A Measurement of Two-Photon Exchange in Unpolarized Elastic Electron-Proton Scattering

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OUTLINE

Motivation

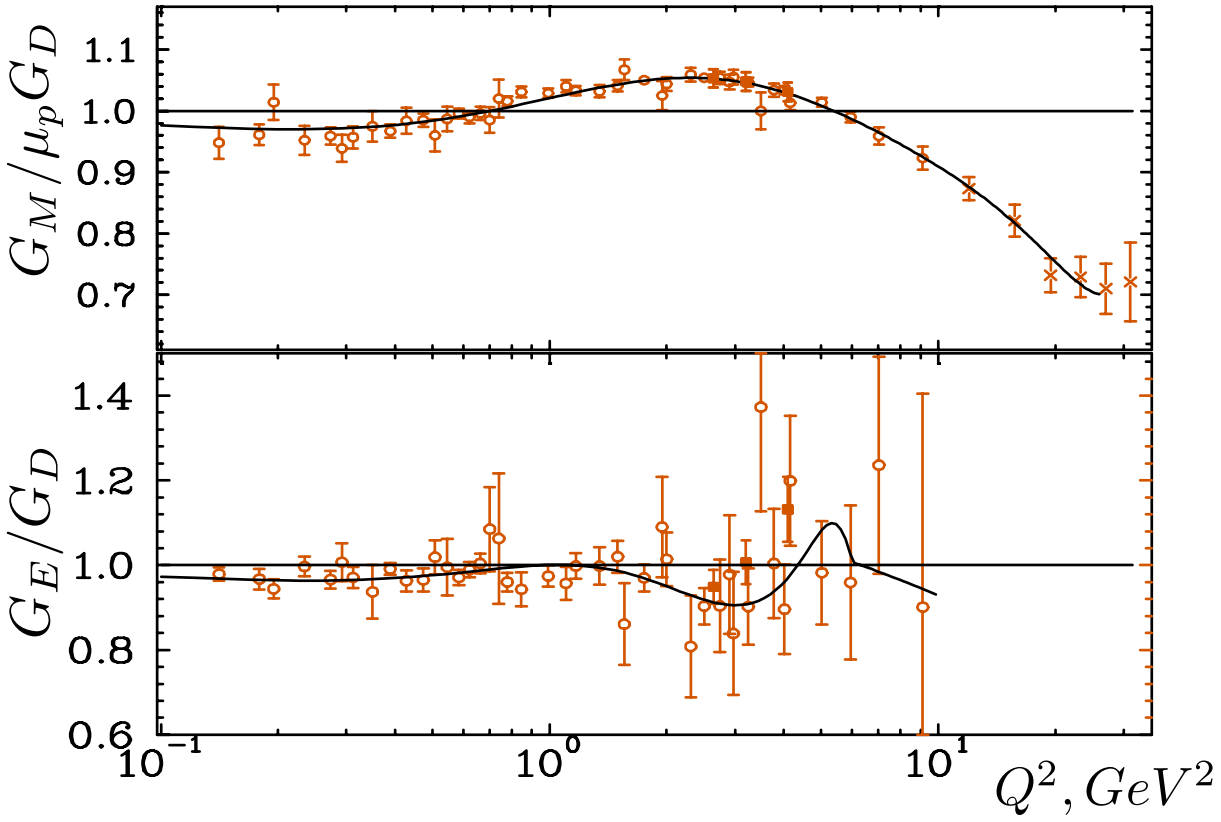
Experiment

Analysis

FORM FACTORS

Elastic scattering experiments allow Form Factors (FF) extraction:

- $G_E^p(Q^2),\ G_M^p(Q^2)$
  - access to structure and dynamics of the hadron
  - charge and current density distribution in nonrelativistic limit
  - $G_D(Q^2) = (1 + a^2Q^2)^{-2} \qquad a^2 = (0.71GeV^2)^{-1}$



J. Arrington et al 2007
J. Phys. G: Nucl. Part. Phys. 34

PROTON FF EXTRACTION

Rosenbluth Separation

$$\sigma_R = \tau G_M^2(Q^2) + \varepsilon G_E^2(Q^2)$$

$$\tau = Q^2/(4M^2)$$
$$\varepsilon = 1/[1 + 2(1+\tau)tan^2(\theta_e/2)]$$

unpolarized beam

measures cross section as a function of ε

gives Form Factors directly

Recoil polarization

$$\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{(E+E')}{2M_p}tan(\frac{\theta_e}{2})$$

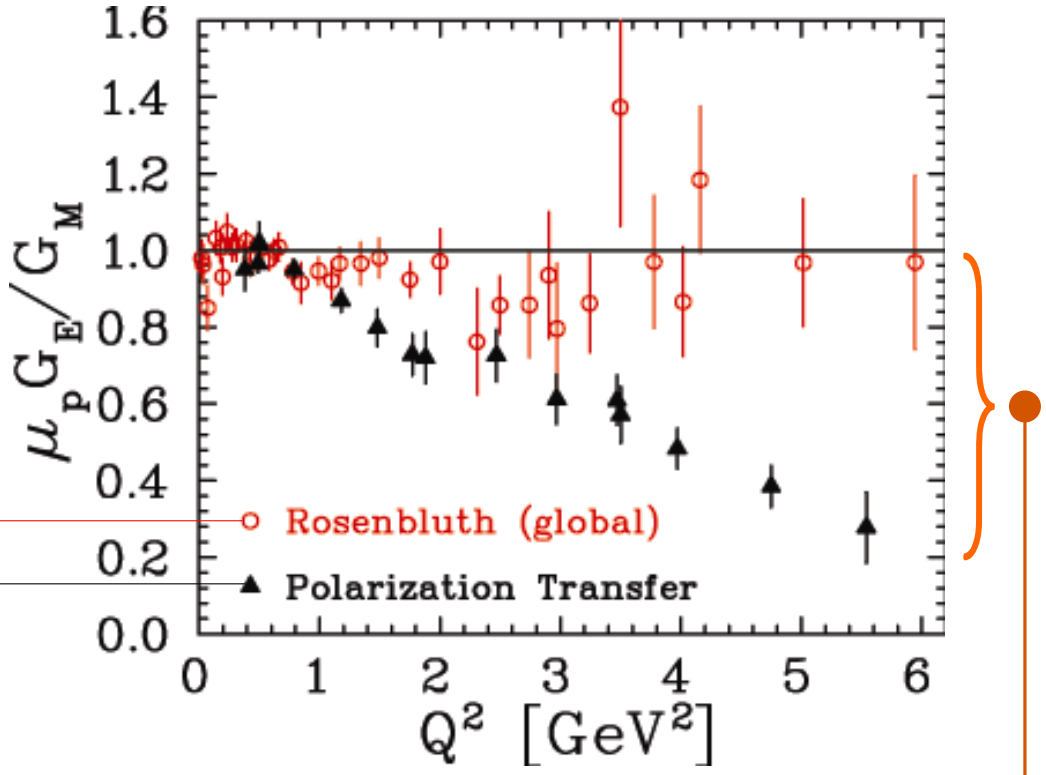
polarized beam

measures transferred polarization of the recoil proton

smaller uncertainties at high Q^2

DISCREPANCY

- Rosenbluth Separation
  - FF scaling - ratio is flat
  - Uncertainties increase with Q^2
- Recoil polarization
  - Decreasing ratio at high Q^2



J. Arrington, Phys. Rev. C69:022201, 2004
M. Jones et al, Phys. Rev. Lett. 84:1398-1402, 2000
O. Gayou et al, Phys. Rev. Lett. 88:092301, 2002

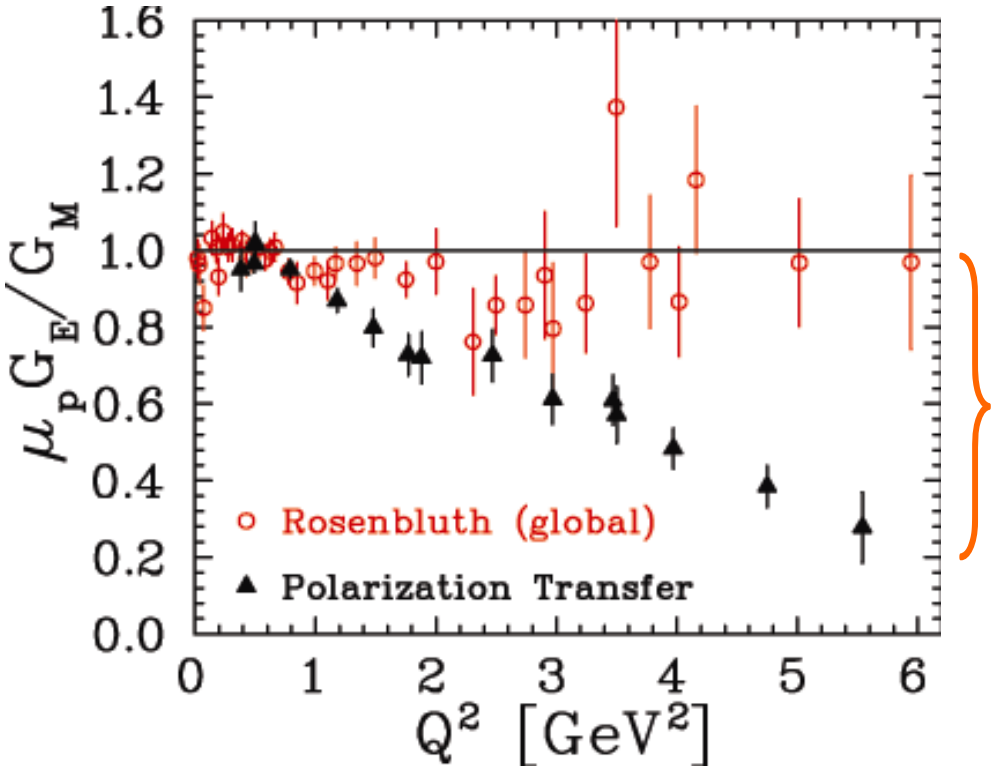
Experimental error?

