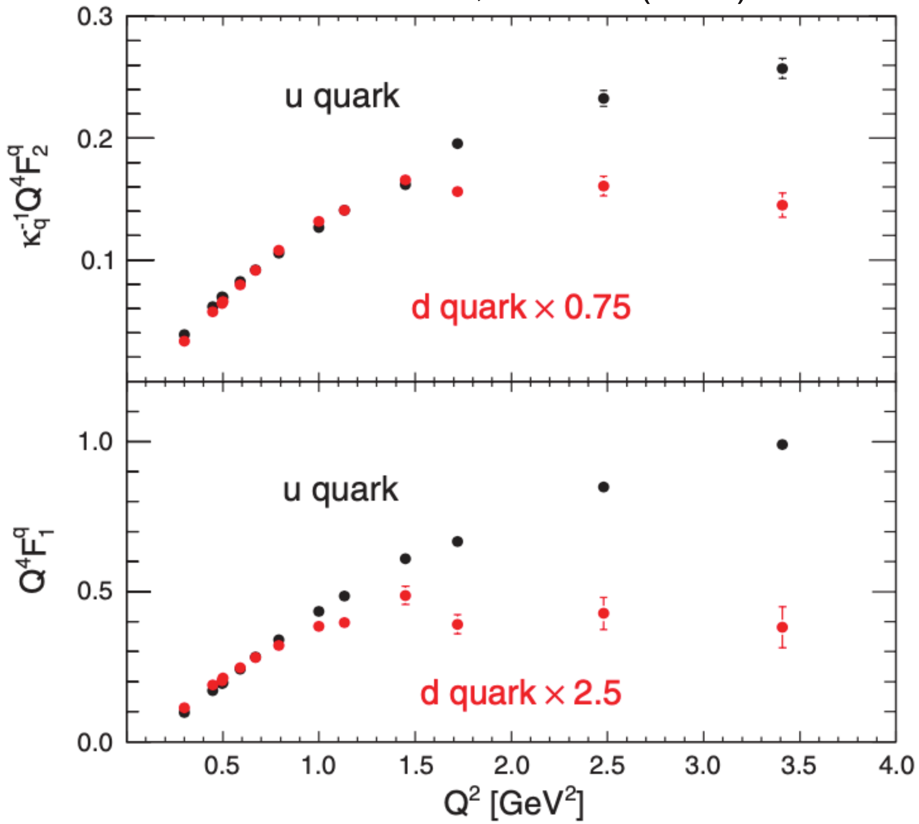
- F1/F2 flavor decomposition for x_{Bj} = 1, diquark evidence



PRL 106, 252003 (2011)



GEP-15

Large Acceptance Proton Form Factor Ratio Measurement at 13 and 15 GeV^2 Using Recoil Polarization Method

C.Perdrisat, L.Pentchev, E.Cisbani,
V.Punjabi, B.Wojtsekhowski
with more than 100 collaborators
from almost 30 institutions

GEp experiment overview

Challenges

$$\text{Form factor} \propto Q^{-4}$$

$$\text{Cross section} \propto E^2/Q^4 \times Q^{-8}$$

$$\text{Figure-of-Merit } \epsilon A_Y^2 \times \sigma \times \Omega$$

$$\propto E^2/Q^{16}$$

GEp-I used an electron in HRS-R, a proton in HRS-R

GEp-II used an electron in 3.4 m^2 ECAL, a proton in HRS-L

GEp-III used an electron in 2.9 m^2 ECAL, a proton in HMS

GEp experiment overview

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Need max statistics → max luminosity + max solid angle

Max luminosity → large background

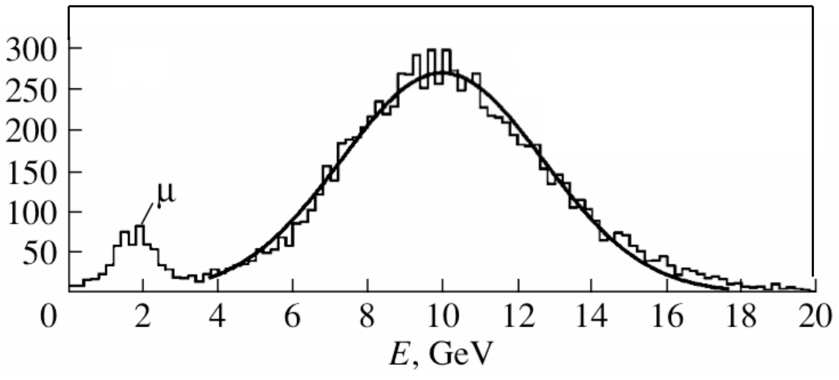
Large solid angle → open detector → huge background

