

GEp – 15 perspectives

B. Wojtsekhowski, TJNAF

on behalf of the SBS collaboration

GEP-15

Large Acceptance Proton Form Factor Ratio Measurement at 13 and 15 GeV² Using Recoil Polarization Method

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with more than 100 collaborators
from almost 30 institutions

GEp experiment overview

Challenges

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

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

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

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

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

GEp-II used an electron in 3.4 m² ECAL, a proton in HRS-L

GEp-III used an electron in 2.9 m² ECAL, a proton in HMS

GEp experiment overview

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

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

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

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

Need max statistics \rightarrow max luminosity + max solid angle

Max luminosity \rightarrow **large background**

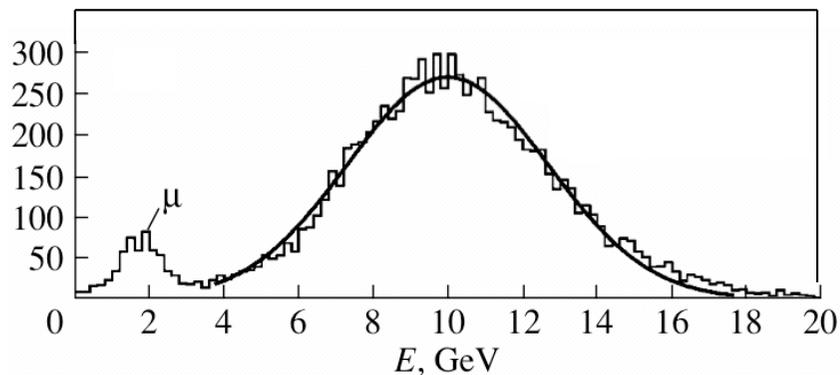
Large solid angle \rightarrow open detector \rightarrow **huge background**

Solution for **a solid angle** is **Super Bigbite Spectrometer**

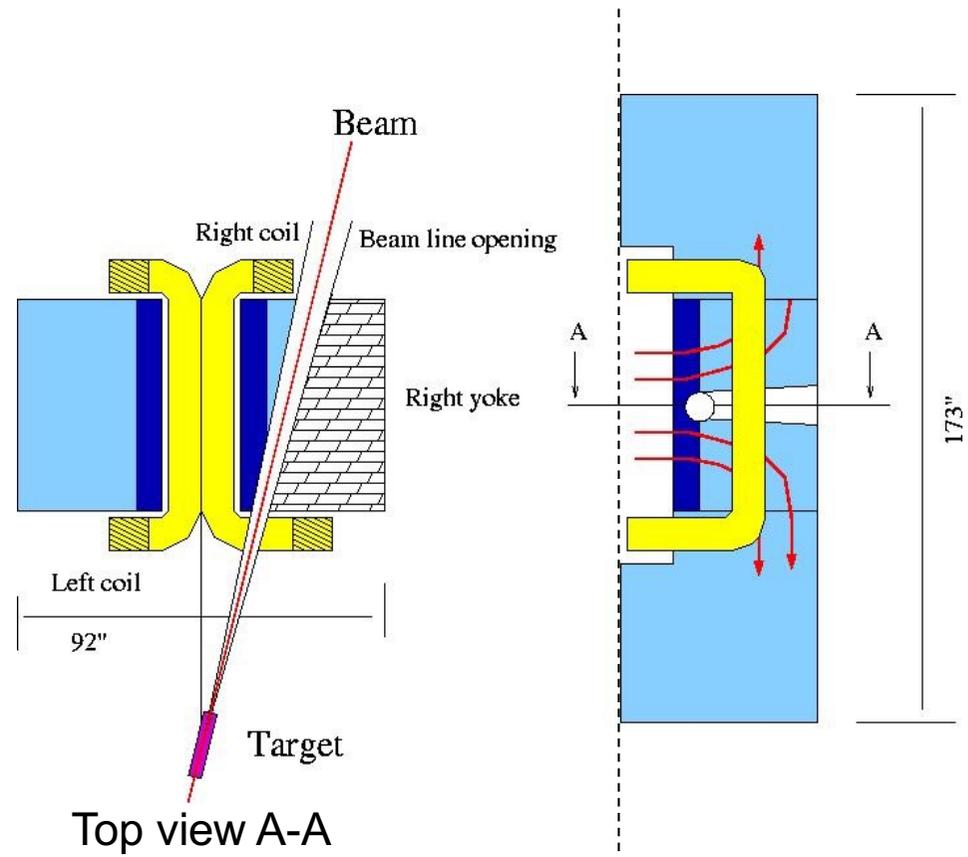
Solution for **a tracking detector** is **Gas Electron Multiplier**