Missing correction?

would need 5-7% epsilon dependence in cross section to resolve it

DETECT PROTON instead of ELECTRON

Achieve uncertainties comparable to recoil polarization technique



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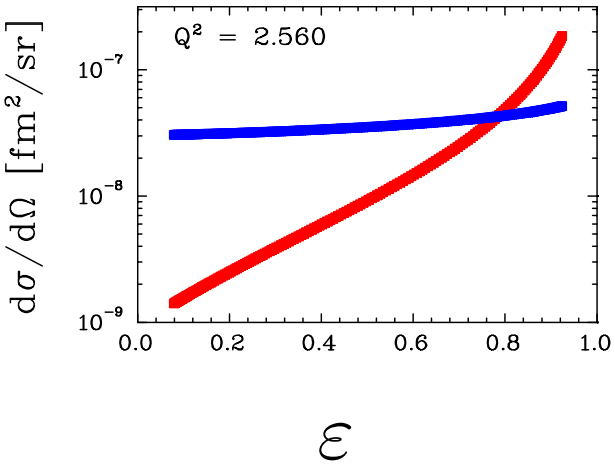
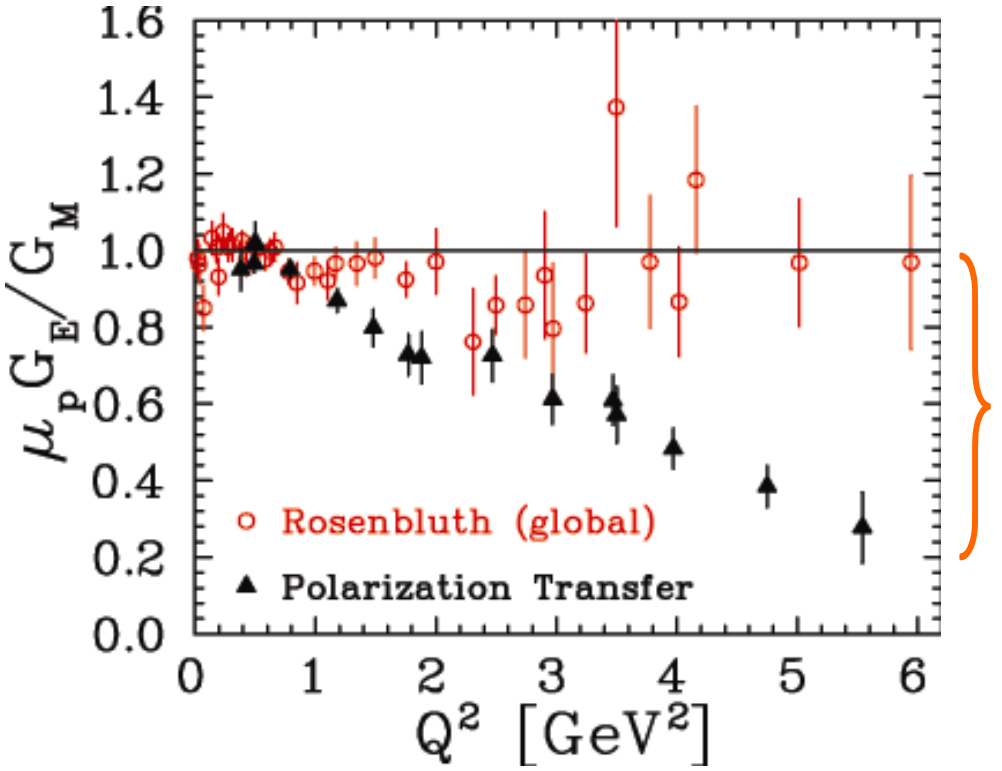


PR05-017, JLab Hall C, 2004



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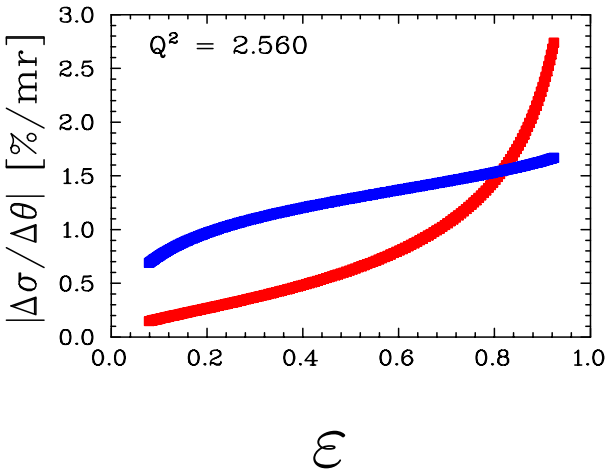

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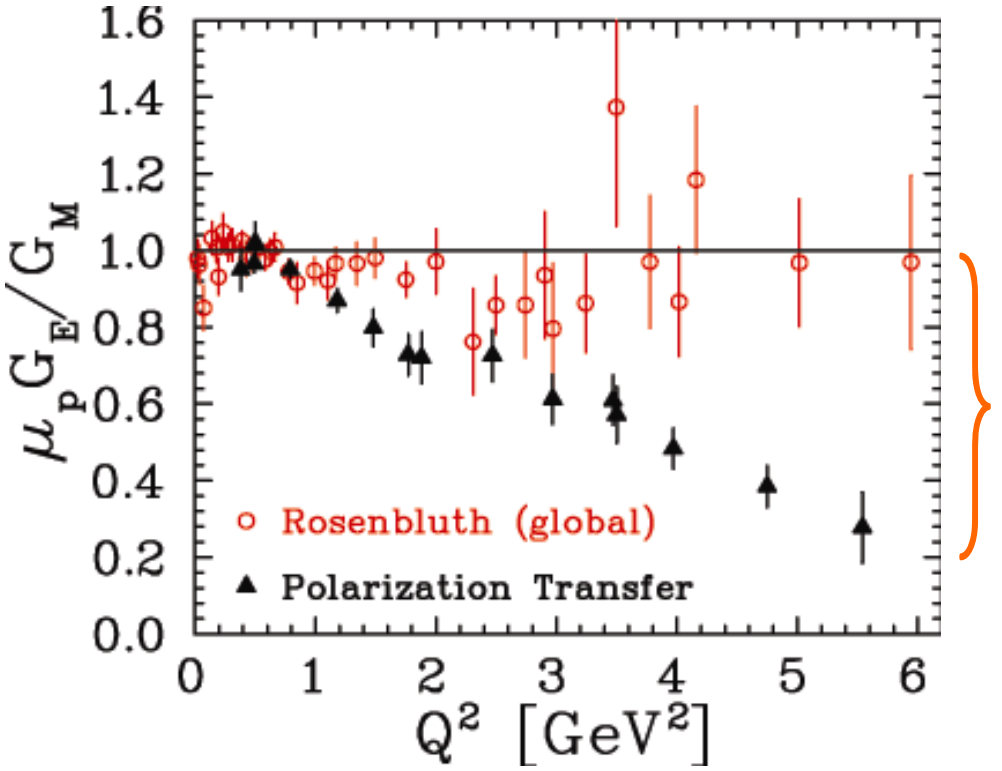

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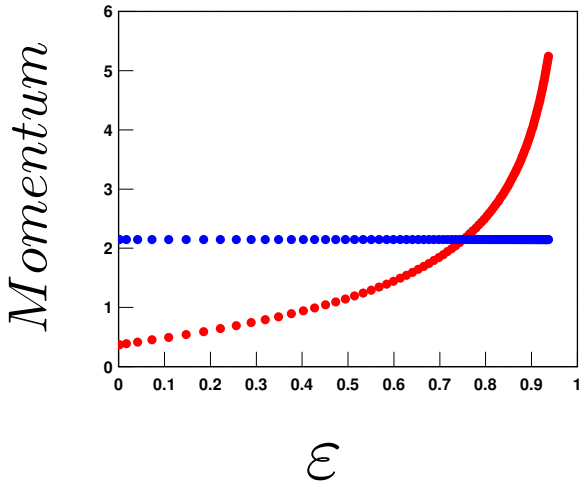
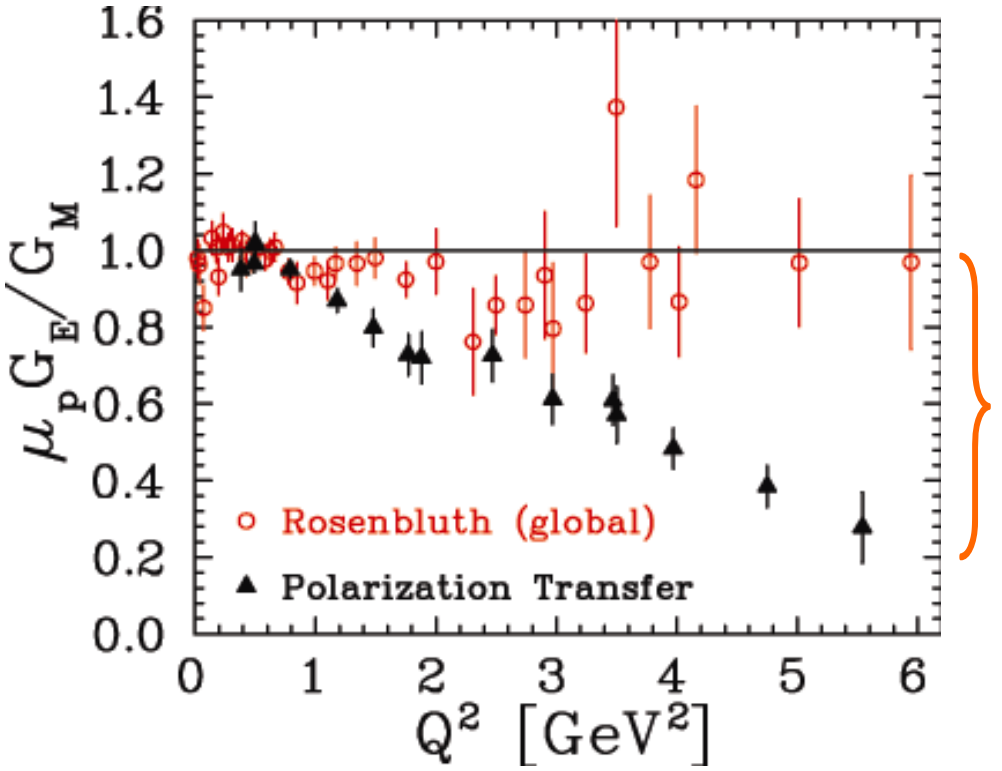