Solution for a solid angle is Super Bigbite Spectrometer

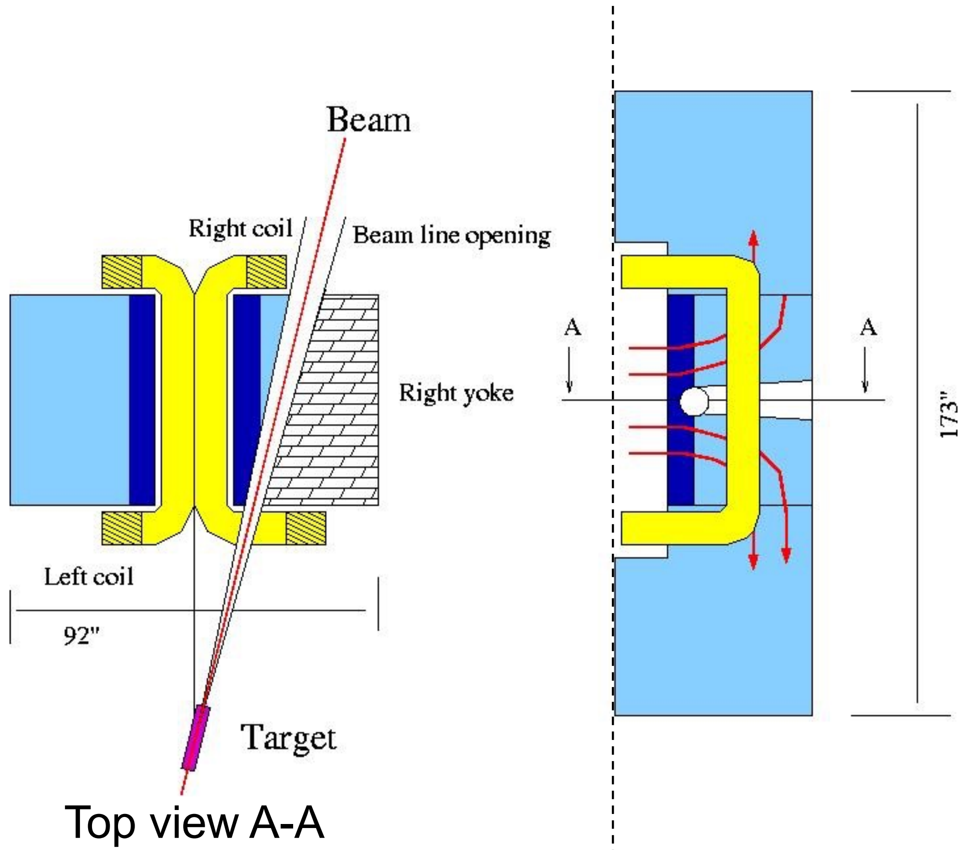
Solution for a tracking detector is Gas Electron Multiplier

GEp experiment overview

- Magnet: 48D48 - 46 cm gap, 3 Tm field integral, 100 ton
- solid angle is 35 msr for GEP, could be ~70 msr at larger angle
  GEM chambers for tracking with 70 μm resolution
- momentum resolution is 0.5% for 8.5 GeV/c proton
- angular resolution is 0.3 mrad
- trigger threshold is 4 GeV from
  hadron calorimeter



Calorimeter response for 10 GeV protons
from test for Compass experiment



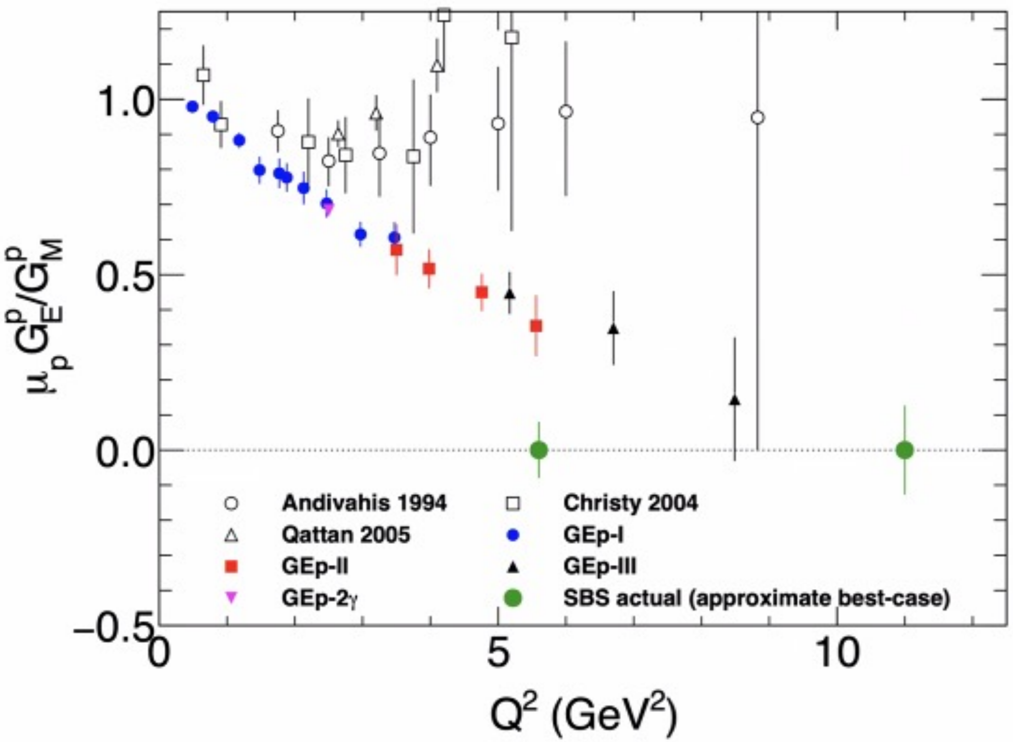
Top view A-A

GEp experiment overview

- 12 GeV CEBAF advance and the high momentum transfer GEp/GMp
- Super Bigbite Spectrometer as in 2007, 48D48, HCAL, GEM, ECAL ++
- Data taking 4.5-month run in 2025 4/10 – 8/24

