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

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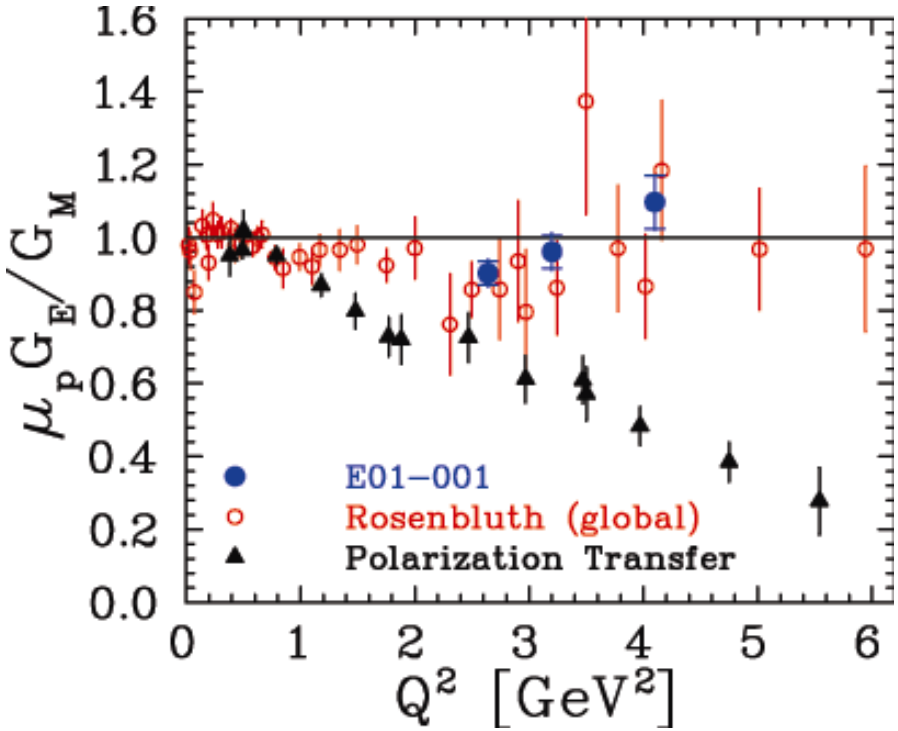
Precision Rosenbluth Results

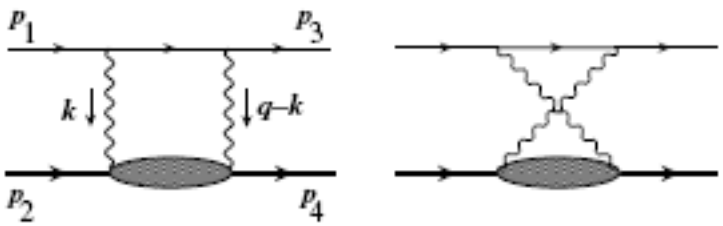
- Precision comparable to polarization transfer
- Agrees with electron Rosenbluth
  - Disagreement is real
  - High-precision measurement of the discrepancy