PR05-017, JLab Hall C, 2004



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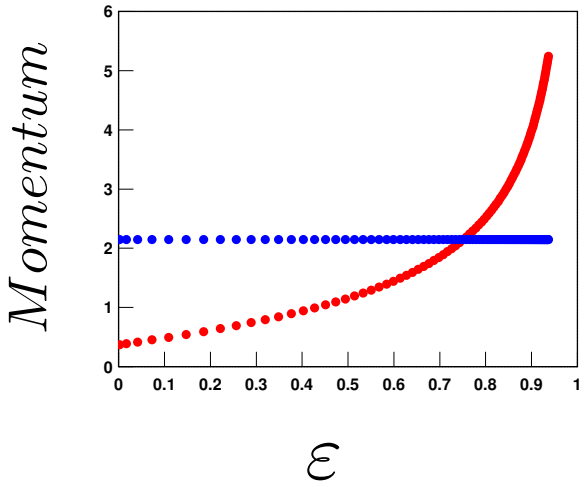

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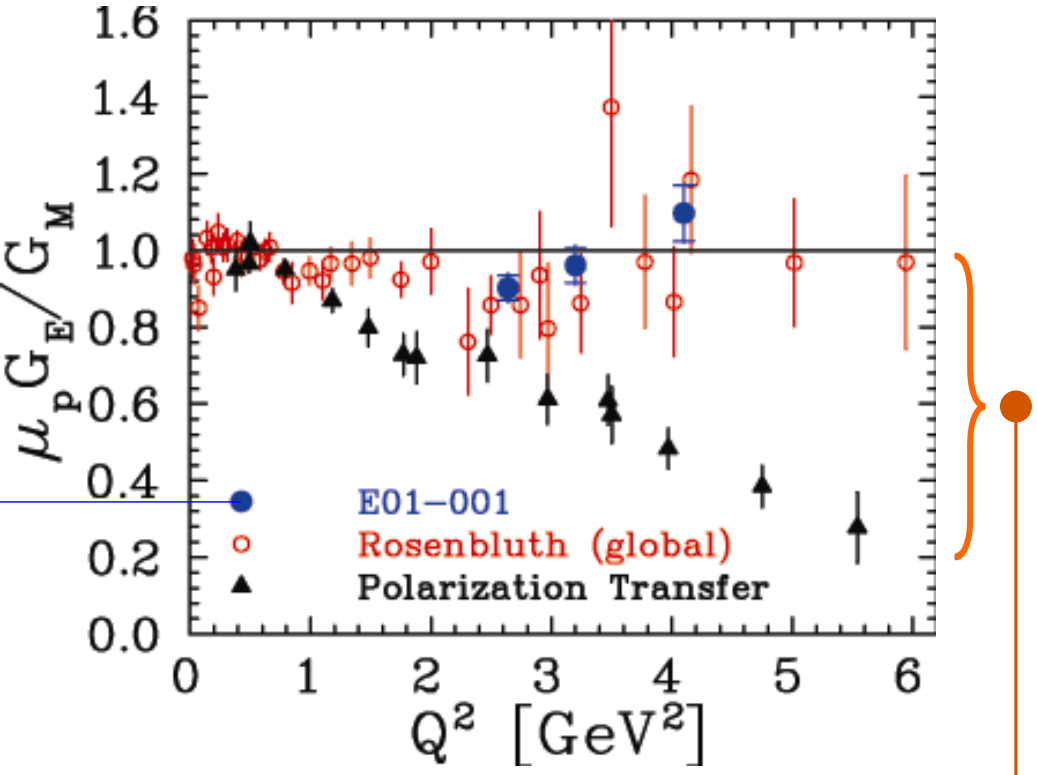


I. A. Qattan et. al, Phys. Rev. Lett. 94:142301, 2005

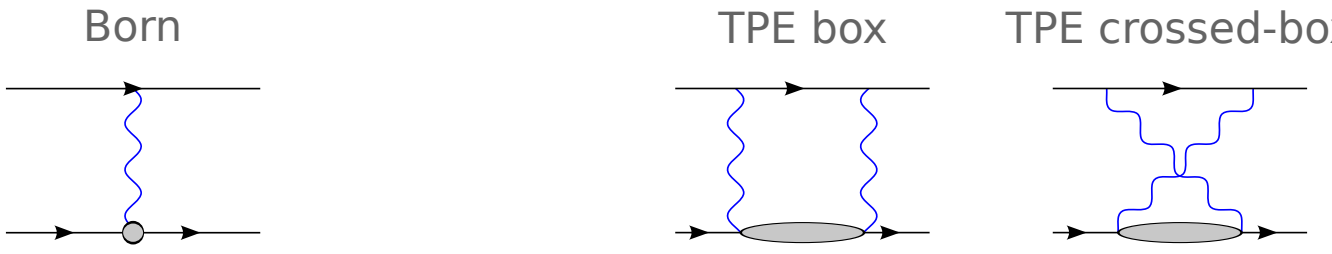
JLab E01-001 detects proton:

- Decrease ε dependent corrections
- Access smaller electron angles

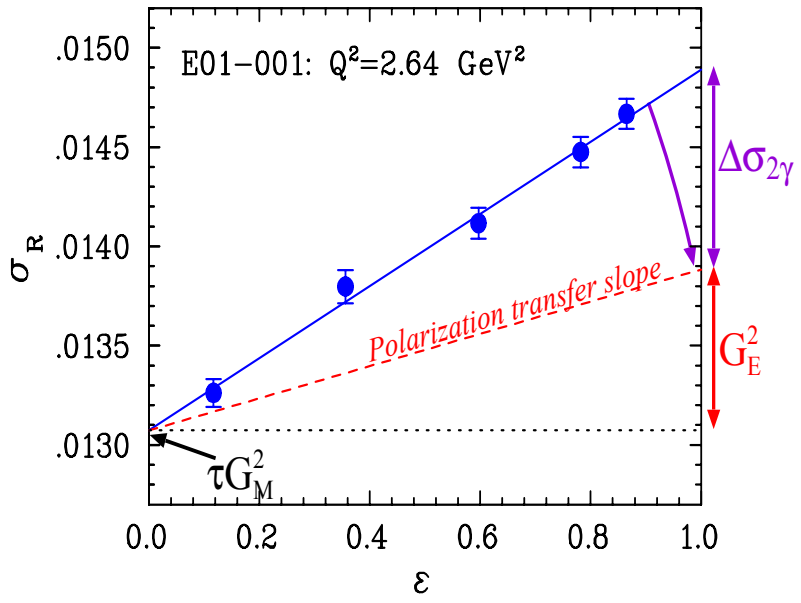
Consistent with electron Rosenbluth

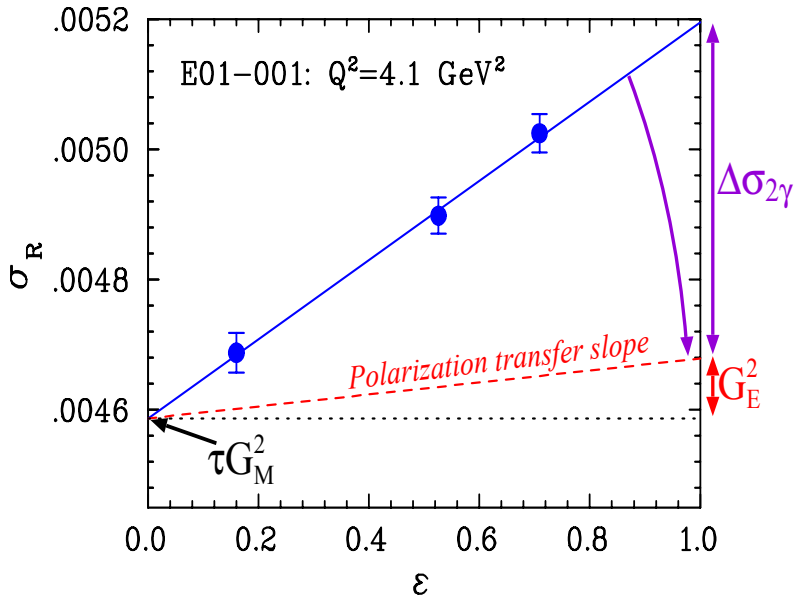
Rules out experimental error in cross section data