Summary of data collected and best-case scenario for physics result

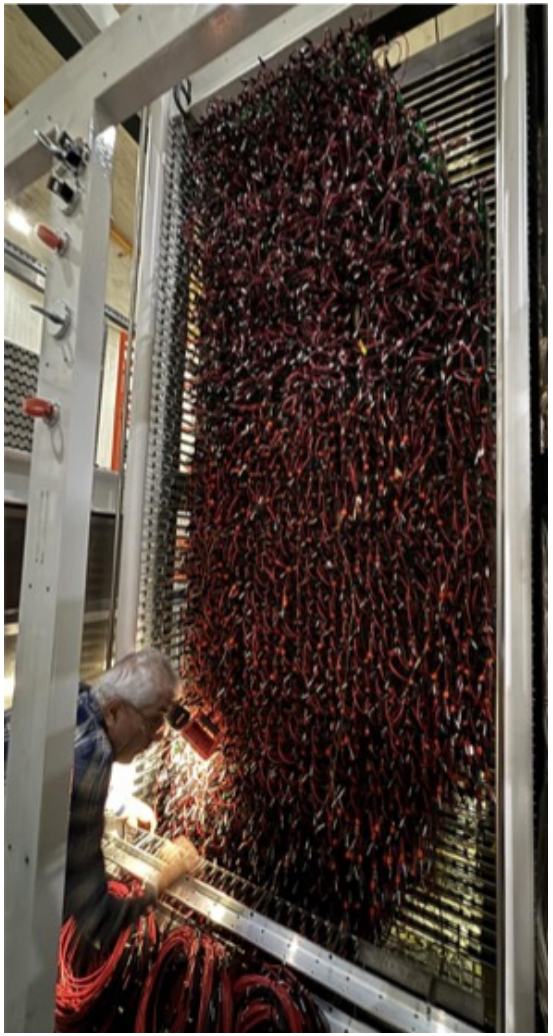
- $Q^2 = 5.6\ GeV^2$: 3.7 C
- $Q^2 = 11\ GeV^2$: 94.2 C
- Note: these estimates are based on the "GEp5 Run Sheet" and may be slight underestimates.
- The two projected points from the SBS GEP experiment as executed represent somewhat optimistic *best-case* scenarios based on the accumulated charge at each Q^2 assuming overall trigger/detection/reconstruction efficiency of 70% (and does not account for radiative losses).
- Reality will fall short of this projection, perhaps significantly.



UCONN

Components of the GEP/SBS experiment

- Electron beam with max energy and polarization
- Cryogenic 30 cm LH2 target
- Electron arm for 3.2 m^2 active area calorimeter, radiation immune



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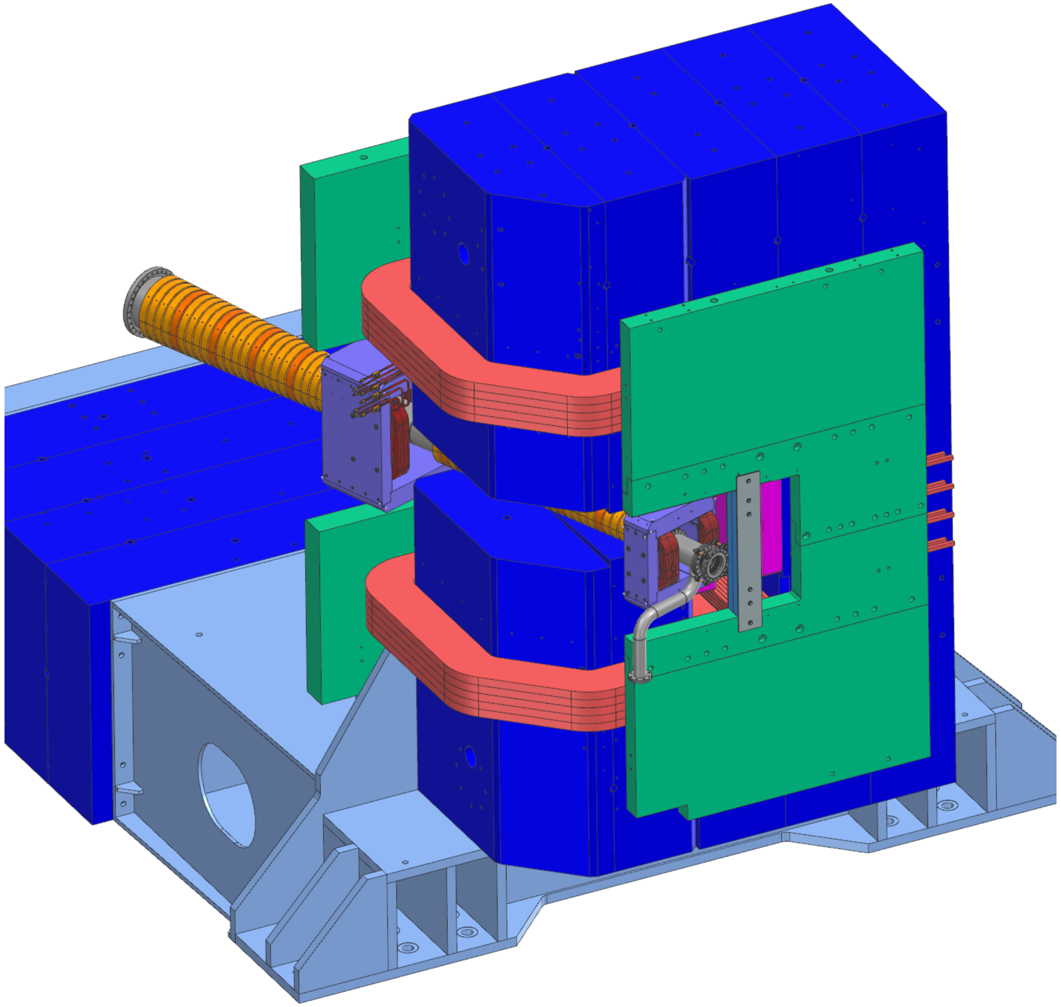