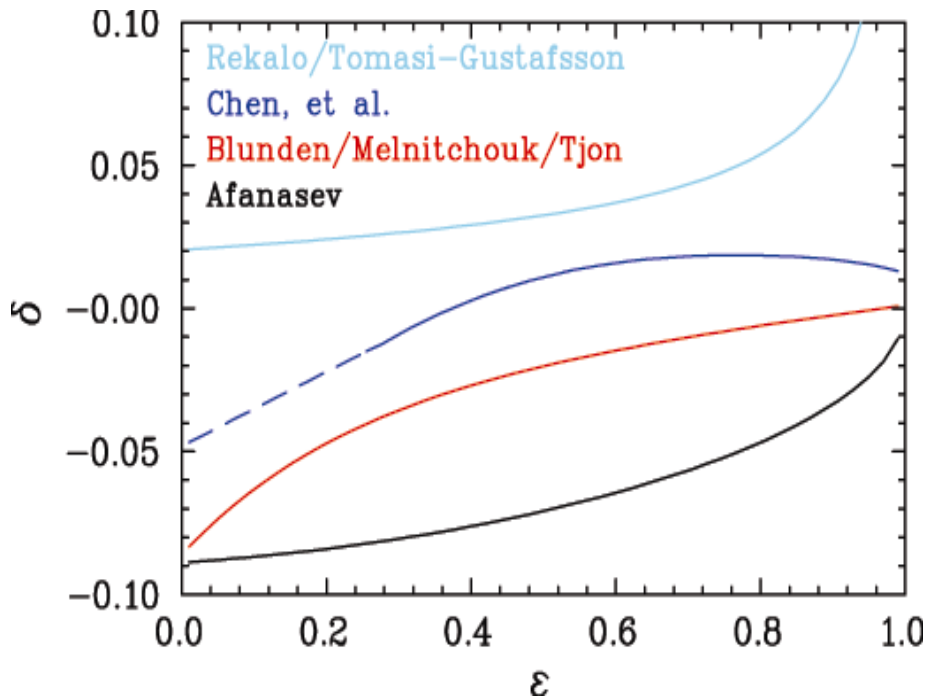


I. A. Qattan *et. al*, Phys. Rev. Lett. 94:142301, 2005

TPE Calculations

- Difficult to Calculate

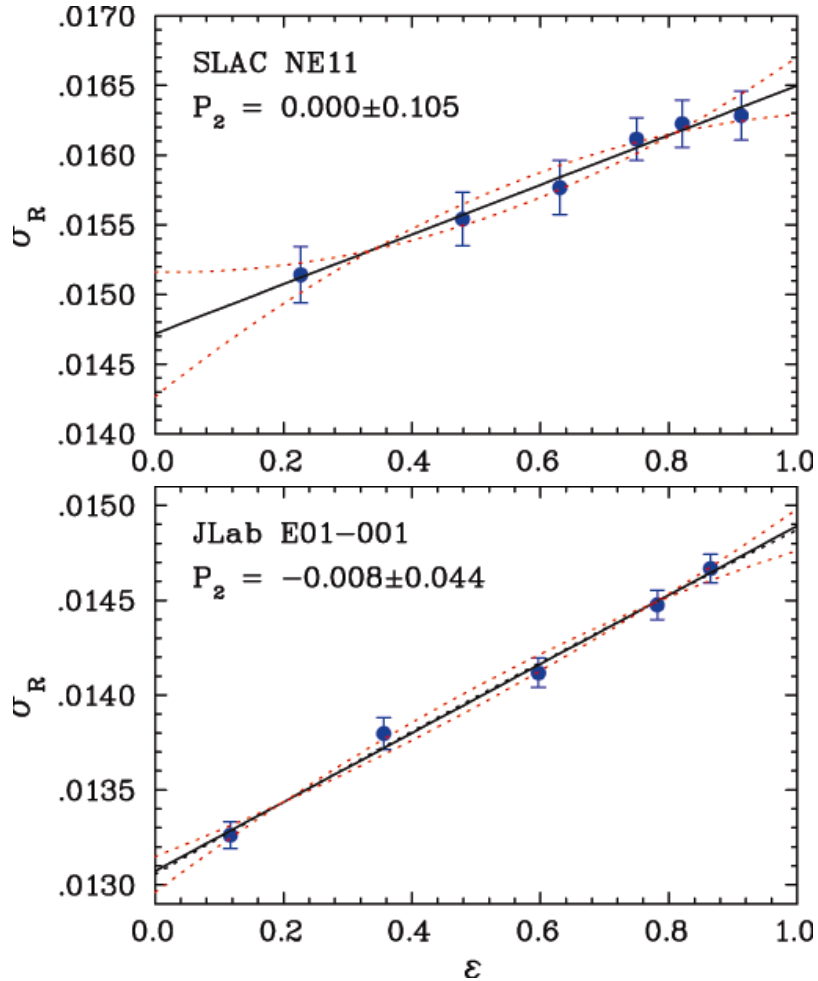




  - Rough qualitative agreement (~5% ε-dependence)
  - Different ε dependence
  - Scale not well predicted
  - Deviations tend to be linear except at extremes of ε

Nonlinearity Tests

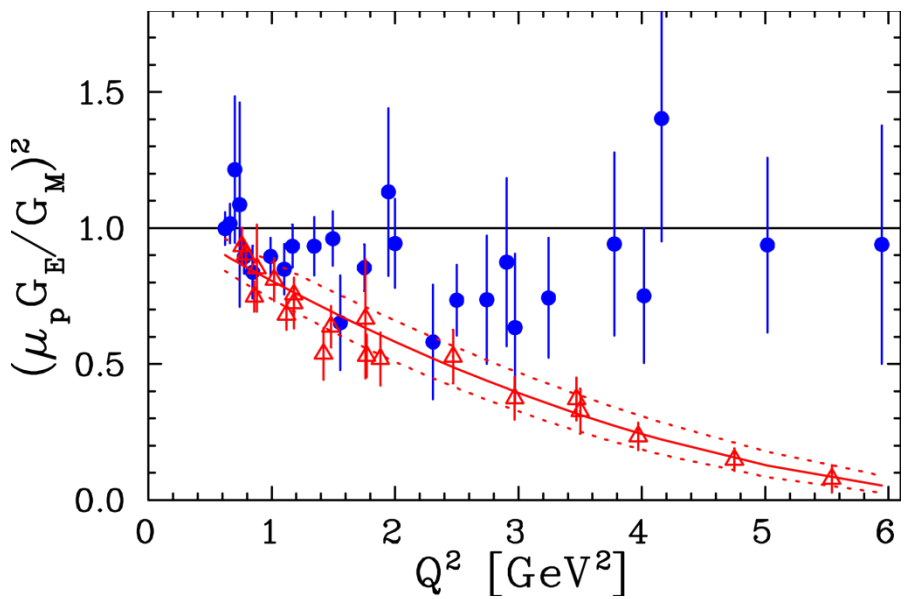
- Rosenbluth expects linearity in ε, TPE would cause a deviation
- E01-001 and NE11 show quadratic terms consistent with zero
- $\sigma_R = p_0[\ 1 + p_1(\varepsilon\text{-}0.5) + p_2(\varepsilon\text{-}0.5)^2\ ]$



NE11: L. Andivahis *et al*, Phys. Rev. D50:5491, 1994

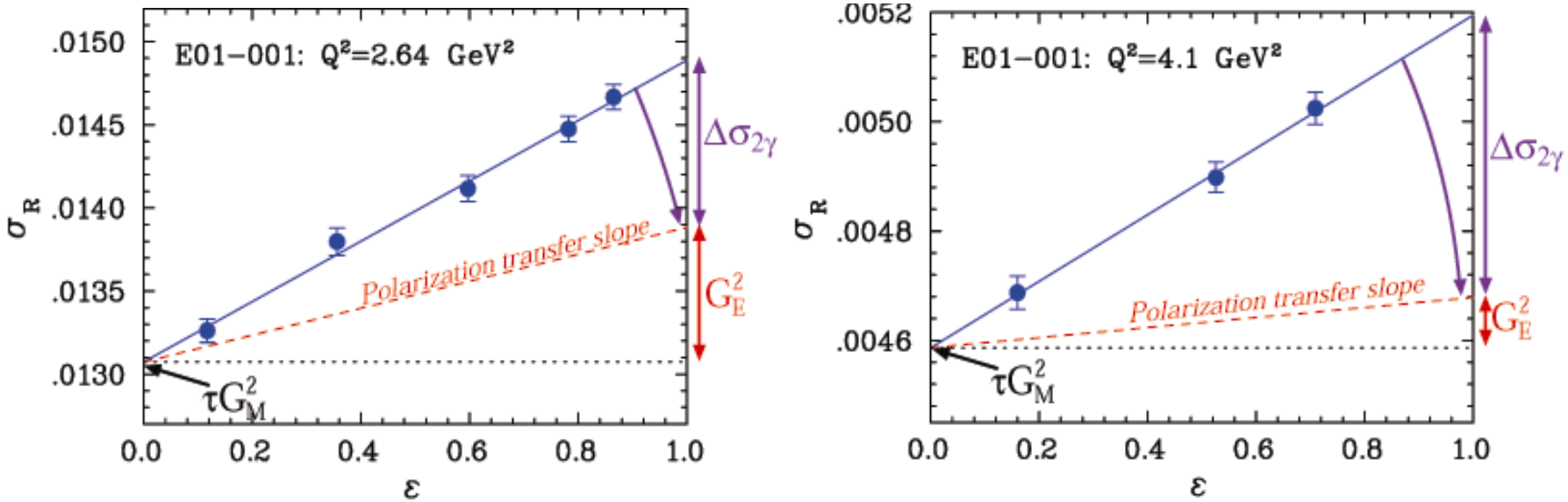
What's Different

- Extremes of epsilon
  - Where we expect the largest TPE effect
- Higher Q^2
- More detail at low Q^2
  - Uncertain whether there is a discrepancy
- Many points at two Q^2
  - Detailed linearity test