TWO PHOTON EXCHANGE



Size of the discrepancy





PR05-017, JLab Hall C, 2004

TWO PHOTON EXCHANGE

- Deviation from linearity in the $\mathcal{E}$ dependence - TPE signature
- Figure of merits to test linearity:

$$\sigma_R = P_0[1 + P_1\varepsilon + P_2\varepsilon^2]$$

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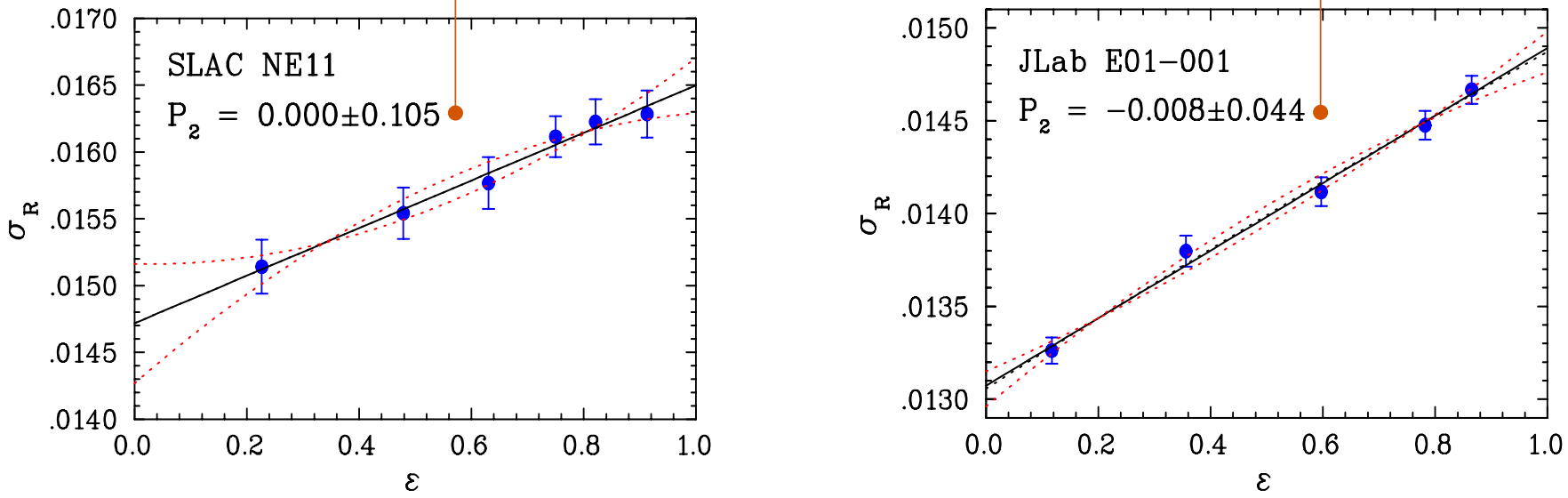


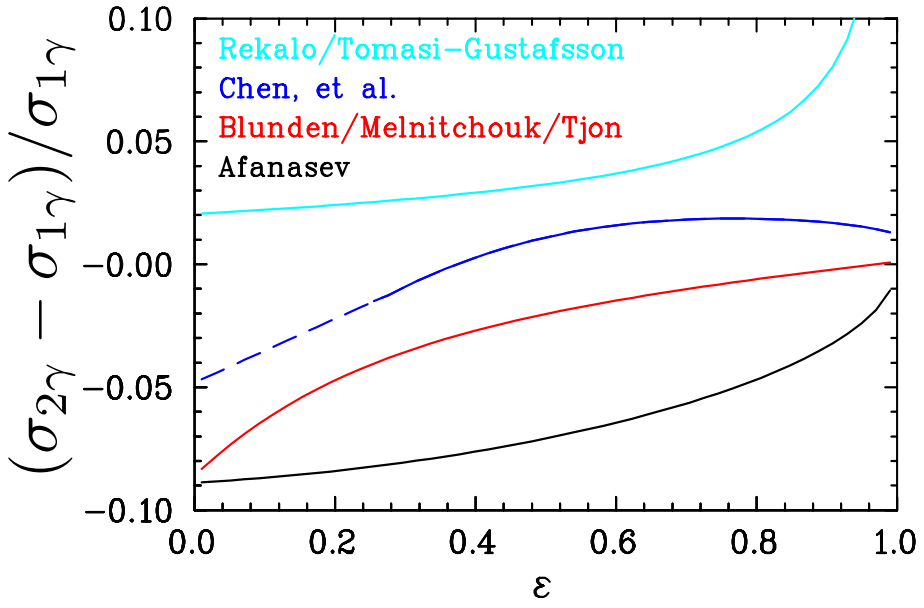
PR05-017, JLab Hall C, 2004

- Previous measurements - P_2 is consistent with 0

TPE CALCULATIONS

New TPE calculations indicate observable nonlinearities in the ε dependence

- Different ranges of ε dependence
- Scale is not well predicted
- Nonlinearities appear at the extremes of ε

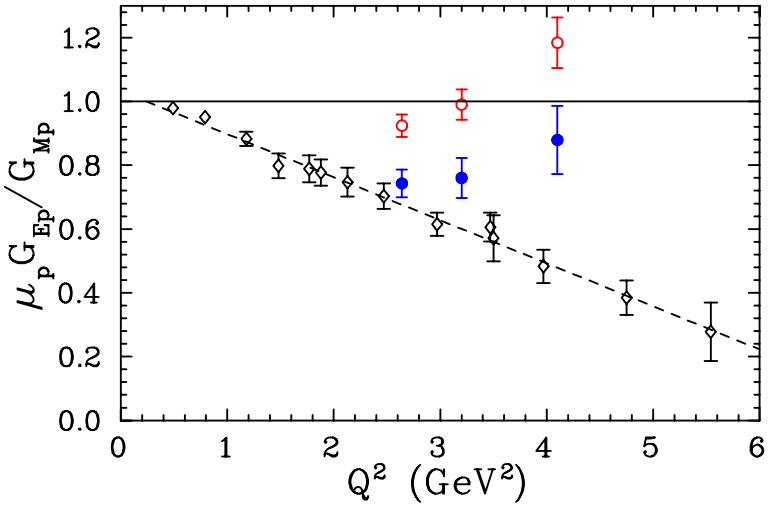


PR05-017, JLab Hall C, 2004

TPE CALCULATIONS

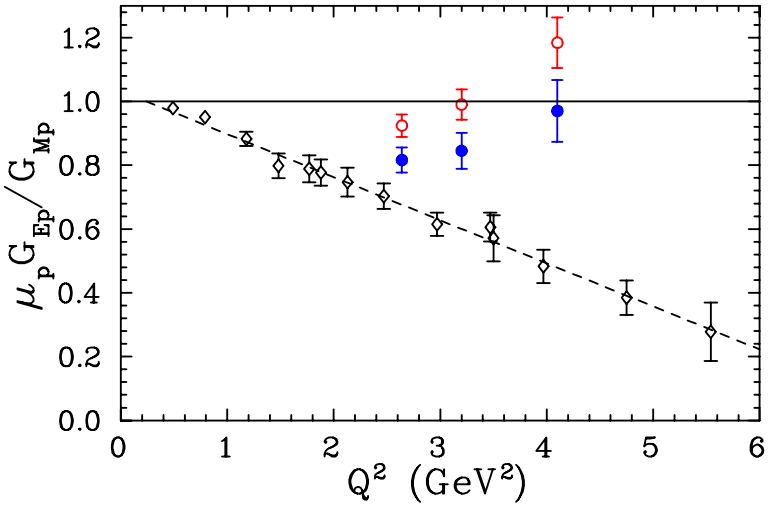
Calculation by Blunden, et al.

Discrepancy is almost resloved
in 2-3 GeV^2



Calculation by Chen, et al.

~50% of what is needed
not expected to be valid at low Q^2



I. A. Qattan, Thesis, 2005

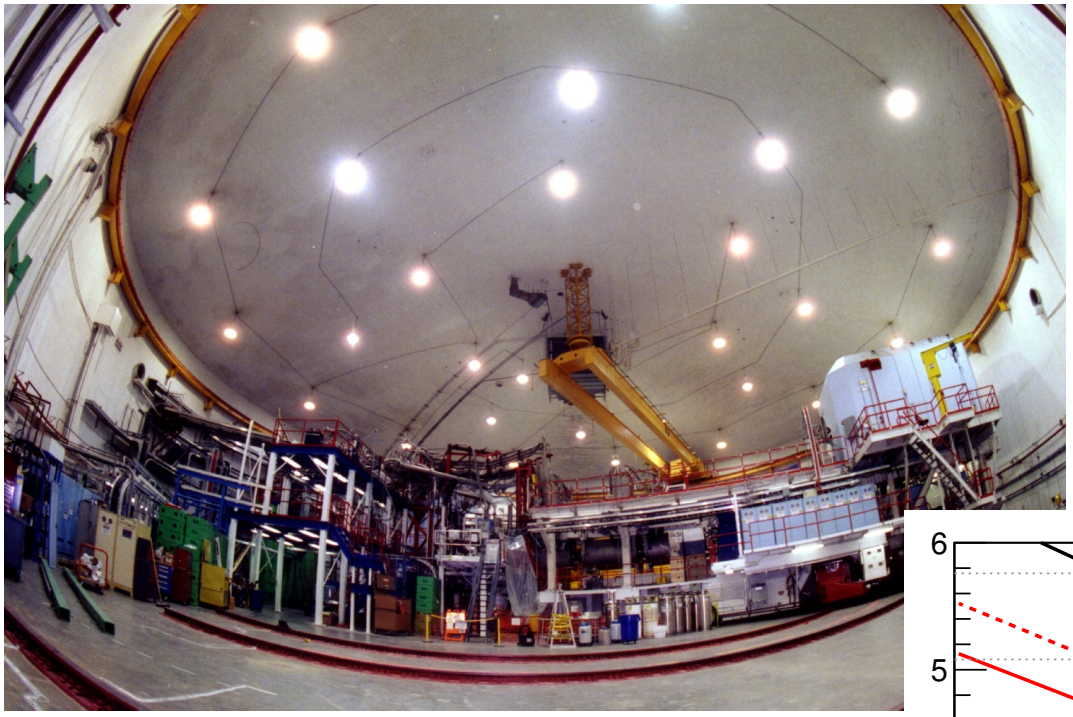
E05-017 goals

- PROTON Rosenbluth to map out ε and Q^2 dependence of TPE
  - Tight limits on deviations from linearity in ε dependence
  - High precision Rosenbluth extraction of $\mu_p G_E/G_M$ for $0.4 \lesssim Q^2 \lesssim 5.7$