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- Electron beam with max energy and polarization
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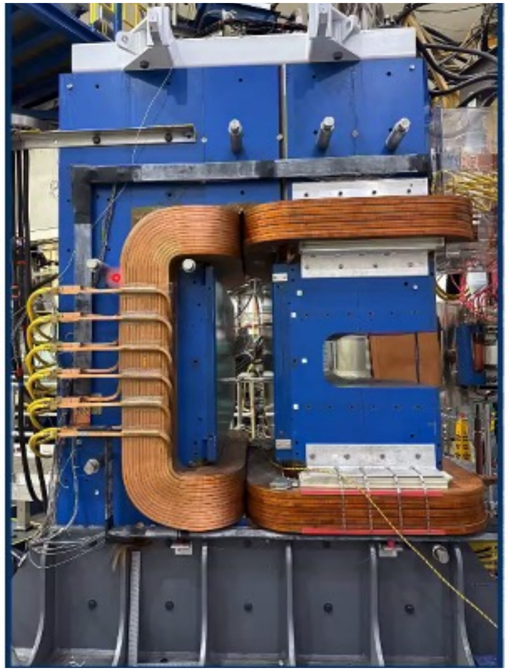
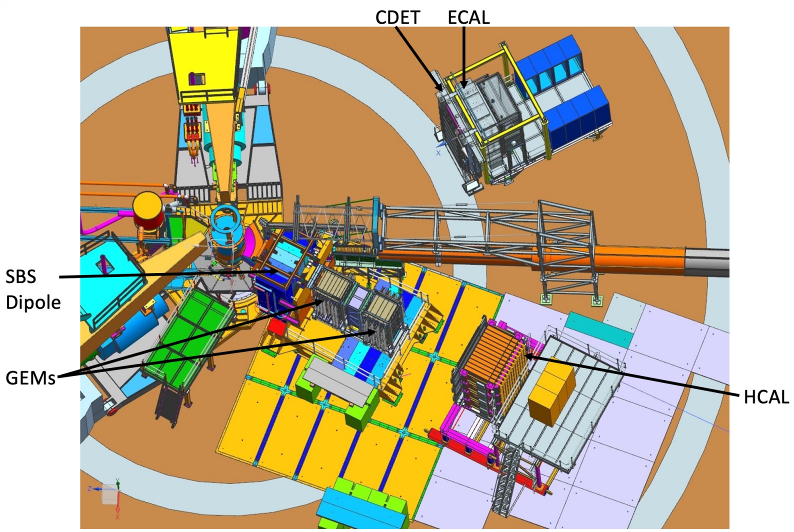
- Electron arm for 3.2 m^2 active area calorimeter, radiation immune
- Proton arm: SBS; 16-plane tracker, a CH2, and segmented HCAL
- Super fast DAQ for 2.0 GigaB per second data rate
- Analysis of 40% occupied multi-layer tracker





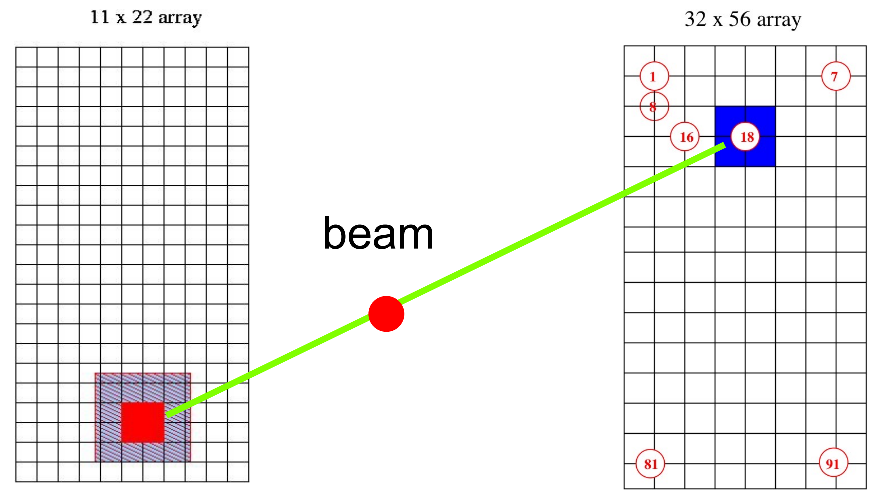
Expected trigger rate

SLAC data for γ,π yield at 9-18 GeV,
DESY data at 6 GeV, Wiser code

$$E\frac{d^3\sigma}{d^3p} = \frac{E}{p^2}\frac{d\sigma}{d\Omega dp}(x_F, p_\perp)$$

trigger threshold leads to $p_\perp \geq 1$ GeV/c

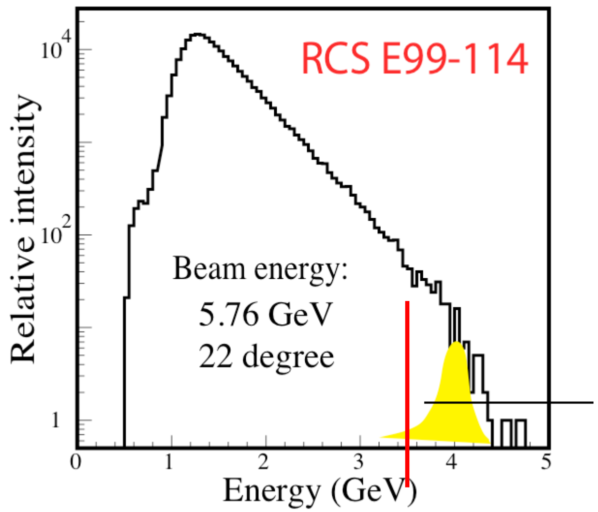
Total proton trigger rate is 1.5 MHz
(above threshold of 4 GeV)



Proton calo

Electron calo

EM calorimeter rate vs. deposited energy



FWHM
of 8%

Electron arm trigger rate (>85%) - 60 kHz

Two level electronic trigger

Level 1 from Electron arm forms gate for ADC

Level 2 from coincidence between two arms with pre-programmed angular correlation between arms. Coincidence time window is 50 ns, resolution of 5 ns.