Magnitude of the Discrepancy

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

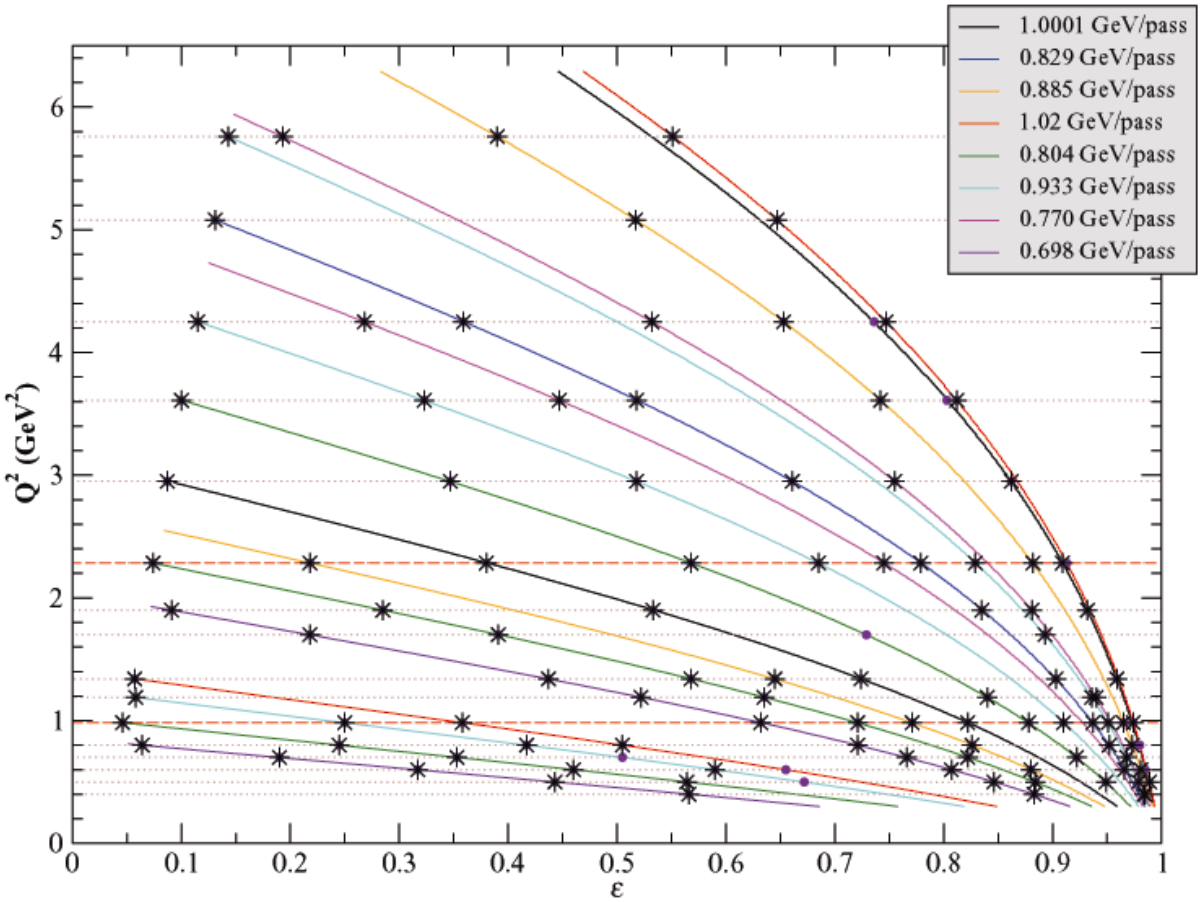


Solid line – fit to E01-001 'Super-Rosenbluth'

Dashed line – taken from polarization transfer ratio

half of the ε dependence at 2.64 GeV^2 (left), and 85% at 4.1 GeV^2

Rosenbluth 2007



102 Kinematics points

Q^2 0.40-5.76 GeV^2

13 points at Q^2=0.983

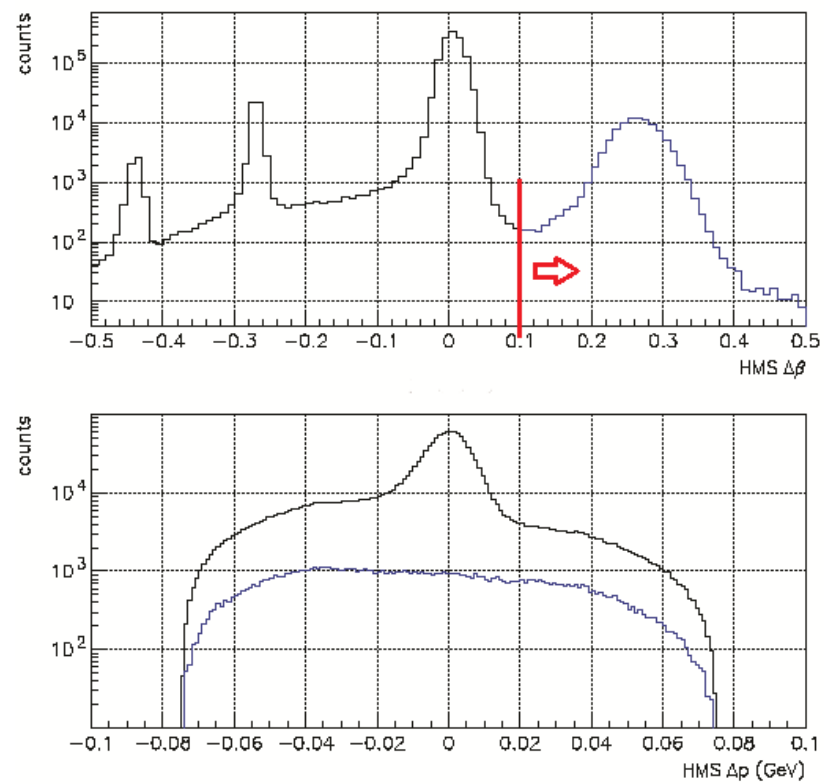
10 points at Q^2=2.284

$$\varepsilon = \left(1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right)^{-1}$$