Difference from E01-001

- Reaches extremes of $\mathcal{E}$ where TPE is expected to be largest
- Performs highly detailed in $\mathcal{E}$ measurements at two Q^2 values
- Gets higher Q^2 where discrepancy is largest
- Maps lower Q^2 to check if discrepancy is present

E05-017 HALL C, JLAB



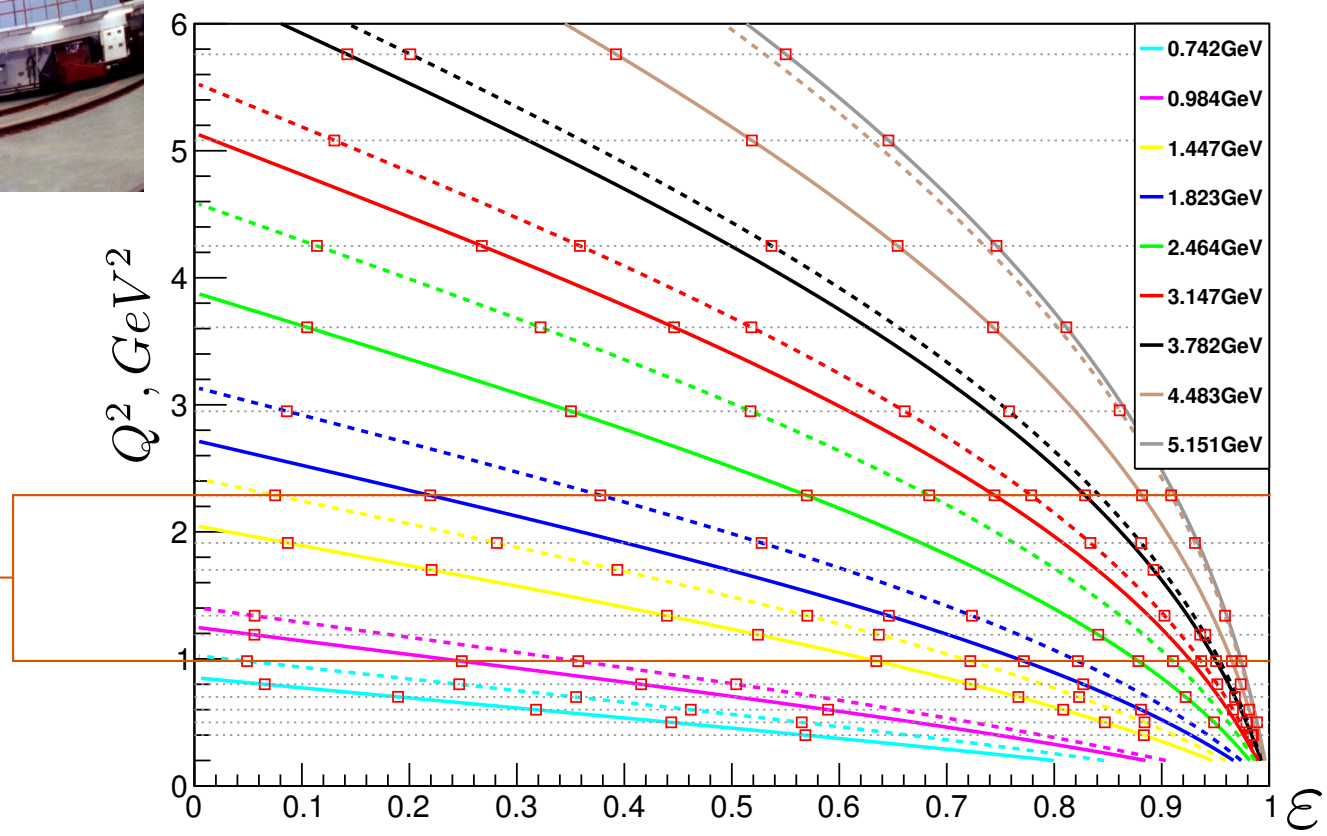
HMS in Hall C at JLab

4 cm LH2 and dummy targets

102 Kinematics points

10 points at $Q^2 = 2.284$

13 points at $Q^2 = 0.983$



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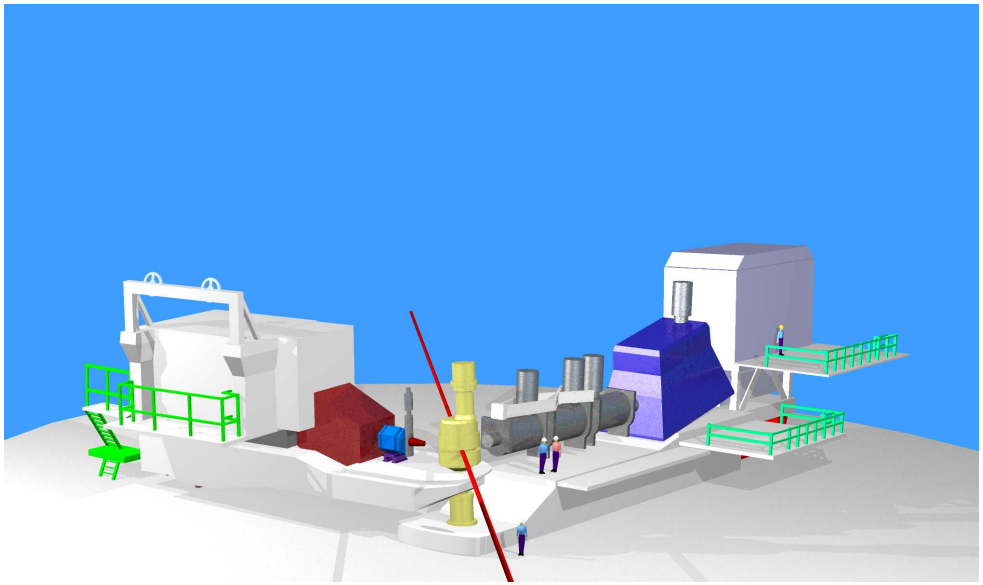
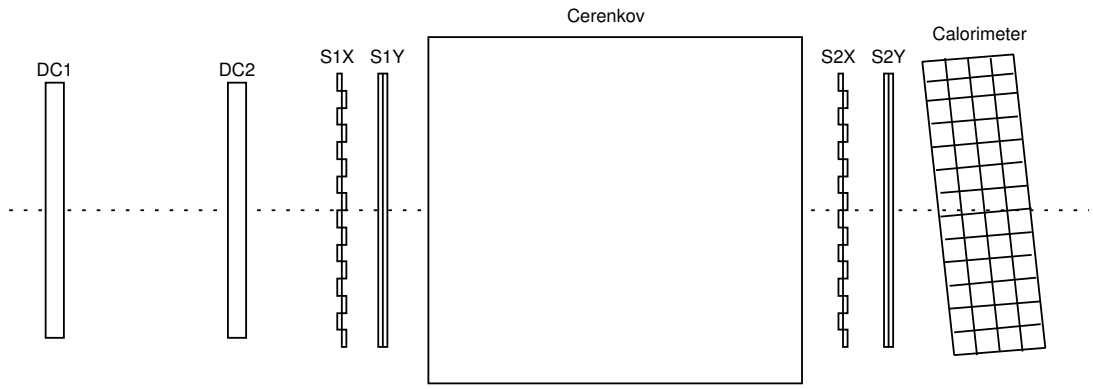


Experimental Hall C Layout



High Momentum Spectrometer Hut

- Beam line (BPM, BCM, raster)
- Target (Dummy foil is thicker than LH2 cell wall)
- Magnets (vertical bend in QQQD configuration)
- Drift chambers (2 wire chambers for tracking)
- Hodoscope (2x2 planes, Trigger, TOF)
- Aerogel Cherenkov (discriminate against pions)
- Gas Cherenkov, Calorimeter (not used)