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

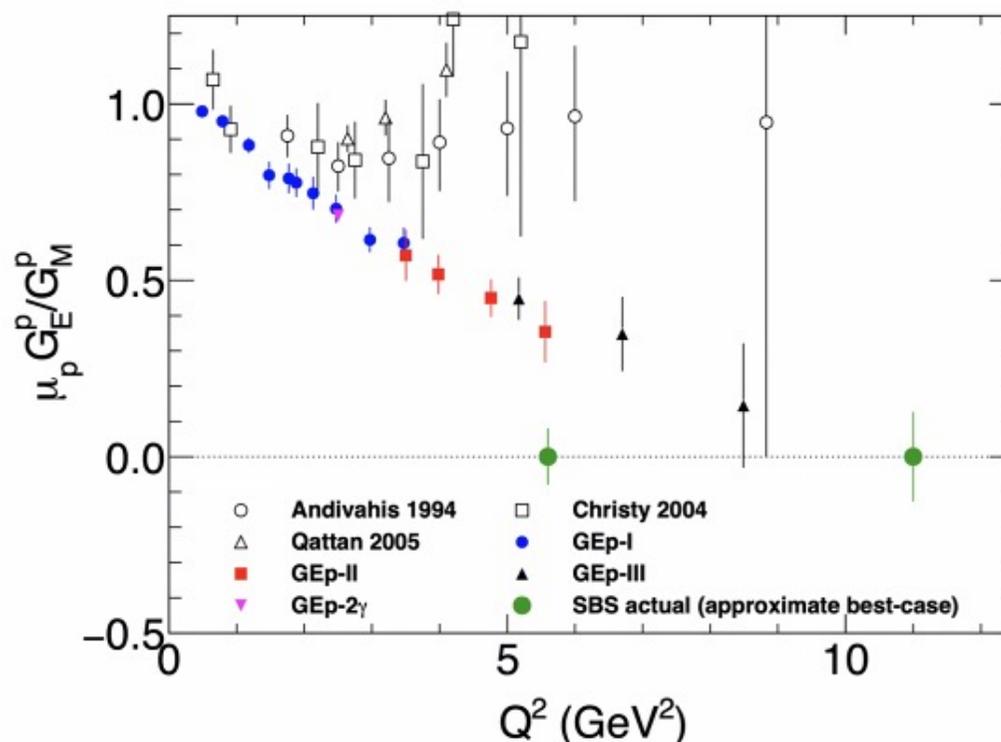


GEp experiment overview

- 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

- $Q^2 = 5.6 \text{ GeV}^2$: 3.7 C
- $Q^2 = 11 \text{ GeV}^2$: 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.



Components of the GEP/SBS experiment

- Electron beam with max energy and polarization
- Cryogenic 30 cm LH2 target
- Electron arm for 3.2 m² active area calorimeter, radiation immune



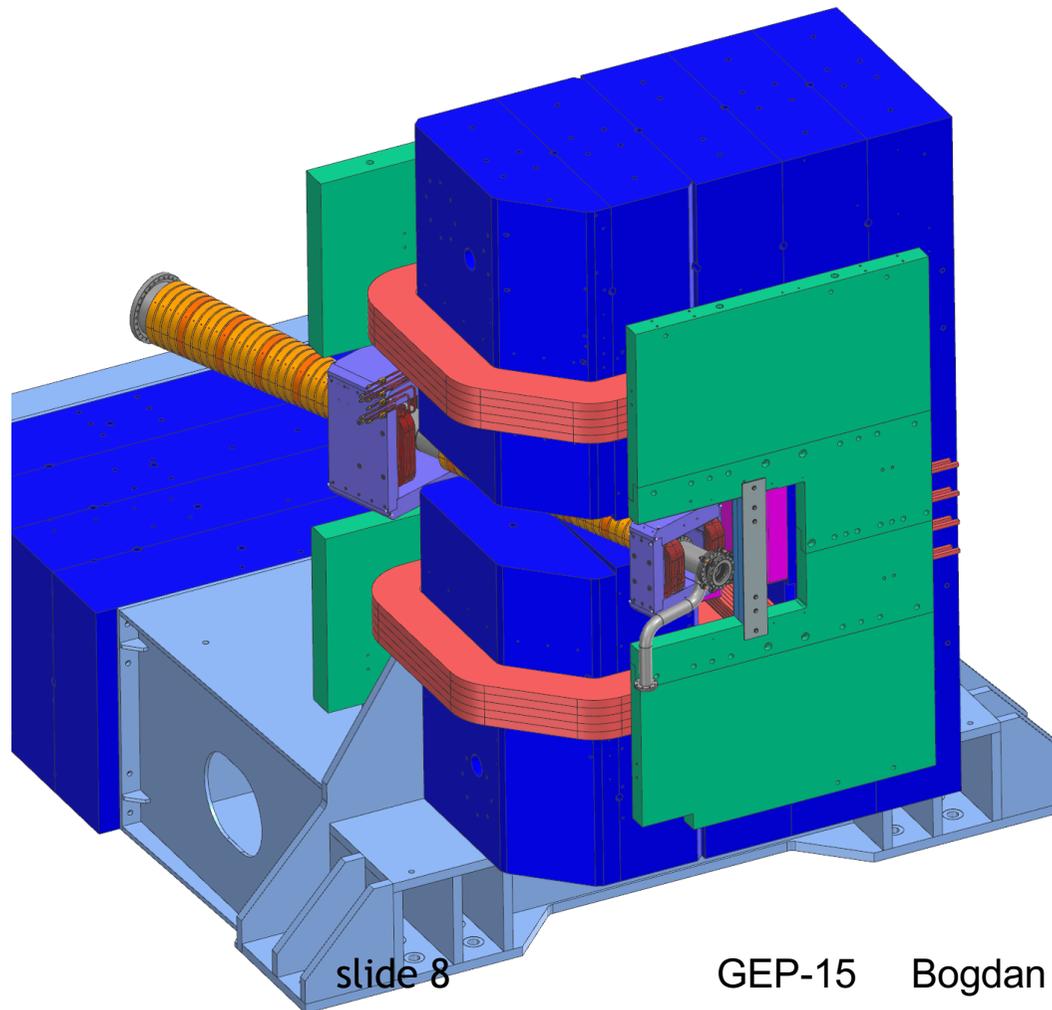
3/2/2026

slide 7

GEP - Bogdan Wojtsekhowski, JLab

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**
- Proton arm: SBS; **16-plane tracker**, a CH2, and segmented HCAL