ToF High Side

2.055 GeV 47 deg; 0.98 GeV^2

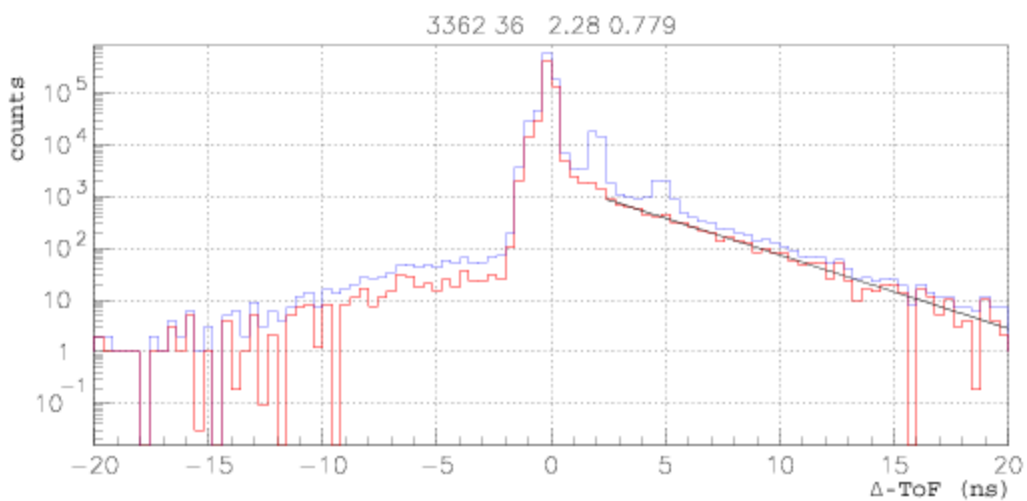
- Excluding pions, faster than protons
- Elastic protons disappear quickly
- Cut just above proton peak
- At higher Q^2 pion tail may extend underneath proton peak



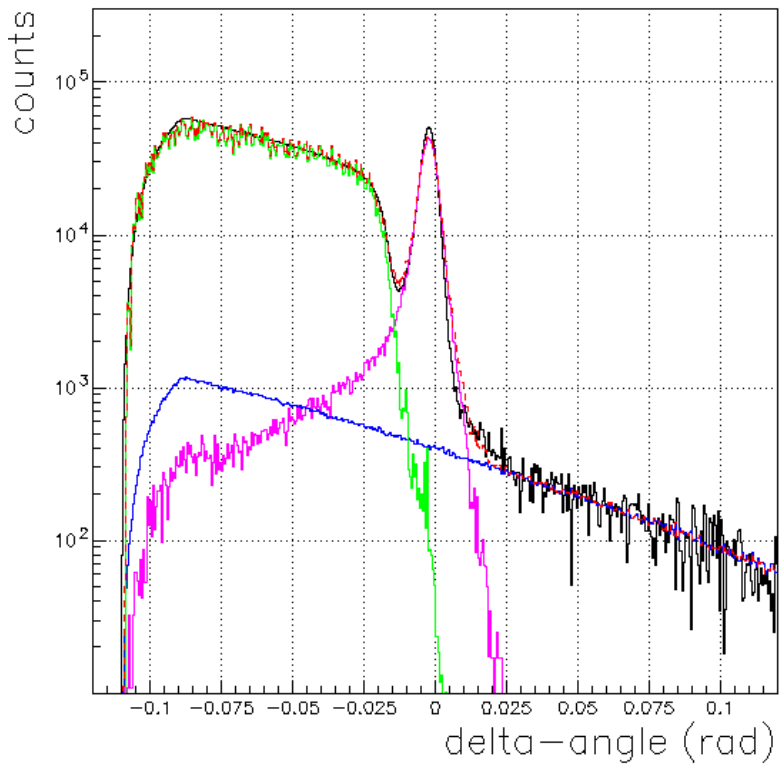
ToF Low Tail

- Look at exponential tails in dummy-subtracted Δ-ToF
  - Dummy subtraction minimizes effect of deuterons, tritons
  - Expect same tails at fixed Q^2
  - Found small angle dependence
- Pion tail expected similar to proton
  - Too little gap to fit

PID efficiency was ε-dependent

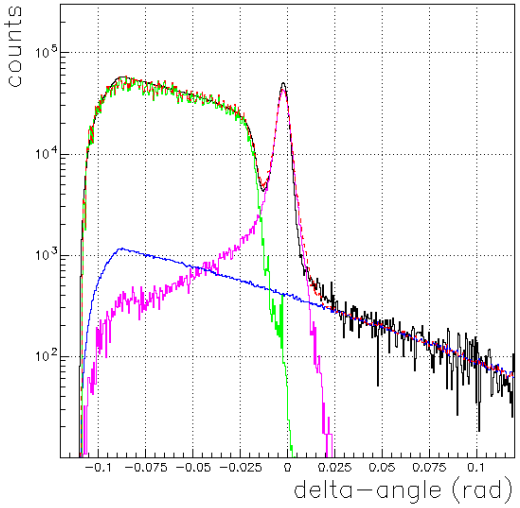


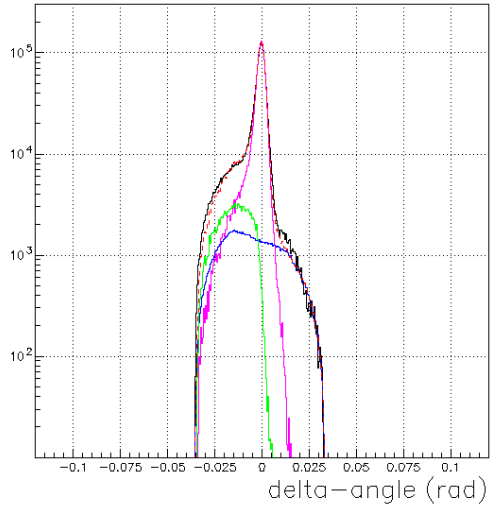
Proton Spectrum



- Hydrogen elastics
  - Compare to simulated elastics
- Background
  - ‘Dummy’ runs for endcap subtraction
  - Simulated π^0 photoproduction