Expected DAQ trigger rate is 500 Hz

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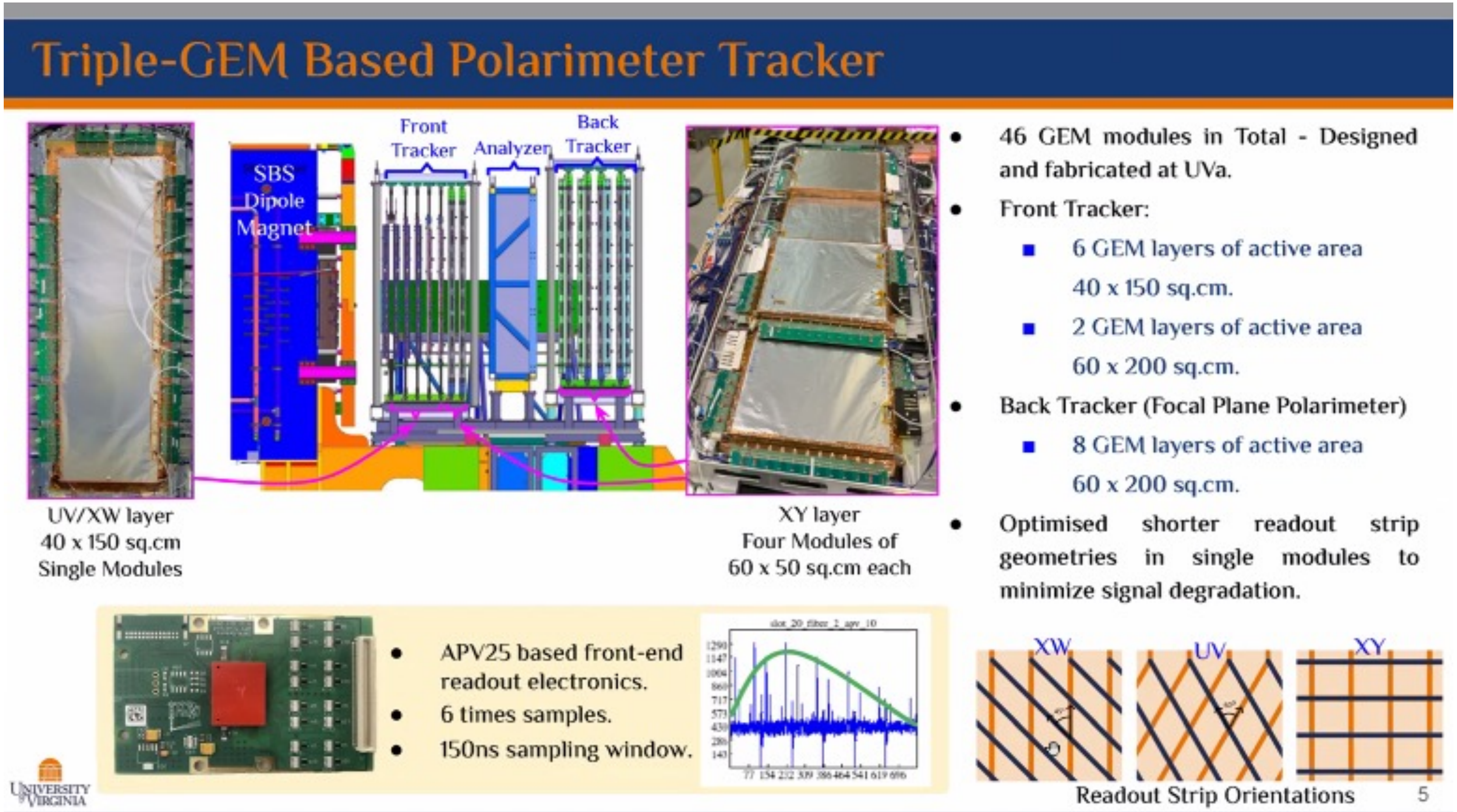
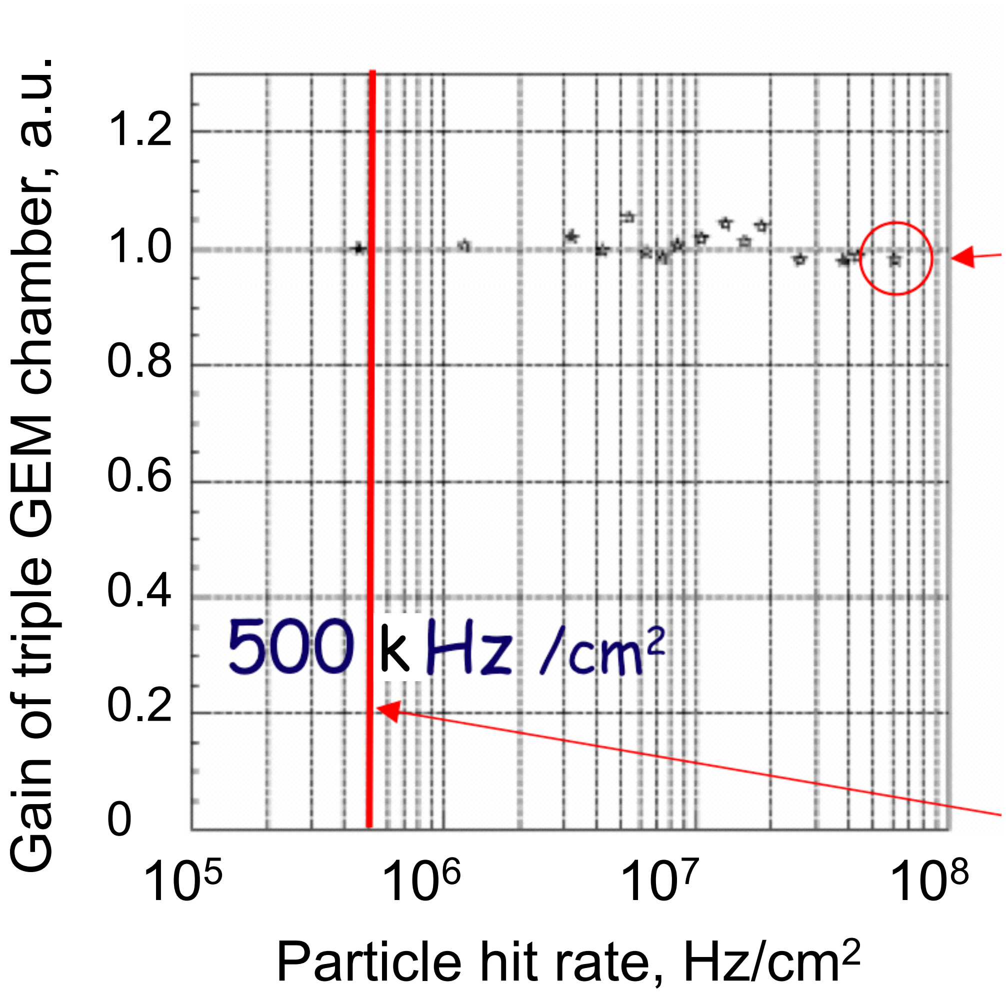
- Proton arm: a tracker, a CH2 analyzer, and a hadron calorimeter