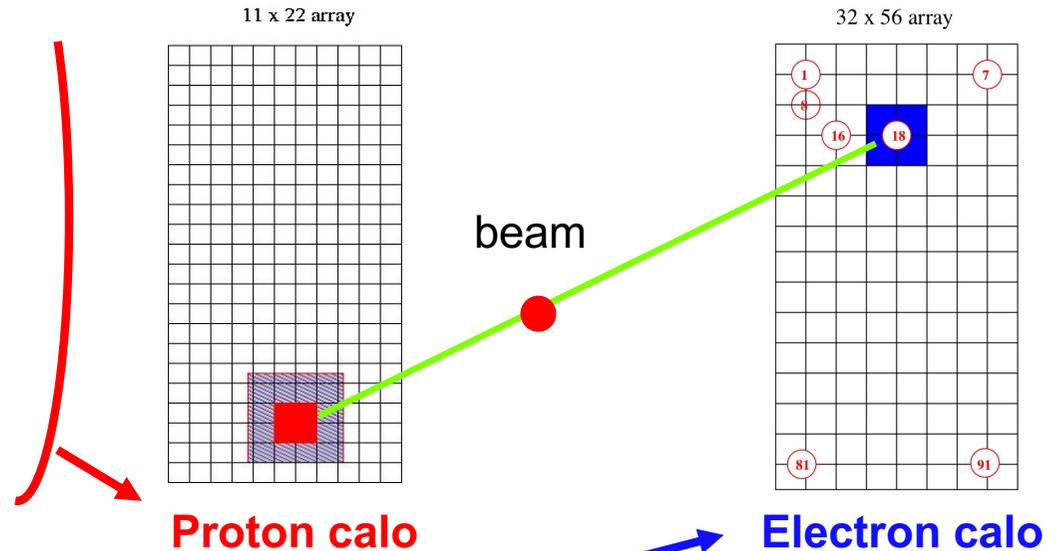
Expected trigger rate

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

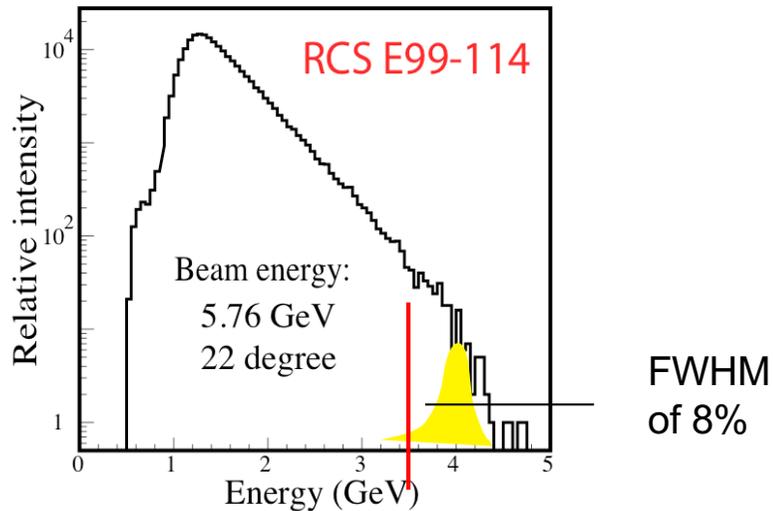
$$E \frac{d^3\sigma}{d^3p} = \frac{E}{p^2} \frac{d\sigma}{d\Omega dp} (x_F, p_\perp)$$

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

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



EM calorimeter rate vs. deposited energy



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

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

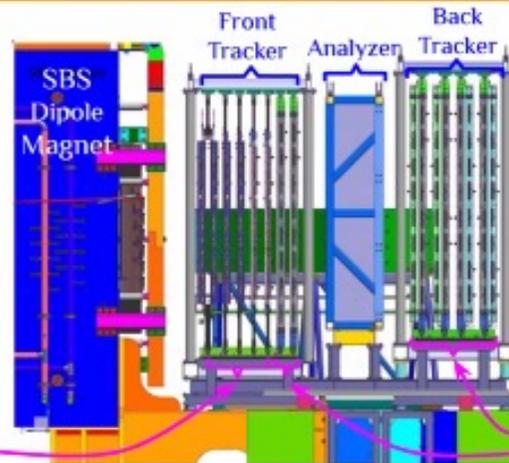
Components of the GEP/SBS experiment

- Electron beam with max energy and polarization
- Cryogenic 30 cm LH2 target
- Electron arm for 3.2 m² active area calorimeter, no radiation effect
- Proton arm: a tracker, a CH₂ analyzer, and a hadron calorimeter

Triple-GEM Based Polarimeter Tracker



UV/XW layer
40 x 150 sq.cm
Single Modules

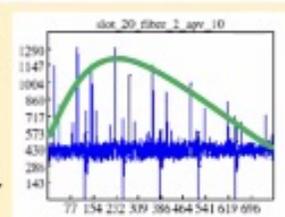


XY layer
Four Modules of
60 x 50 sq.cm each

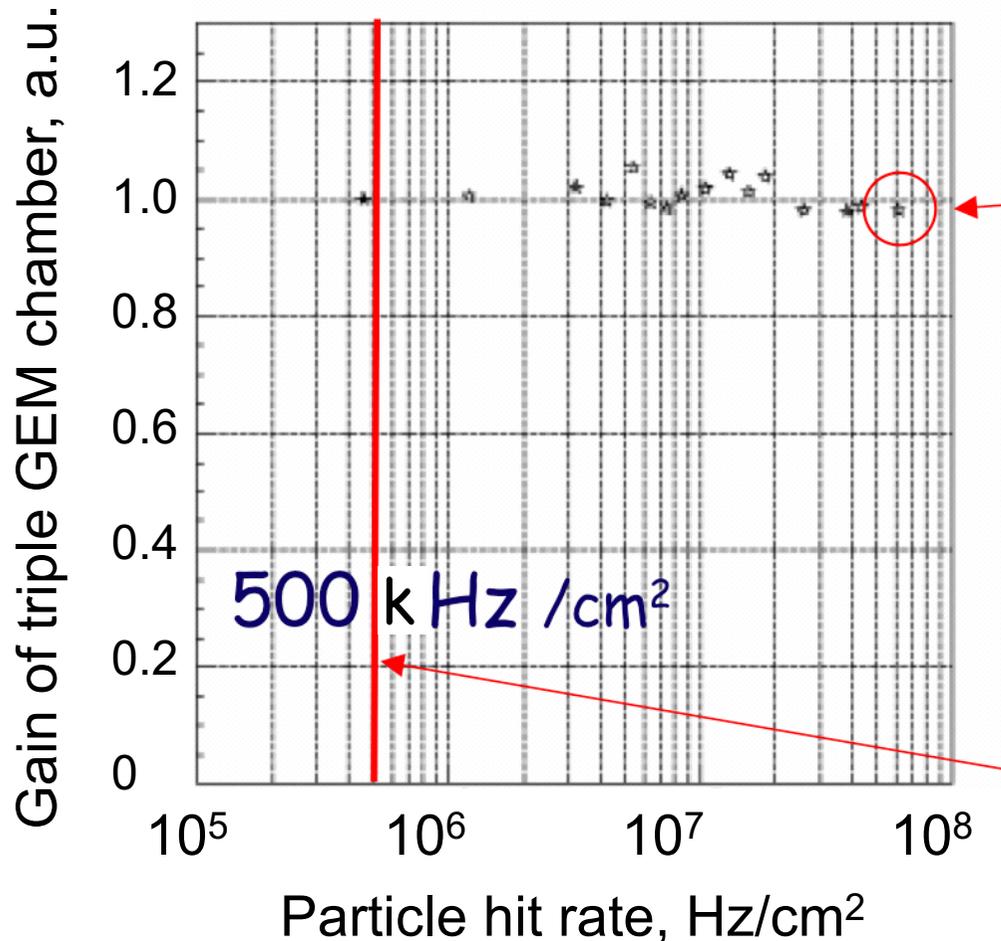
- 46 GEM modules in Total - Designed and fabricated at UvA.
- Front Tracker:
 - 6 GEM layers of active area 40 x 150 sq.cm.
 - 2 GEM layers of active area 60 x 200 sq.cm.
- Back Tracker (Focal Plane Polarimeter)
 - 8 GEM layers of active area 60 x 200 sq.cm.
- Optimised shorter readout strip geometries in single modules to minimize signal degradation.