Background Separation

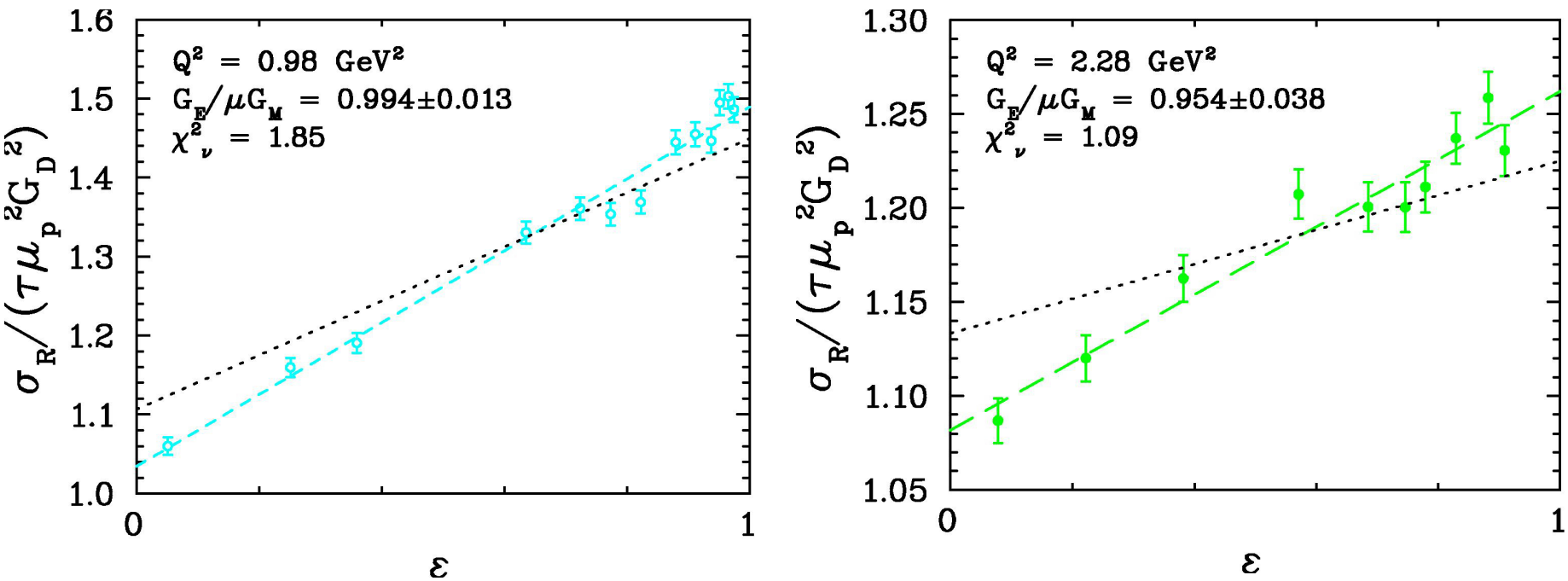




2.28 GeV^2,
lowest and
highest angles

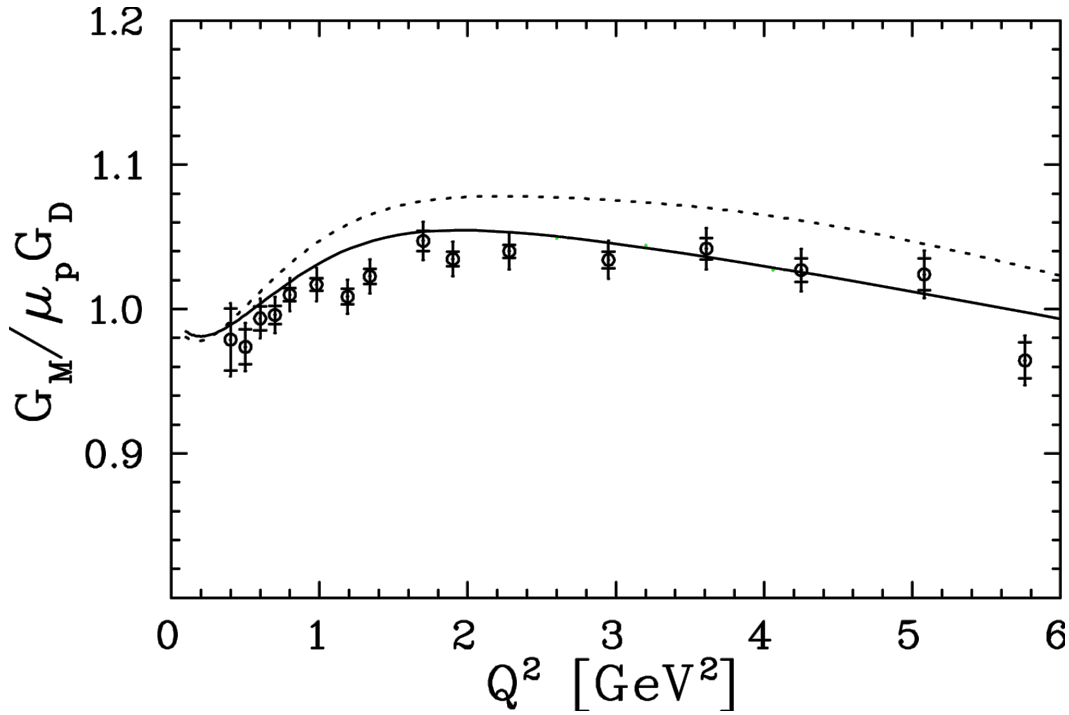
- Lowest proton angle – Background larger than peak, but well separated
- Highest proton angle – Background significantly under peak, but much smaller