Study of GEM rate capacity



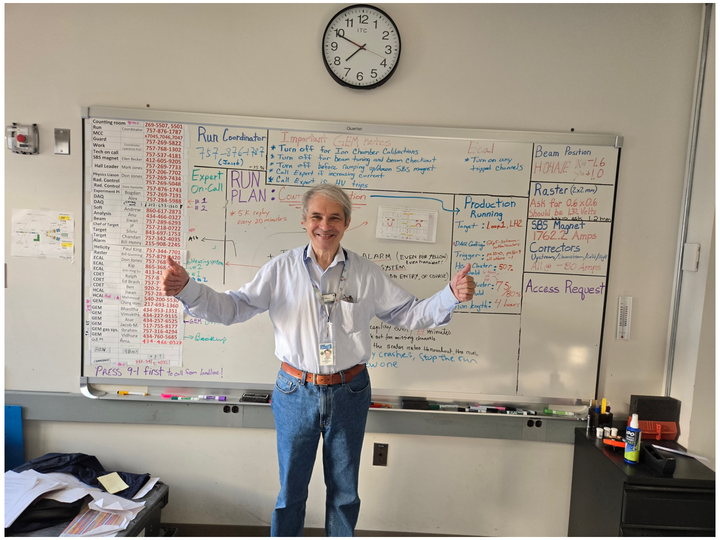
A very good gain stability up to 50 MHz/cm^2

Rate observed in GEp kin#3 has 40% occupancy for 60x0.05 cm^2 in 150 ns window or 1 MHz/cm^2