- APV25 based front-end readout electronics.
- 6 times samples.
- 150ns sampling window.



Study of GEM rate capability



A very good gain stability up to **50 MHz/cm²**

Rate observed in GEp kin#3 corresponds 40% occupancy in 60x0.05 cm² / 150 ns window or ~ **1 MHz/cm²**

LHCb maximum rate

Study of GEM rate capability

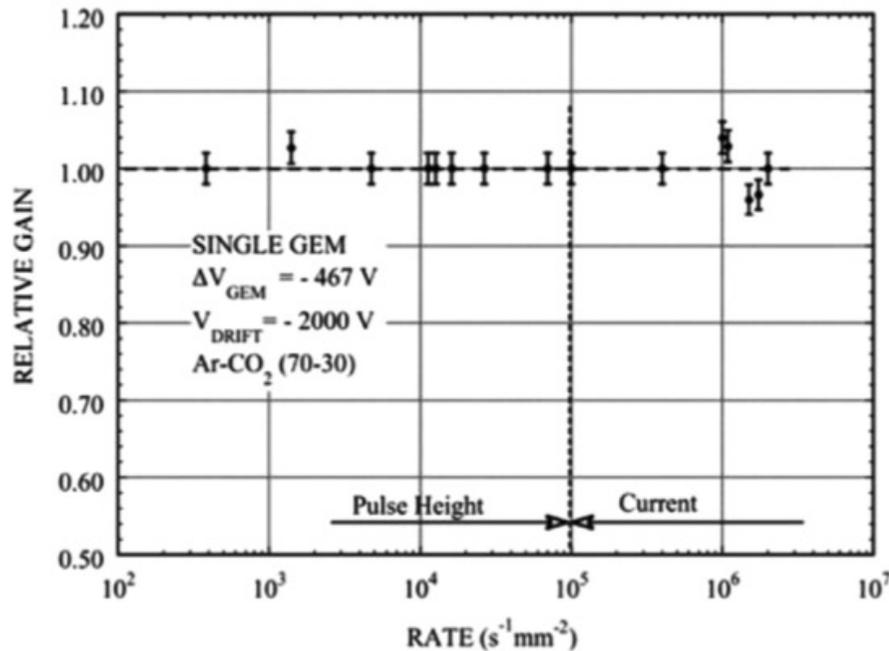


Fig. 42. Relative gain as a function of rate for a single GEM.

100 MHz/cm²

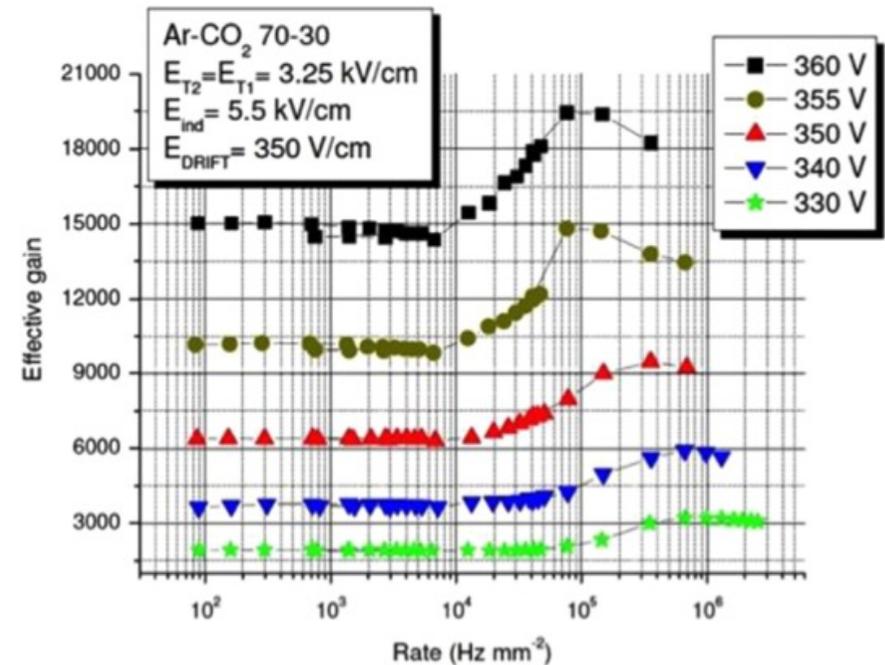
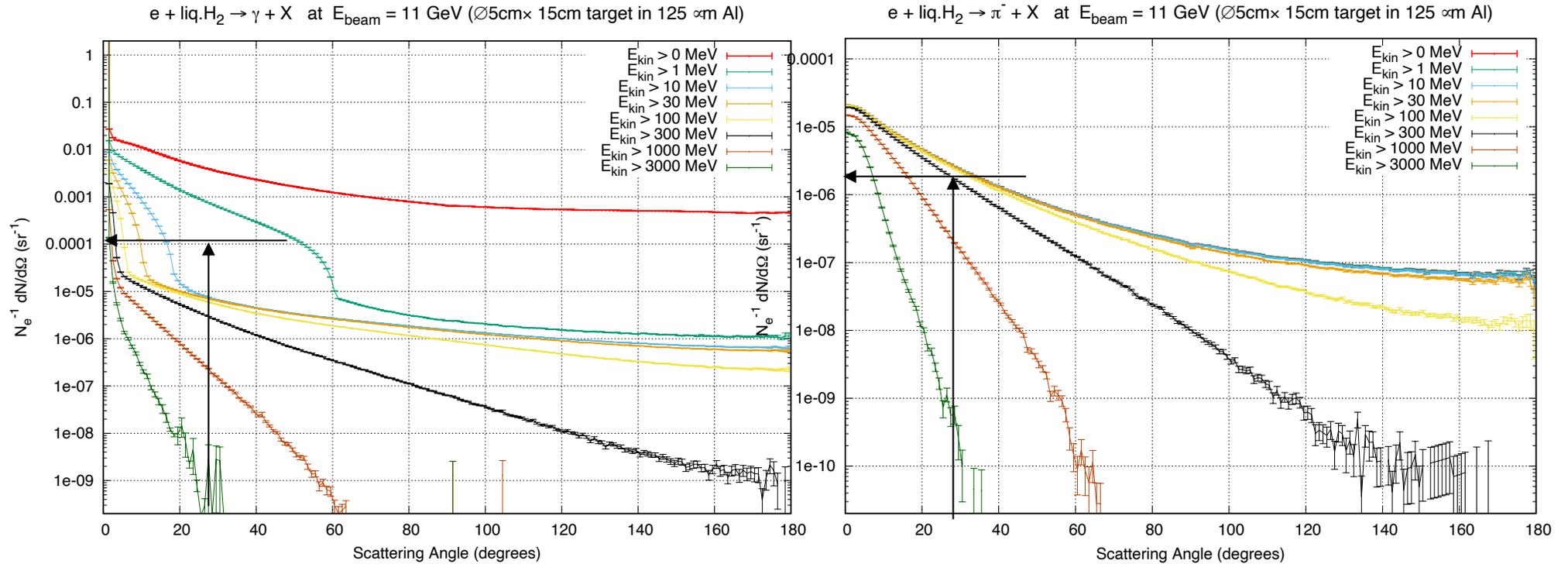