L-T Separations



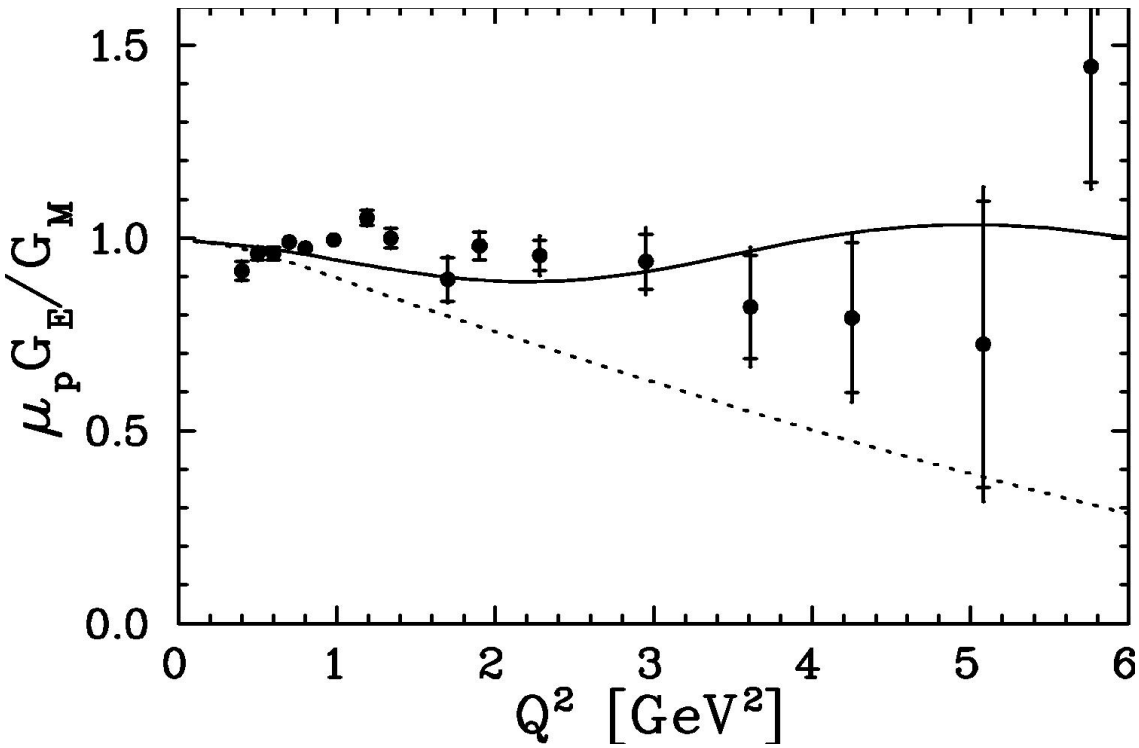
- G_M^2 from intercept
- G_E^2 from slope

$G_M/\mu_p G_D$



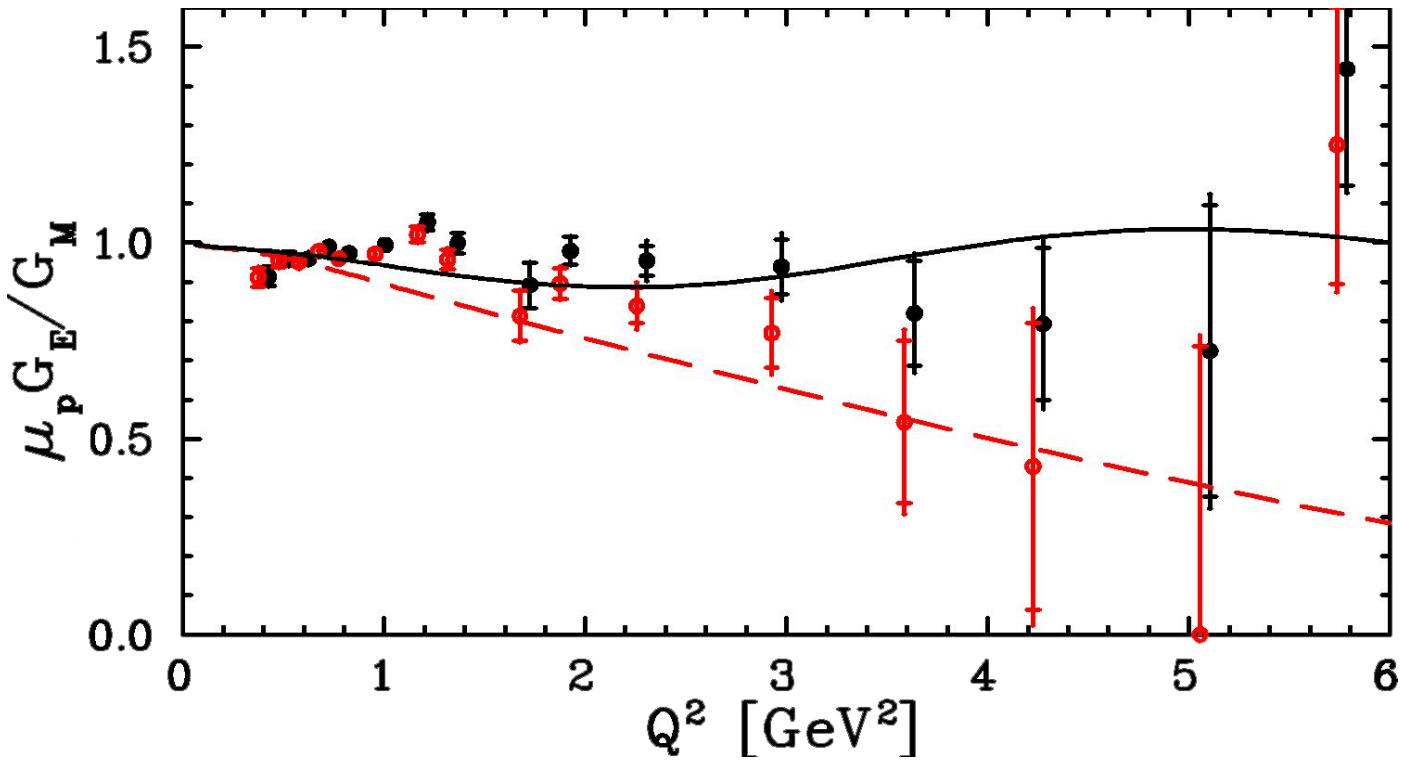
- Agrees with fit to previous data (solid line)
- Dashed line is what we would see with only single photon exchange