LHCb maximum rate

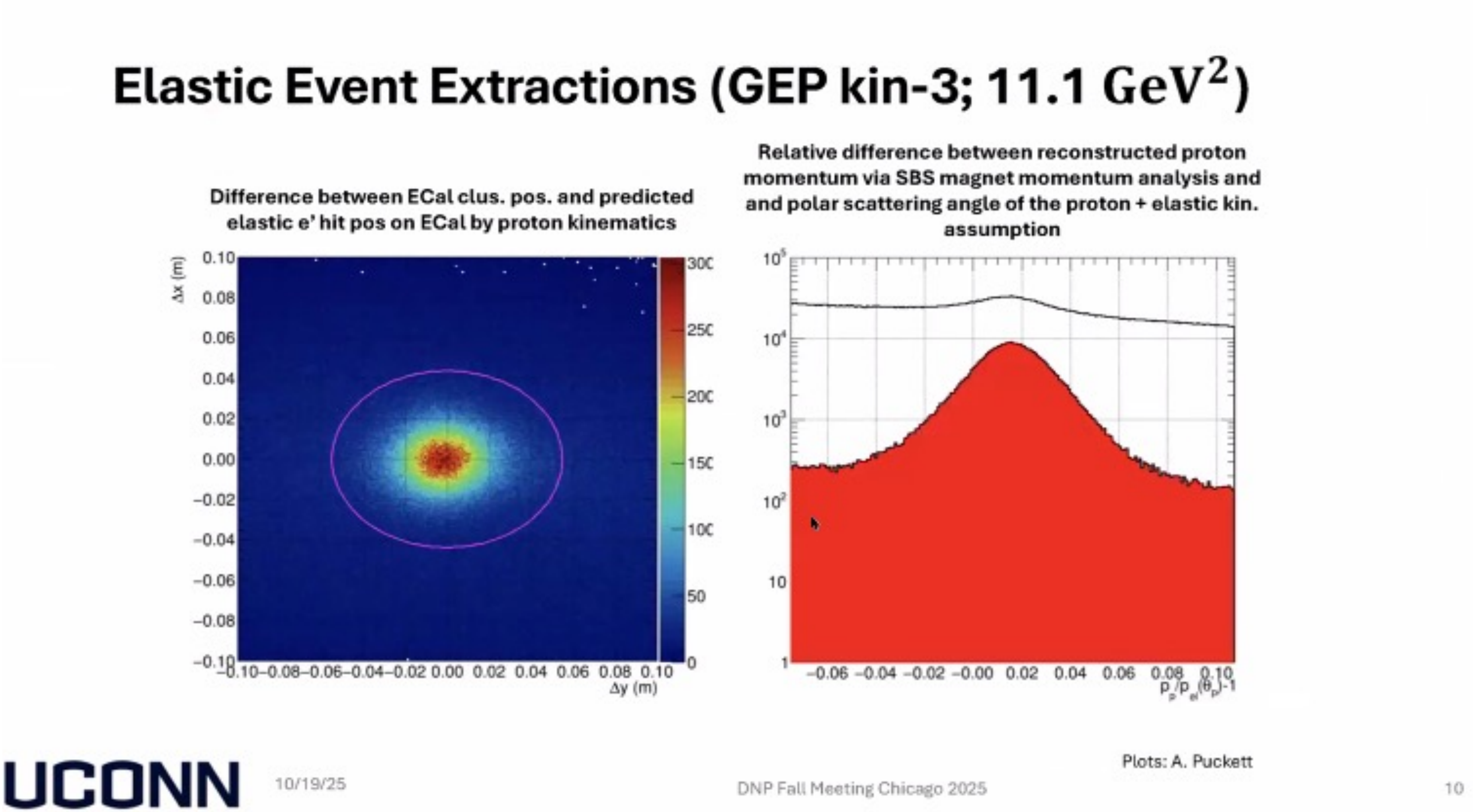
Lessons to learn

- Collaboration did a great job doing data taking, A+
- Beam, polarimeter, target and magnets, A+
- Calibration of the detectors needs a lower beam current
- Calorimeter temperature could start with a lower value
  and also needs better PMT selection
- Hadron signal energy analysis needs to be done
- Tracker needs better electronics for higher occupancy
- Preparation of components was completed on time
  more cosmic calibrations could help



Status of data analysis

- Very good **e-p** elastic selection is already achieved
- Calibration of calorimeter in progress – next talks
- Tracking efficiency – in progress – next talks