Fig. 43. Rate dependence of a Triple-GEM gain at increasing values of GEM voltages.

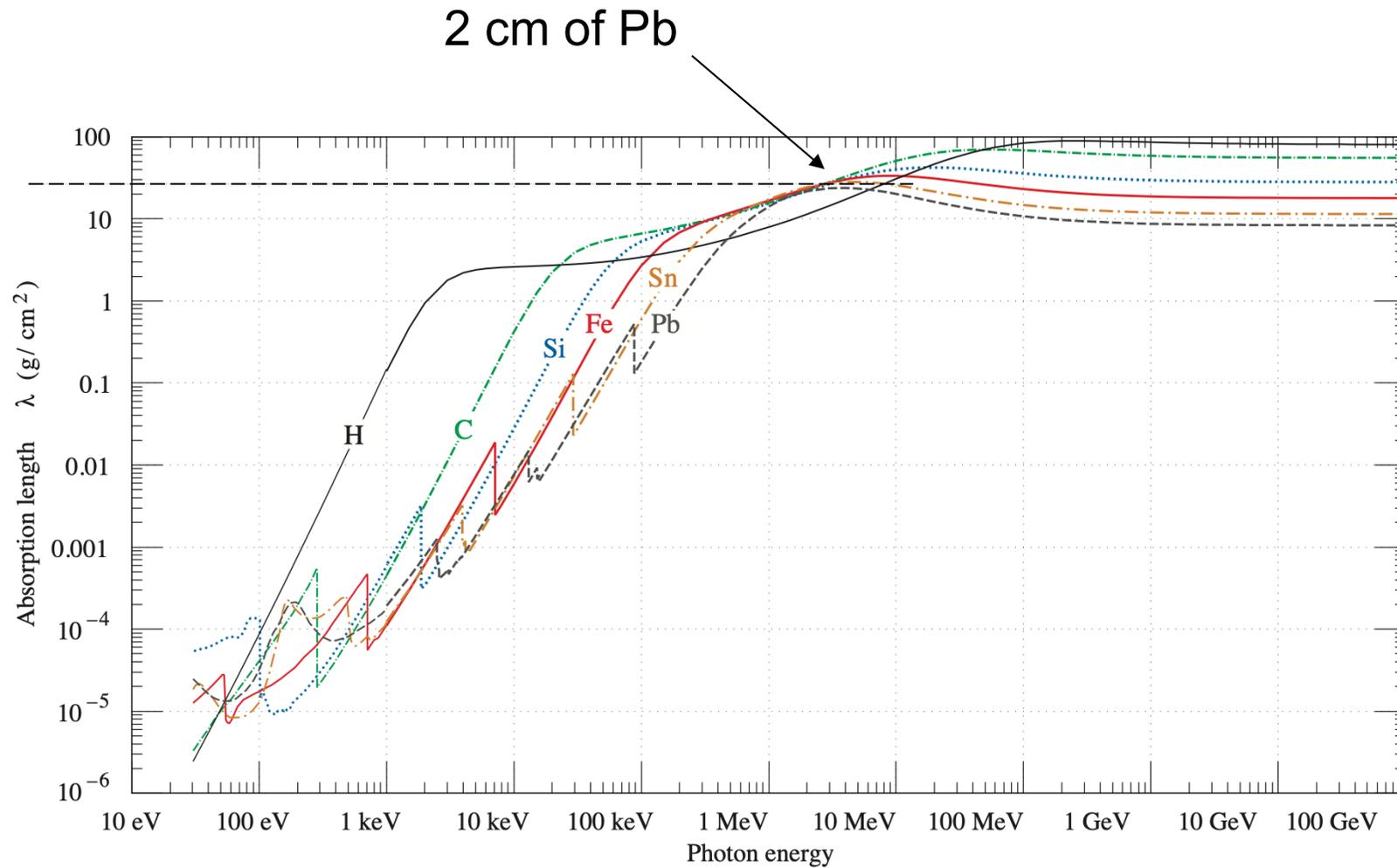
Background rates vs. angle and energy

from Pavel's MC (FLUKA)