$\mu_p G_E/G_M$



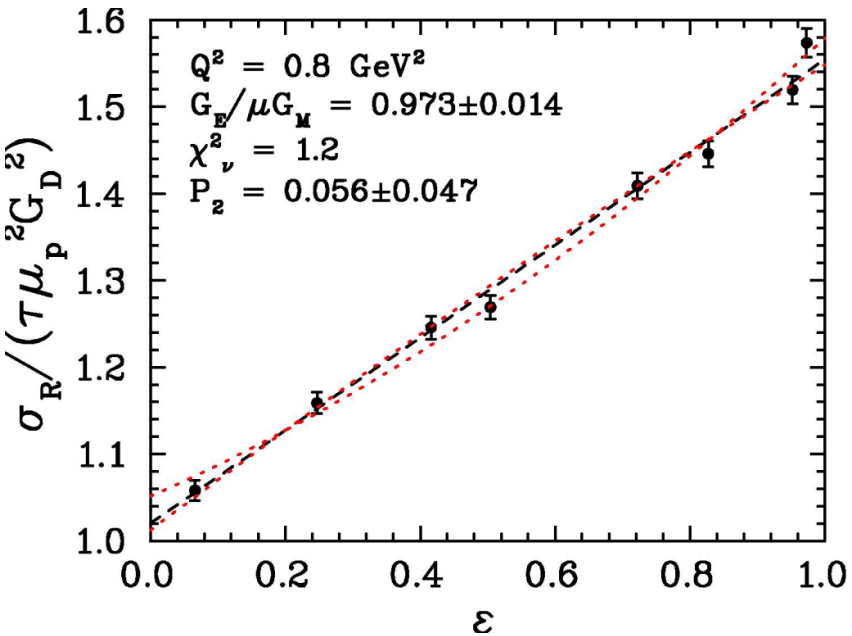
- Errors get large above 3 GeV^2 – unexpected ε dependence in particle identification

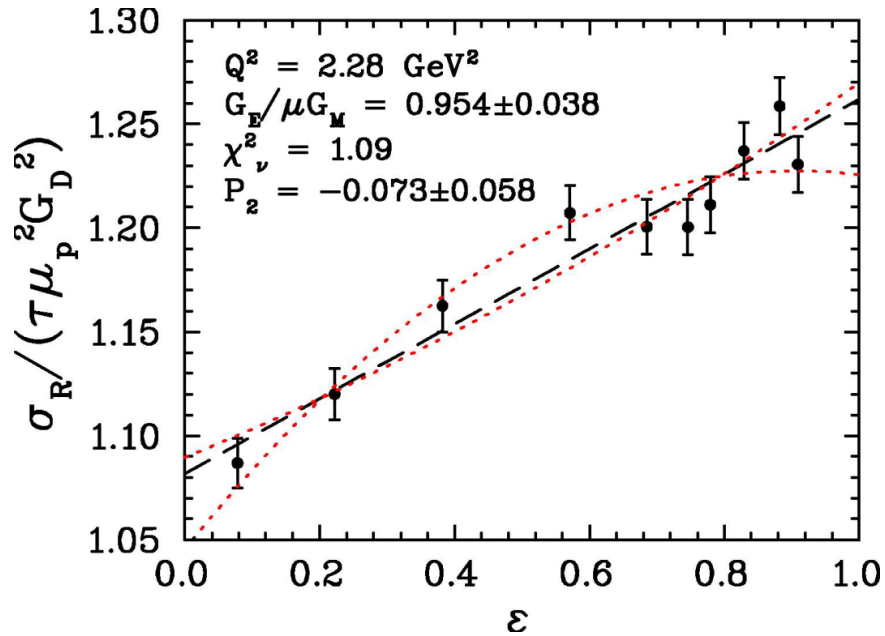
$\mu_p G_E/G_M$ TPE Correction



- TPE correction of BMT 2005
  - Increases with Q^2, linear in ε

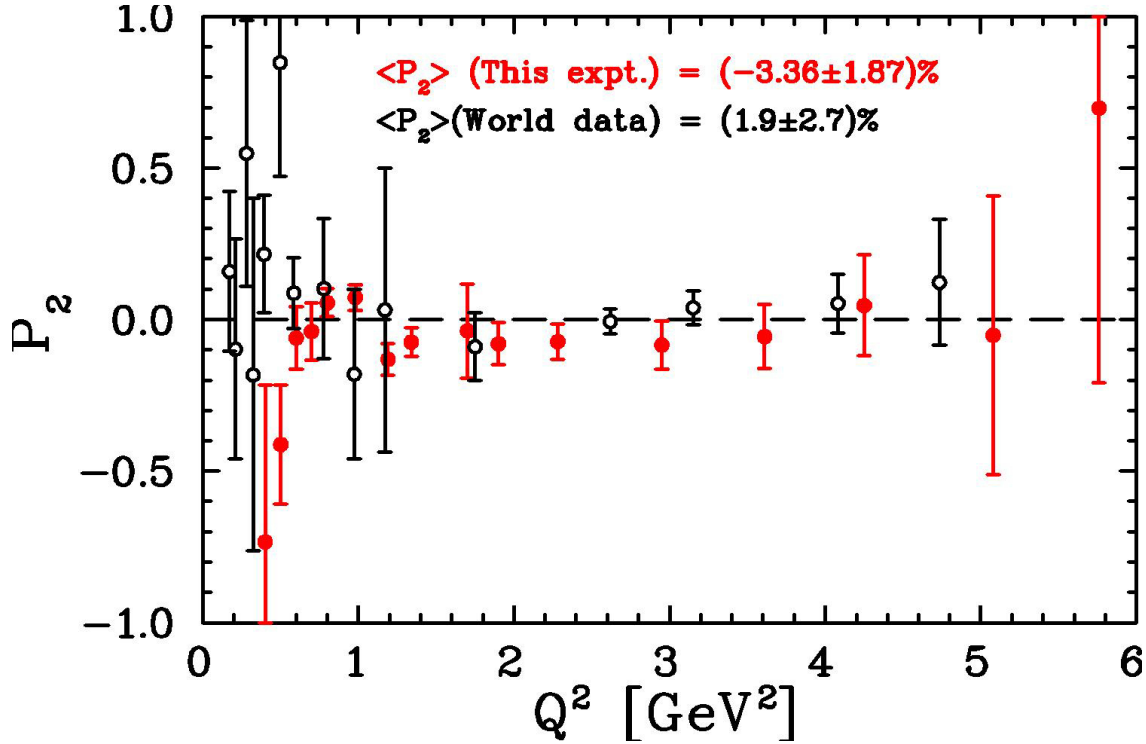
Linearity Measurement





- Any deviation from linearity would necessarily be from TPE
- Fit a quadratic to find the size of the nonlinearity