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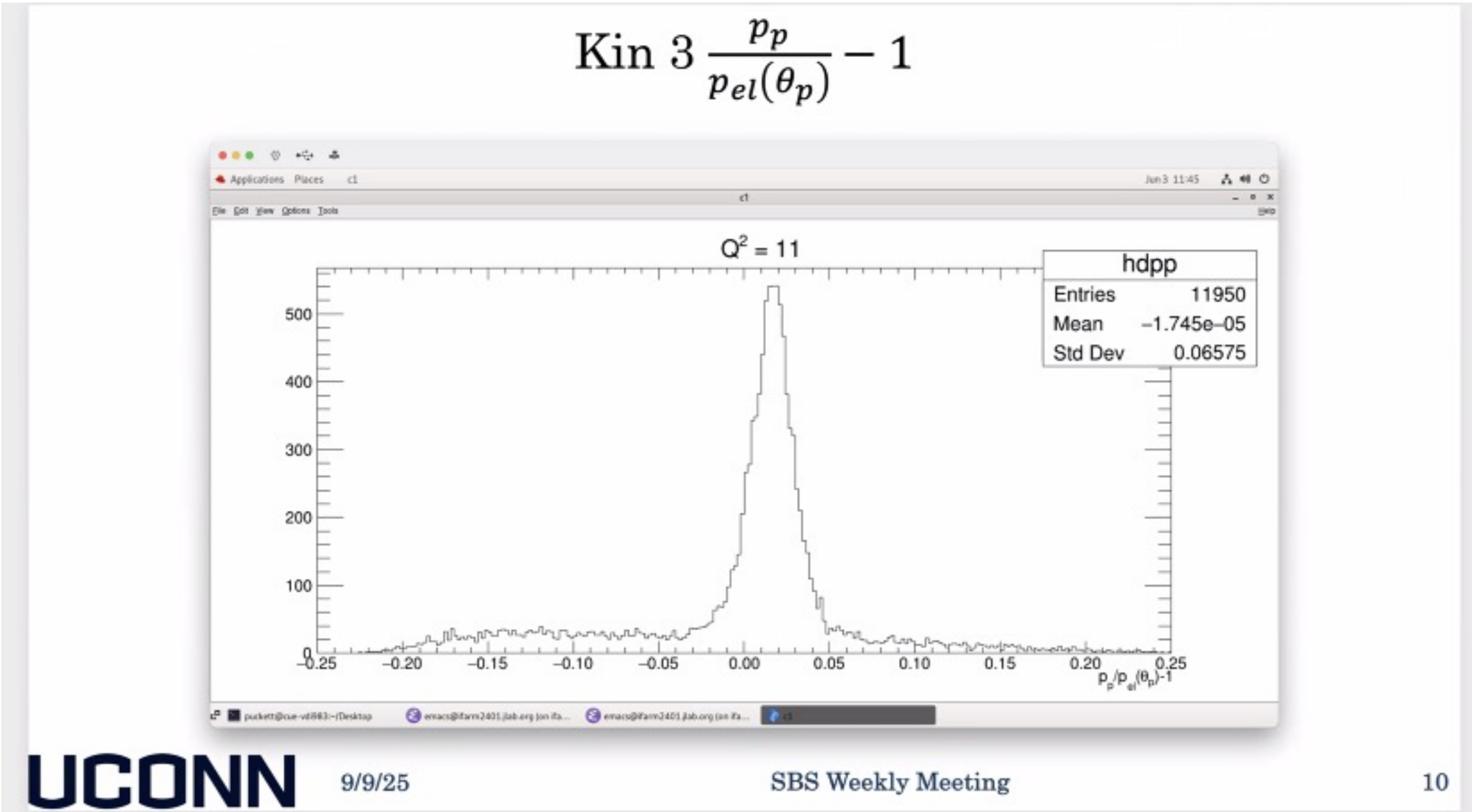
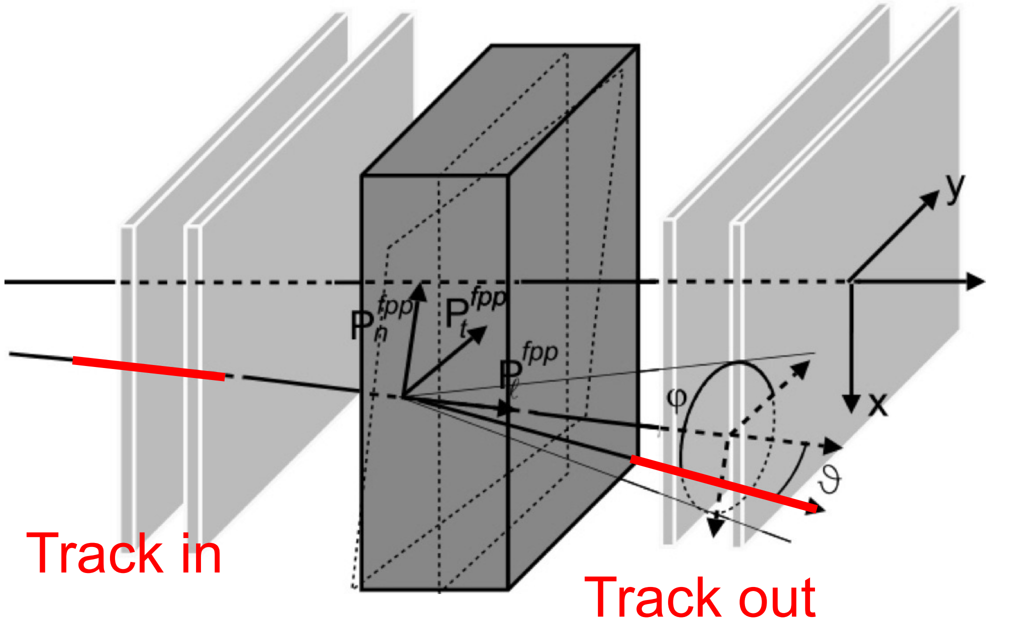
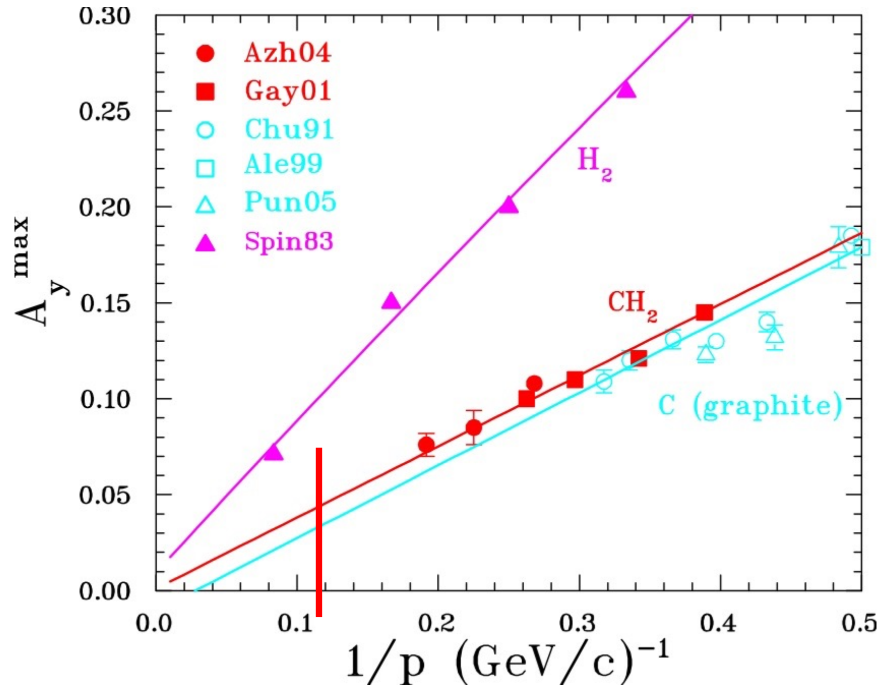


Method: Focal Plane Polarimeter



Analyzing power vs. inverse proton momentum



$$f^{\pm}(\vartheta,\varphi) = \frac{\epsilon(\vartheta,\varphi)}{2\pi}\left[1 \pm A_y(P_x^{fpp}\sin\varphi - P_y^{fpp}\cos\varphi)\right]$$

where ± refers to electron beam helicity

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

p will be ~ 8.5 GeV/c

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

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- Tracking efficiency is in progress – next talks

- Very preliminary plots may come in March, 2026

- Publication GEp/GMp result in 2028 is our goal

Collaboration in the SBS FF program

- 28 Ph.D. students (13 already graduated)

- 43+ currently active faculty
- 19 postdocs worked on experiment
- 10 active faculty retired

- 12 members of SBS CC
- Next collaboration meeting on 3/2-4/2026

Perspectives for higher Q2

- Will reach momentum transfer $Q^2 = 15\ (GeV/c)^2$

- An electron calorimeter (like NPSx10) is needed, 4 m^2 area,
  based on lead-glass will be cost-effective option

- SBS tracker electronics upgrade is needed, in UVA plan

- 20 g/cm^2 Pb shield in front of the dipole will reduce background

- Charge exchange mode of proton polarimetry may help

- Could it be ready by the time of Moller completion?

Photon attenuation vs. energy