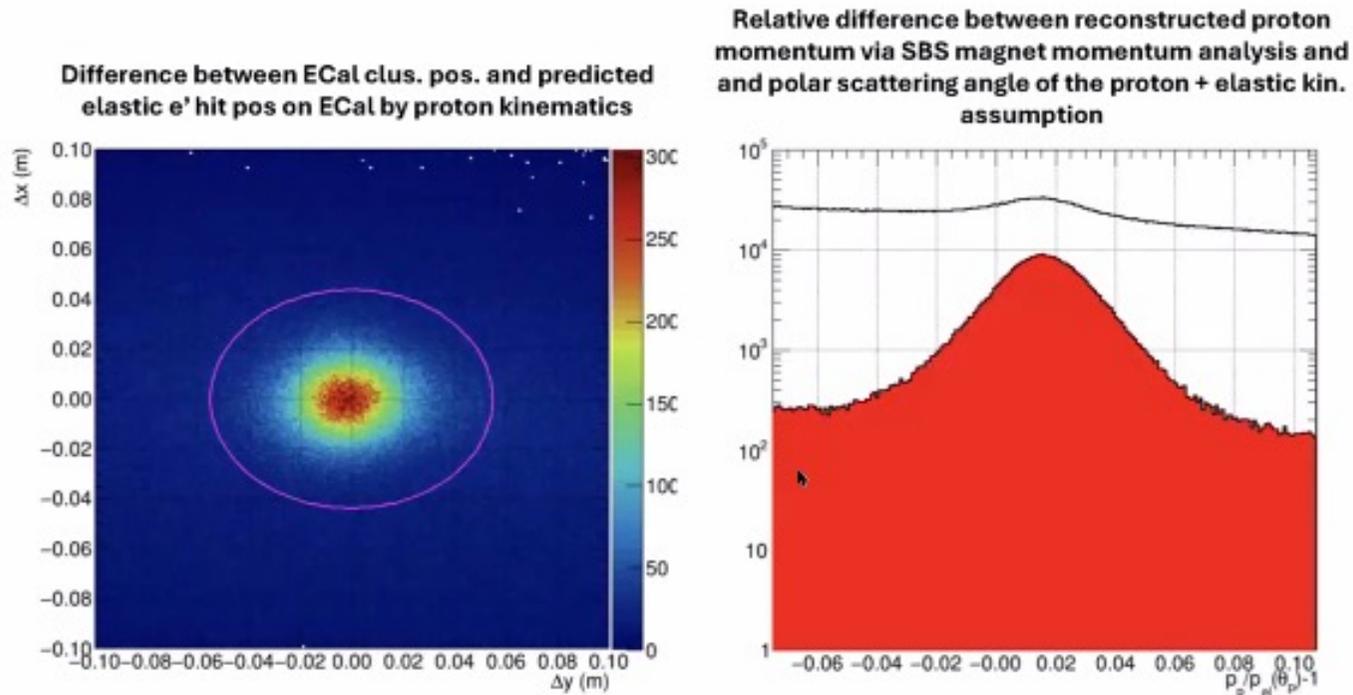
Photon/Pion intensity difference $\sim 10,000$

Photon attenuation vs. energy



The elastic e-p events selection

Elastic Event Extractions (GEP kin-3; 11.1 GeV²)



UConn

10/19/25

DNP Fall Meeting Chicago 2025

Plots: A. Puckett

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The elastic e-p events selection

Recoiled proton scattering in 4 cm Pb

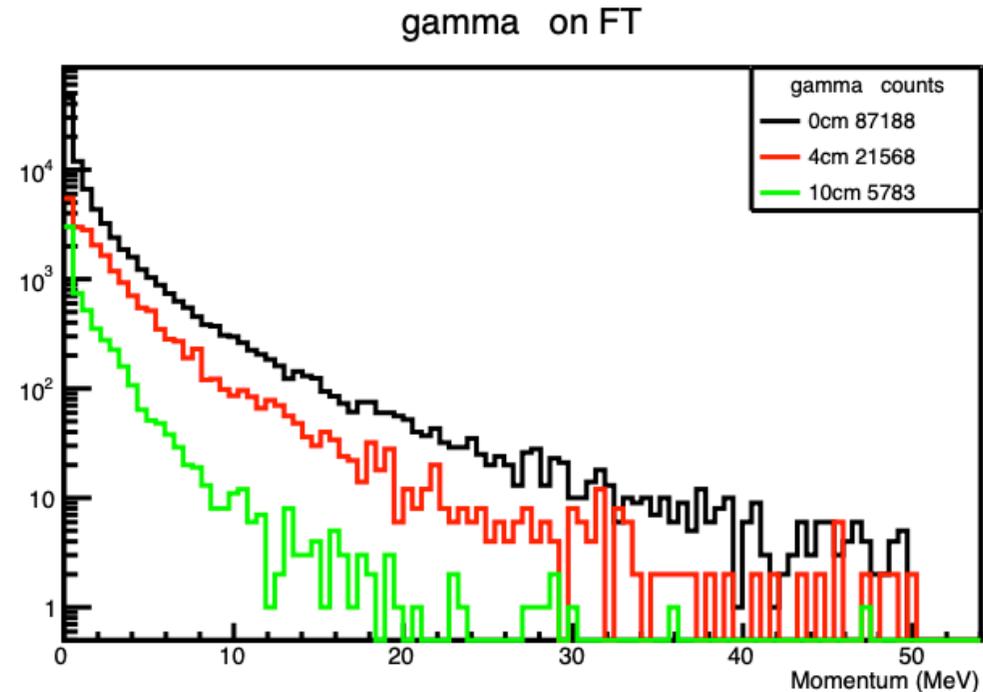
$$\theta_0 = \frac{13.6 \text{ MeV}}{\beta c p} z \sqrt{\frac{x}{X_0}} \left[1 + 0.088 \log_{10} \left(\frac{x z^2}{X_0 \beta^2} \right) \right]$$

At $Q^2 \sim 15 \text{ GeV}^2 \Rightarrow 4.1 \text{ mrad}$

For 2 cm coordinate resolution on electron arm calorimeter at 6 m \Rightarrow angular resolution of 3 mrad