Linearity



- Negative curvature consistent with Chen, Blunden; not yet significant
- World data from combining different experiments
  - V. Tvaskis, et al., PRC73 (2006) 025206

Conclusions

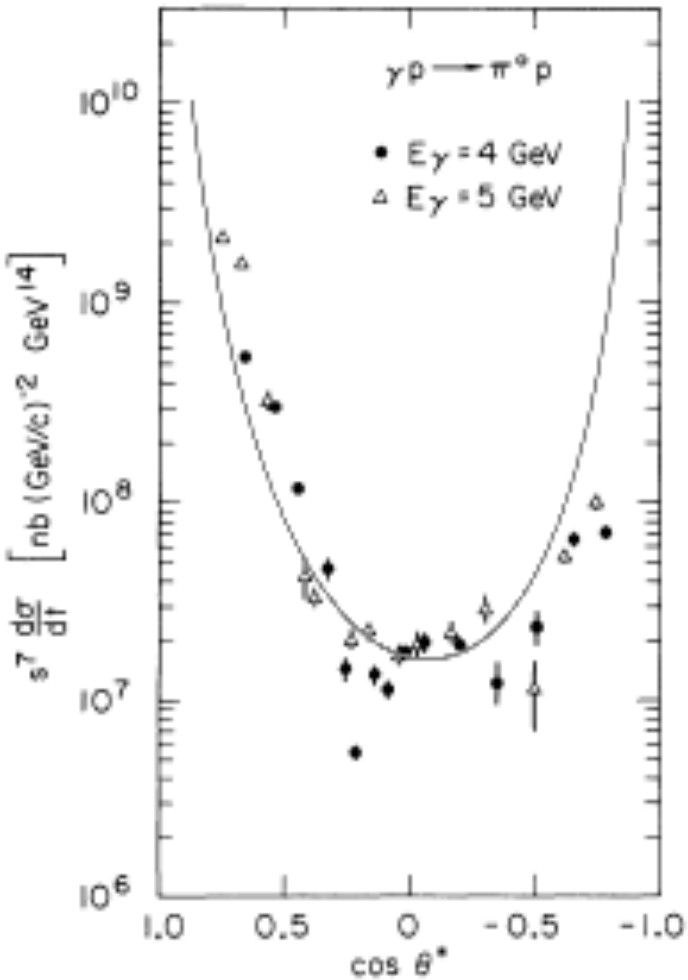
- Improvement in 1.0 – 2.0 GeV^2 range
  - Large errors above due to unexpected ε dependencies
- Suggest negative curvature
  - Consistent with hadronic or GPD model of TPE
  - Better limits from single experiment
- Uncertainties approaching what is needed to see model dependence

Future Work

- High Q^2 – Improved efficiencies
  - Explain unexpected ε dependence in PID
- Low Q^2 – Improved simulation statistics
- Pion Photoproduction – may be possible to get cross sections from background subtraction

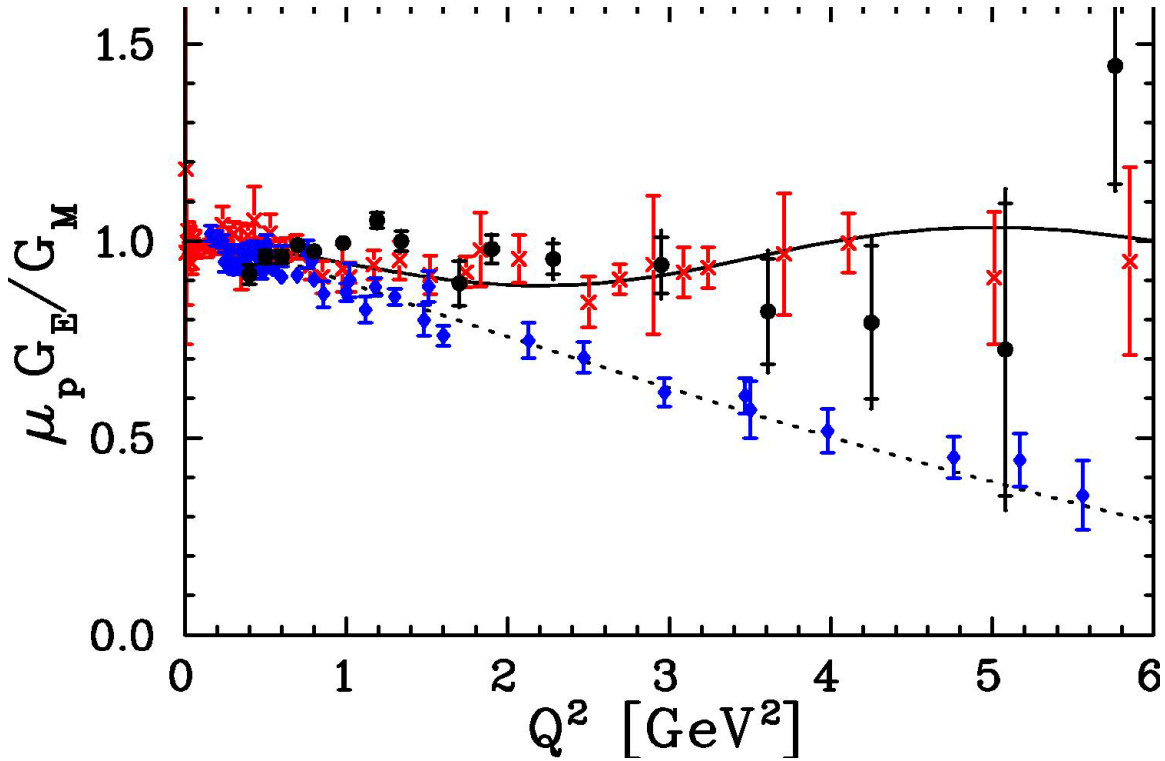
Photoproduction Simulation

- Cross section known only roughly
  - Full scale is determined through fitting
- Compton scattering as photoproduction with different kinematics



R. L. Anderson et al, Phys. Rev. D 14:679, 1976

$\mu_p G_E/G_M$



- Black – our data, red – prior Rosenbluth, blue – polarization transfer