Target Ladder

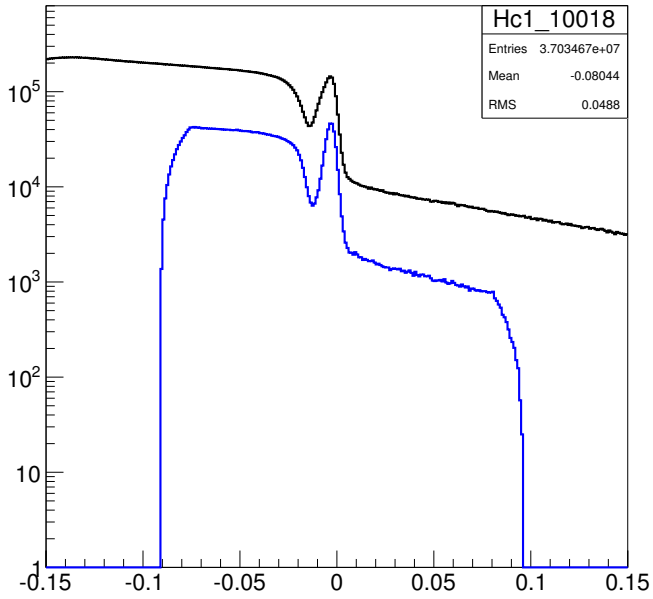
WHAT DO WE SEE

Observe:

- Protons
  - Elastic scattering
  - Inelastic scattering
  - Inelastic from target endcaps
  - Cosmic Rays
- Deuterons & Tritons
  - From target endcaps
- Pions
  - Inelastic scattering
  - From target endcaps

$$\Delta P = P_{measured} - P_{elastic}(\theta_{measured})$$

Q^2 = 1.90
ε = 0.09
E_{beam} = 1.44
θ_{spec} = 12.3



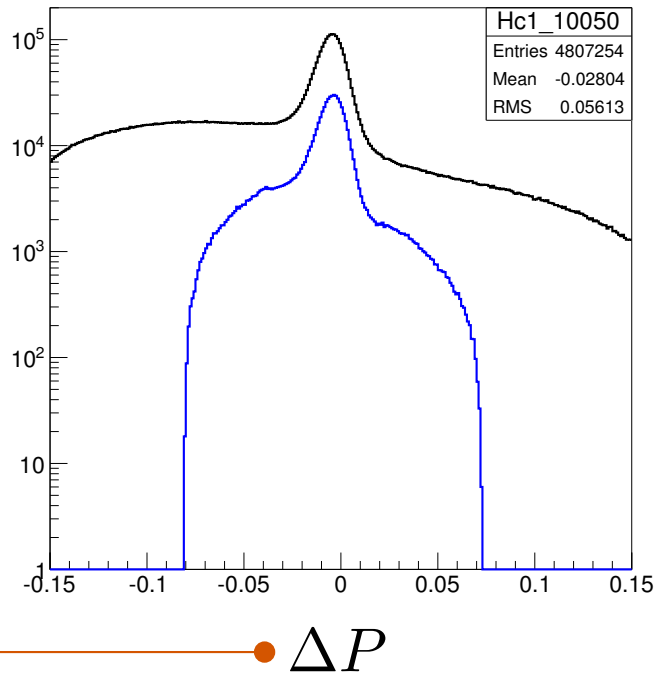
WHAT DO WE SEE

Observe:

- Protons
  - Elastic scattering
  - Inelastic scattering
  - Inelastic from target endcaps
  - Cosmic Rays
- Deuterons & Tritons
  - From target endcaps
- Pions
  - Inelastic scattering
  - From target endcaps

$$\Delta P = P_{measured} - P_{elastic}(\theta_{measured})$$

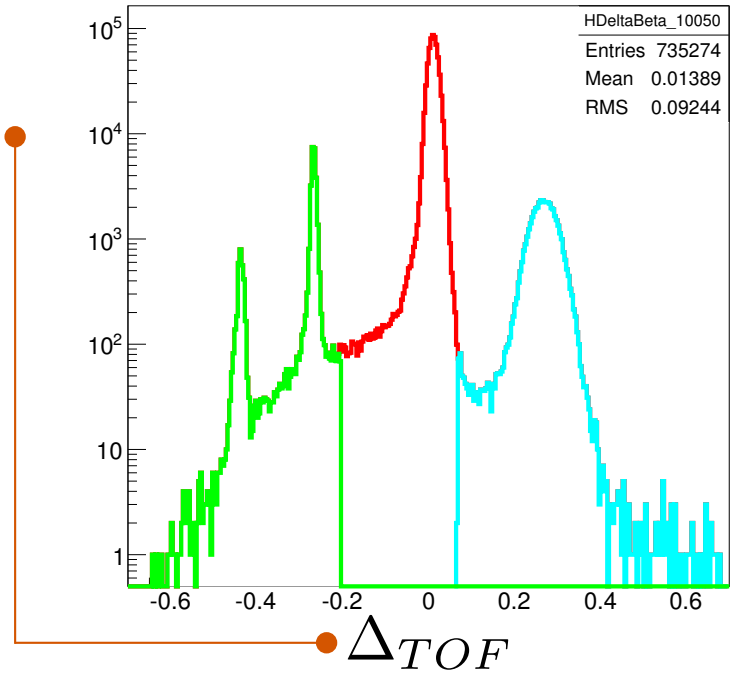
Q^2 = 0.98
ε = 0.88
E_{beam} = 2.45
θ_{spec} = 49.7



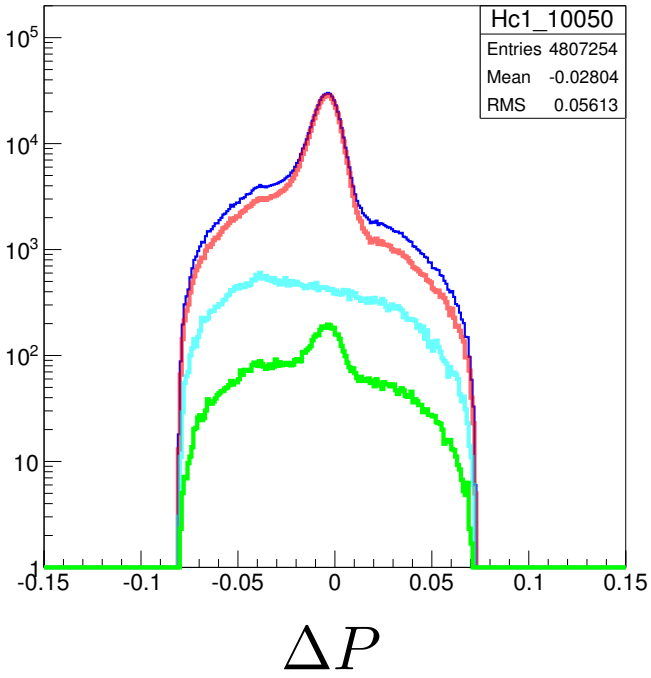
PARTICLE ID

$$\Delta_{TOF} = TOF_{measured} - TOF_{calculated}$$

- TOF cut to select elastic
  - Elastic peak around zero
  - Right side: pions
  - Left side: deuterons, tritons

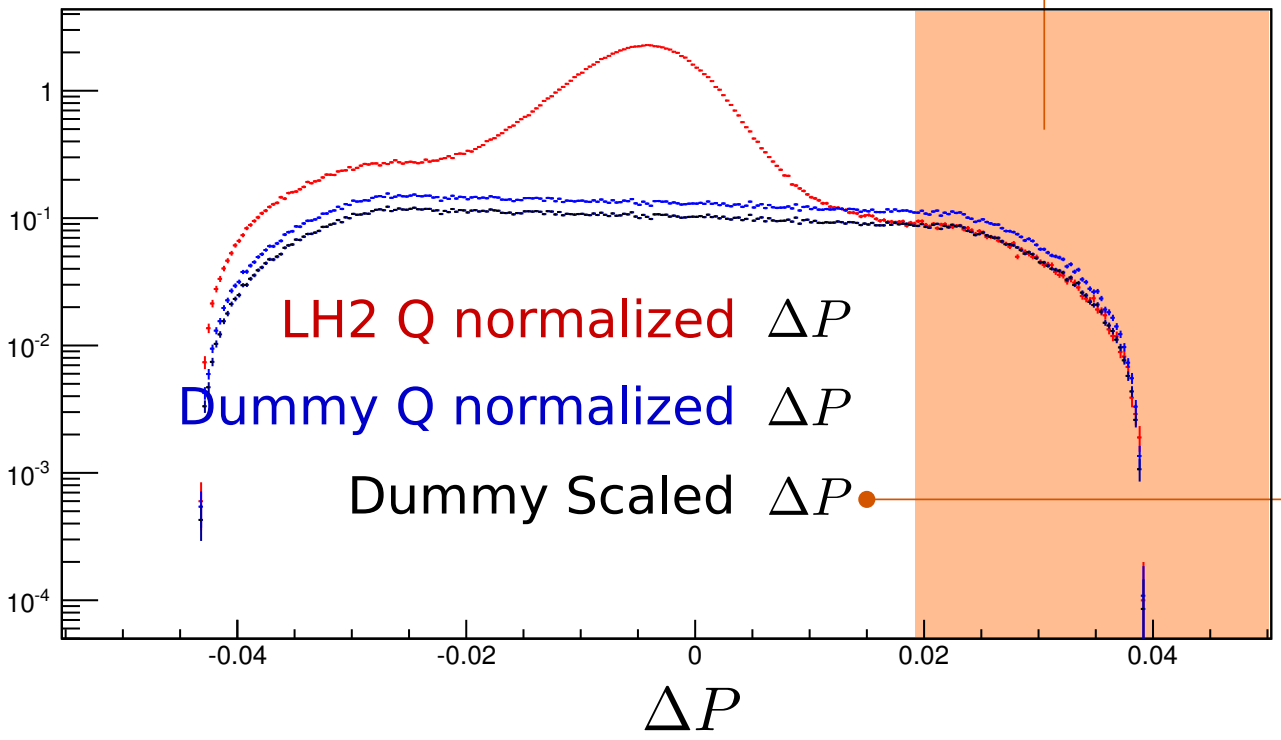


- Aerogel cut to exclude pions
  - Used to check TOF efficiency
  - Low pion count runs / Noisy ADC
  - Not used in the final analysis