The elastic e-p events selection

Recent Geant3 MC
results from Evaristo



The combined angular correlation resolution is **5.1 mrad**

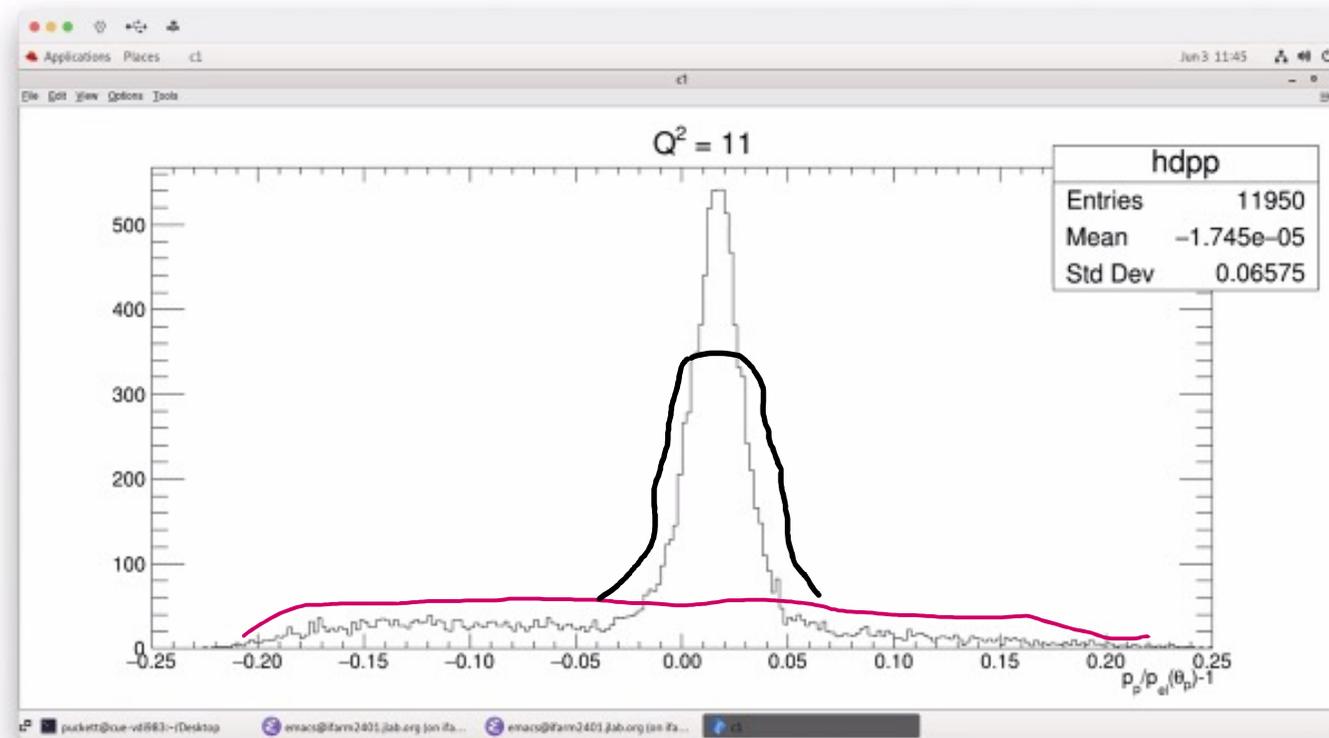
With 4 cm Pb reduction of the background rate is **4 times**

with **2x** impact on the e-p tracks angular correlation

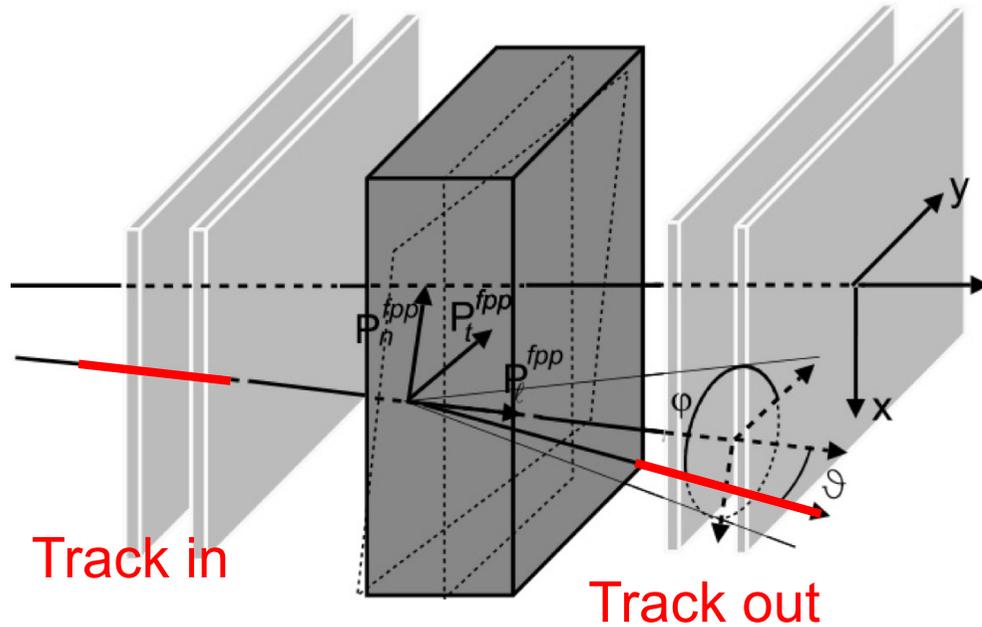
and just small impact on momentum resolution

The elastic e-p events selection

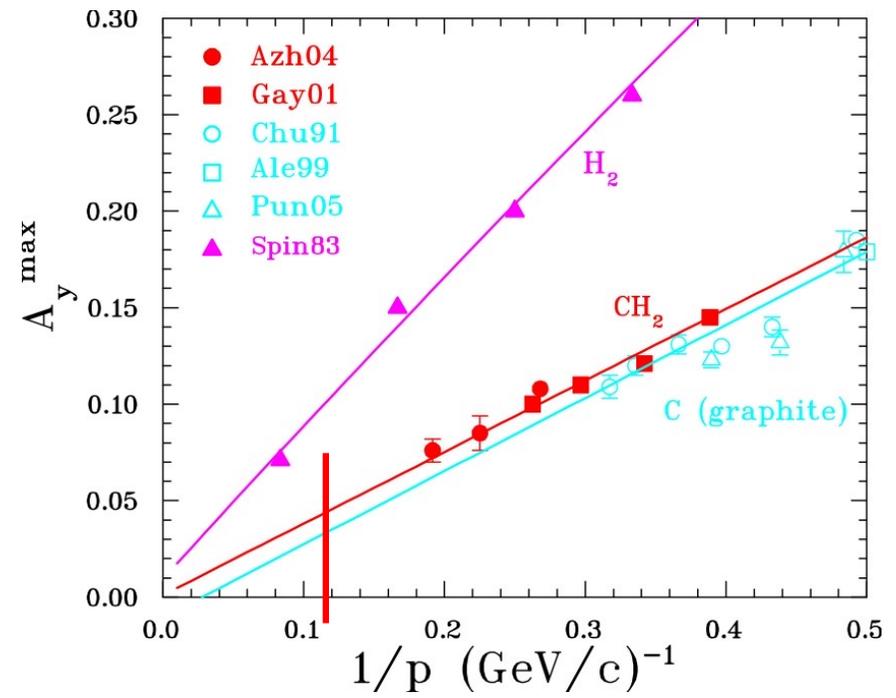
$$\text{Kin } 3 \frac{p_p}{p_{el}(\theta_p)} - 1$$



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 \pm refers to electron beam helicity

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

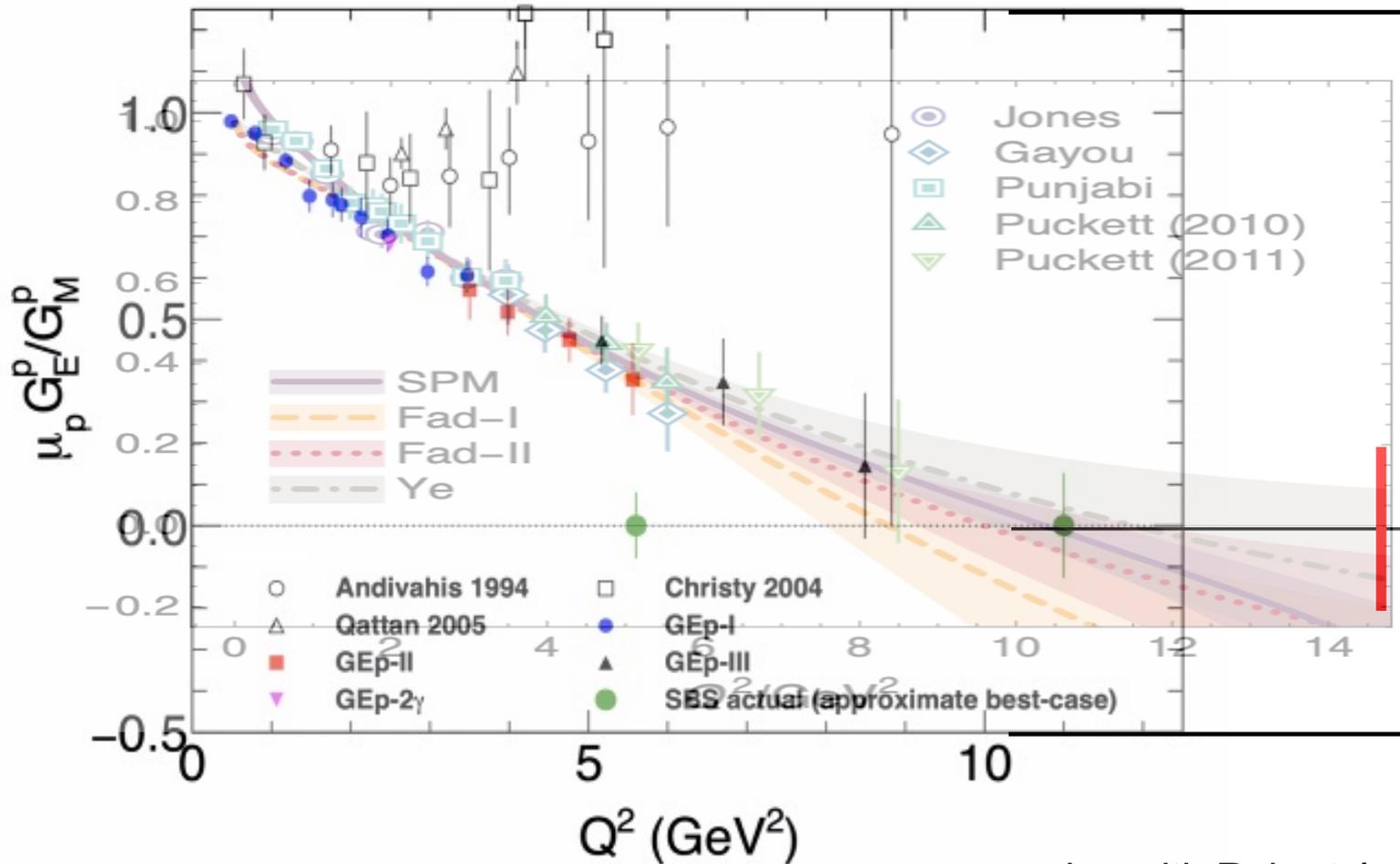
p will be ~ 8.5 GeV/c

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

Perspectives for significantly higher Q2

- Will reach momentum transfer $Q^2 = 15 \text{ (GeV/c)}^2$
- An electron calorimeter (like NPSx10) is needed, 4 m² area, based on lead-glass will be cost-effective option
3k+ PMTs from SLAC DIRC are available
- SBS tracker electronics upgrade is needed, in UVA plan
- 4 cm Pb shield in front of the dipole will cut the background rate by a factor 4 – fresh result from Evaristo
- use 30 cm target 40 uA with 20% GEM occupancy
- a 60-day run

Perspectives for significantly higher Q²



FOM
 $Q^2 = 11 \rightarrow 15$
 reduction
 due to E^2/Q^{16}
 is 10

overlap with Roberts' plot