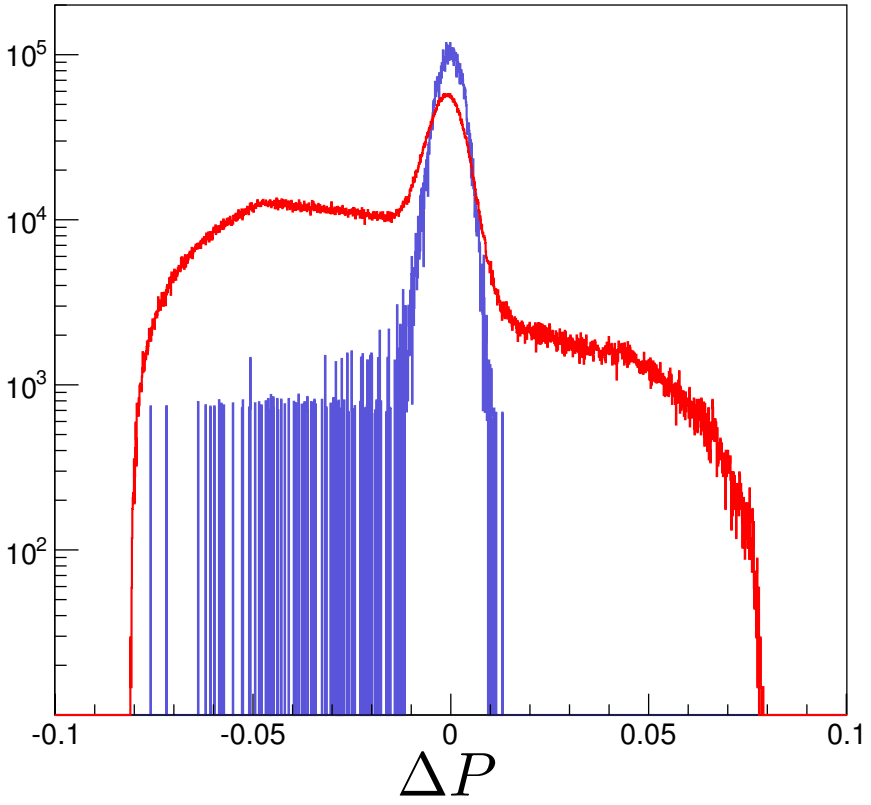
ENDCAP SUBTRACTION

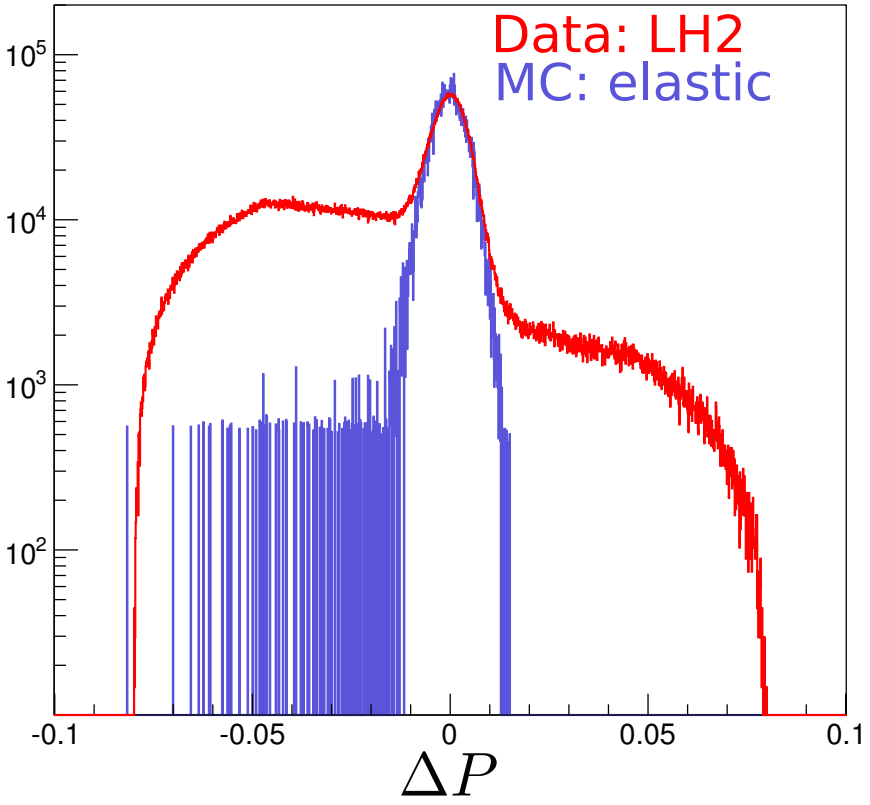
- Dummy target foils are thicker - minimize run time
- Bremsstrahlung initiated reactions in downstream endcap - scale
- "Superelastic" region - only endcaps contribution



SIMULATION

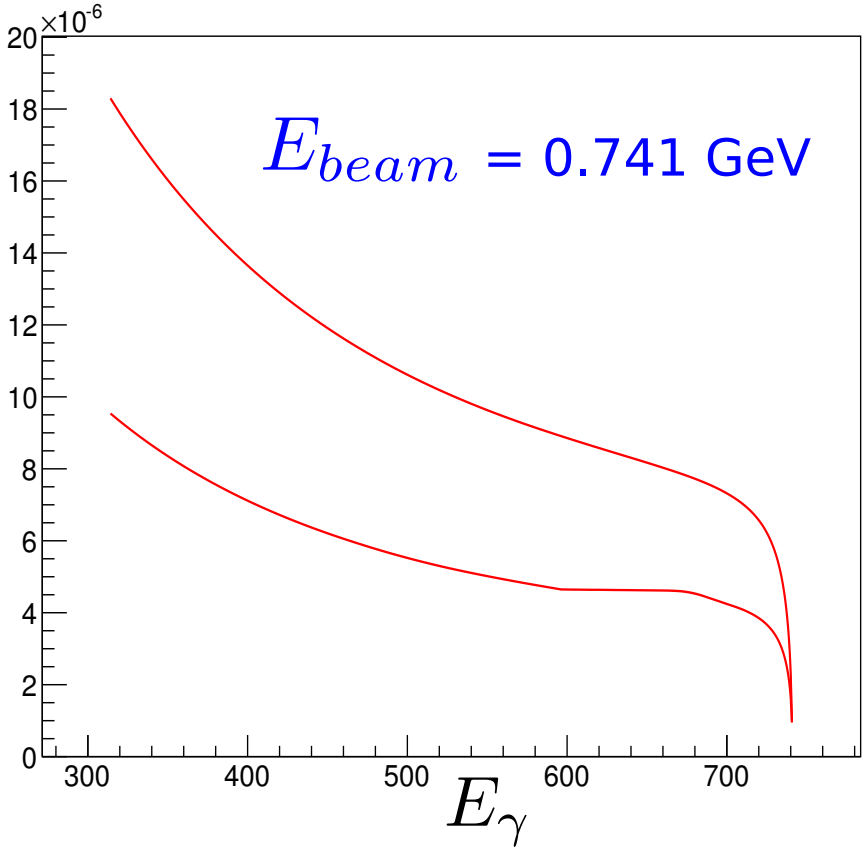
- Elastic simulation - SIMC package
  - adjusted to allow scattered proton generation
  - to generate event: beam energy, scattering position and angle
  - propagate through magnets to the detector hut
  - apply smearing to match data

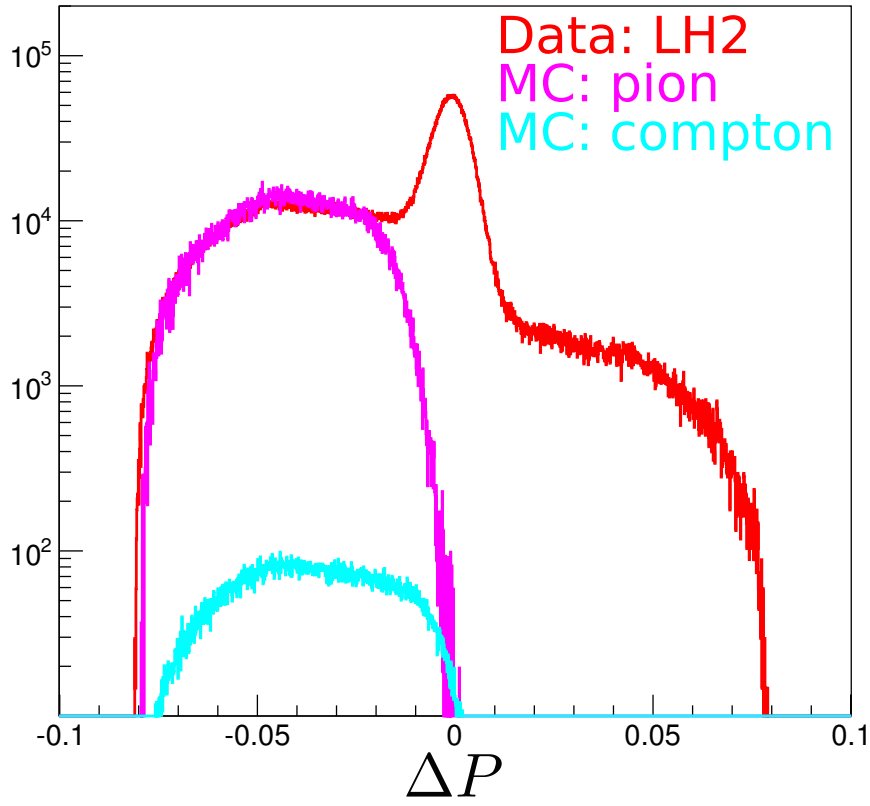




SIMULATION

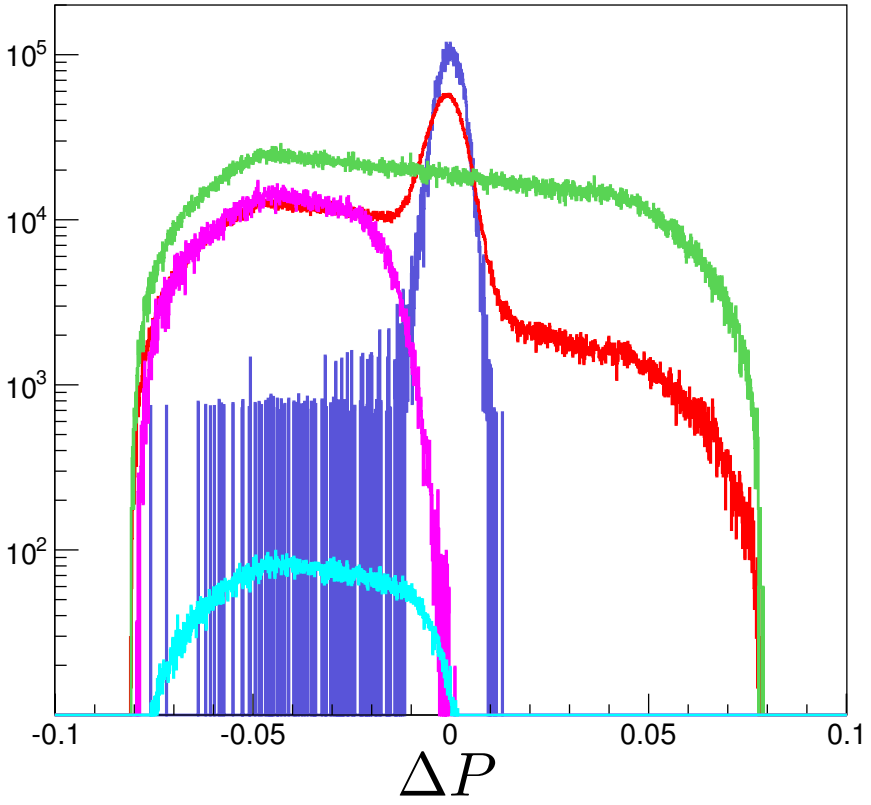
- Background simulation
  - pion photoproduction and compton scattering
  - generate bremstrahhlung, get photon energy
  - repeat steps for protons as in the case of elastic
  - apply smearing to match data

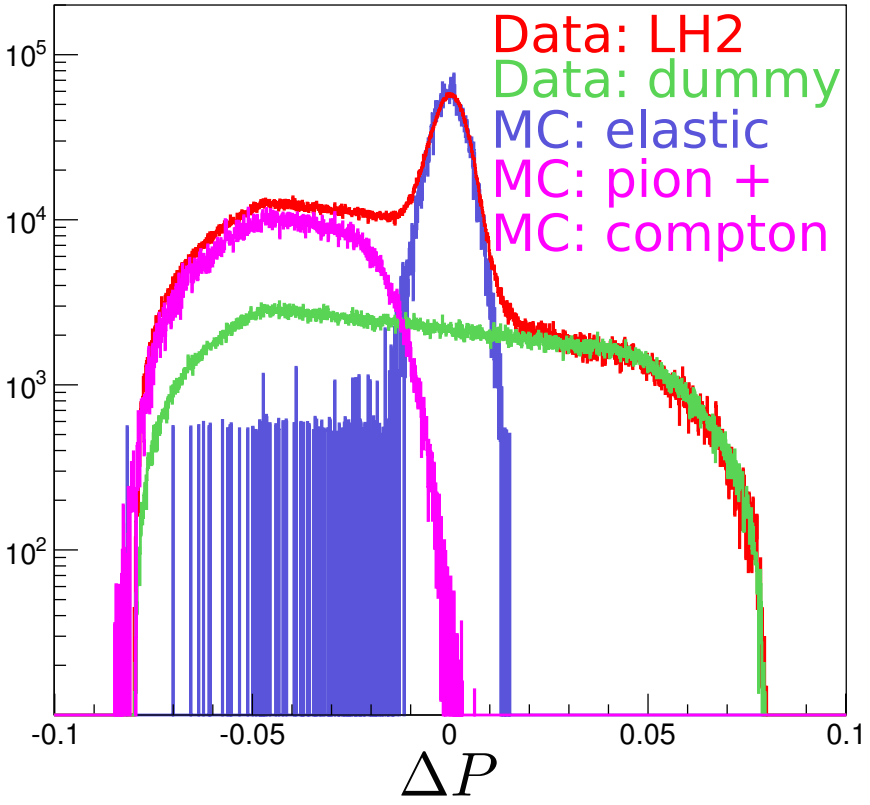




SCALING, SUBTRACTION

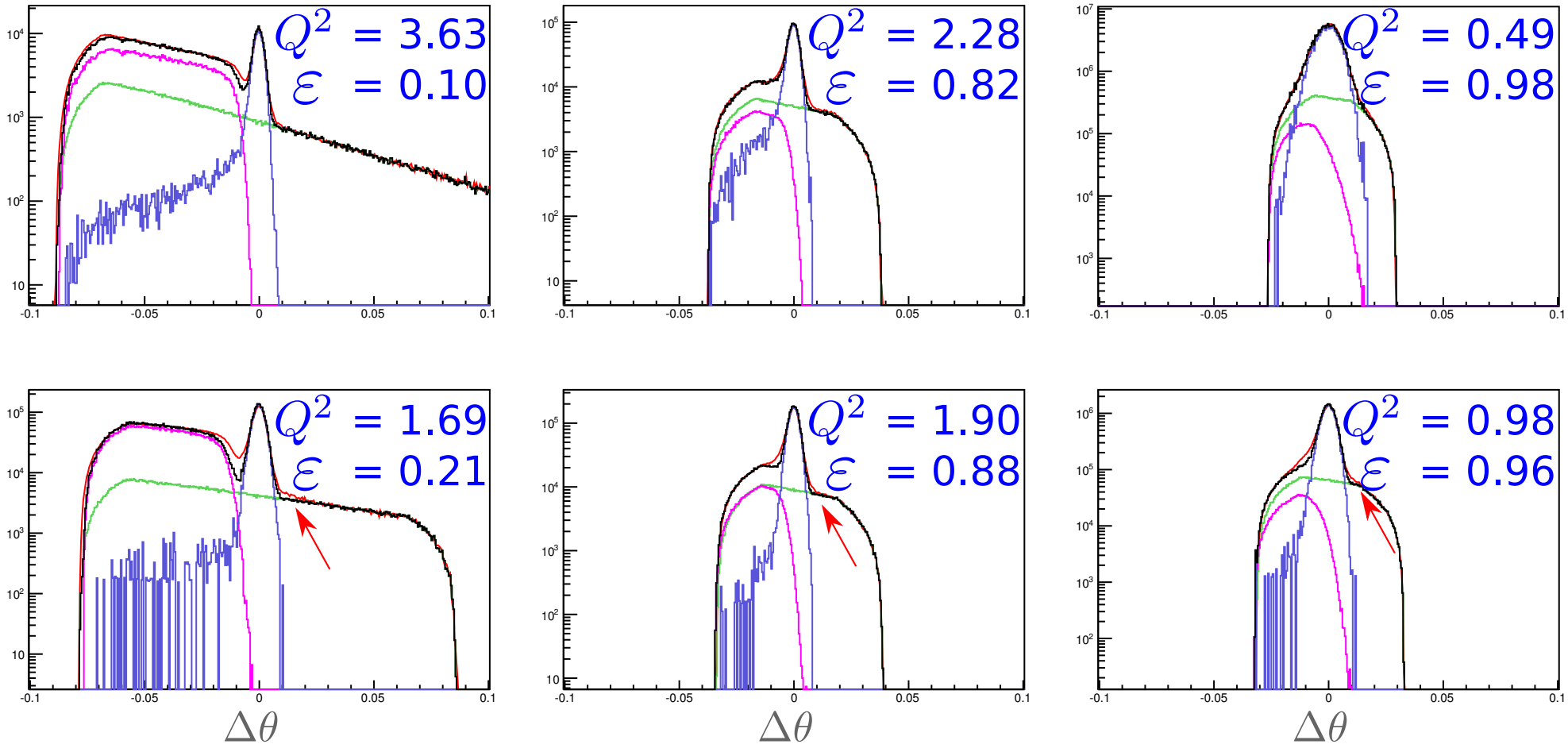
- Fit scaled MC + Dummy to Hydrogen spectrum
- Get elastic by subtracting backgrounds
- Determine final number of elastic events by applying cut on ΔP





SIMULATION

- Finish compton background scaling
- Non-gaussian tails in data - additional smearing



CORRECTIONS

Electronics livetime	Calculated for each run by reconstruction package
Computer livetime	
Trigger efficiency	
DC cut efficiency	
Prescale	
Absorption correction	Calculated for each run inside the analysis package
Target boiling correction	
Target length correction	
PID efficiency	Not in the code yet

TO BE DONE

- resolution mismatch, proper scaling to fit data
- increase MC statistics, cover all kinematic points
- efficiencies, systematics
- extract cross sections, FF ratios

THANK YOU