E05-017 Update: Measurement of Two-Photon Exchange in Unpolarized Elastic Electron-Proton Scattering

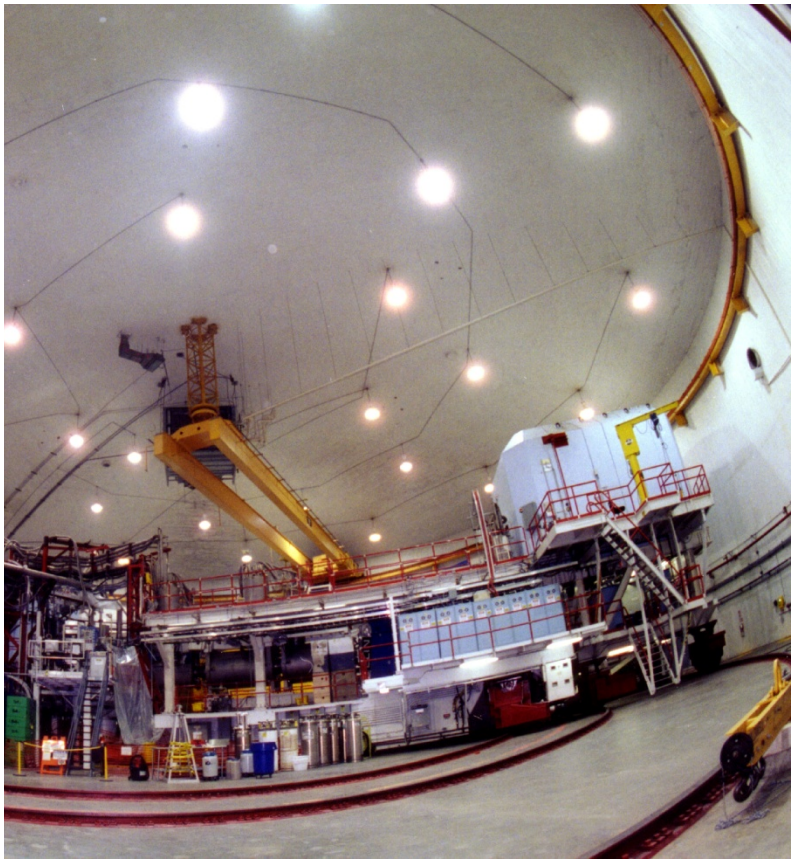
Part of the ROSEN07 Collaboration

P. Solvignon, M. Johnson, J. Arrington, R. E. Segel, et al…

Rosenbluth 2007

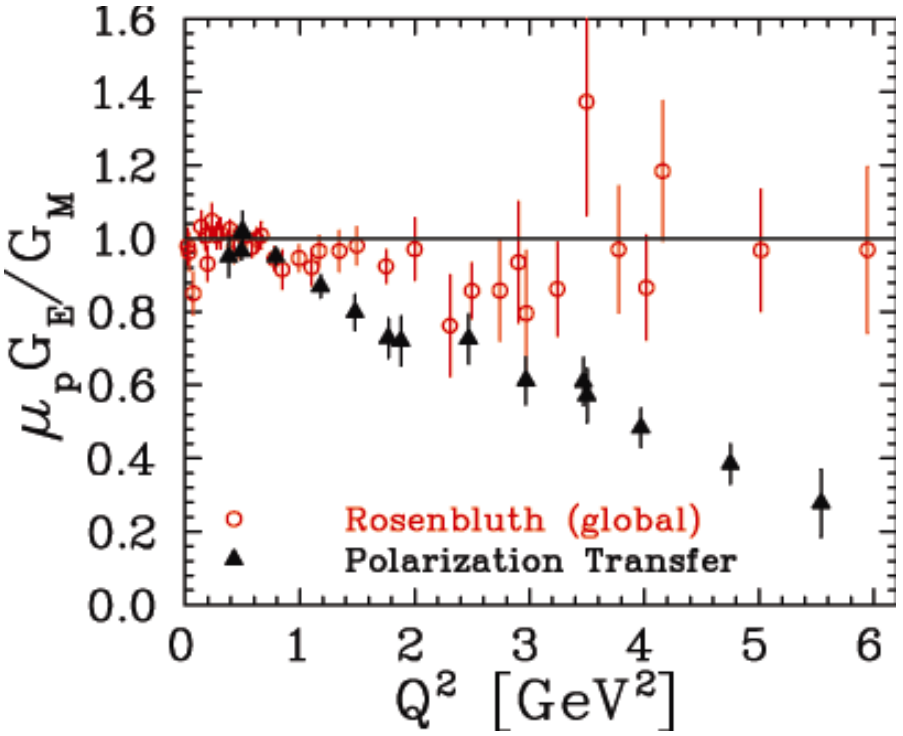
JLab E05-017

- 0.7-5.0 GeV beams (8 linac settings, 17 energies)
- Detect struck (elastic) protons in HMS
- 4 cm liquid hydrogen target for elastics; 4 cm aluminum dummy for endcap subtraction
- May 8 – July 13, 2007



Rosenbluth vs. Polarization

- **Rosenbluth (LT) extractions show scaling (ratio ≈ 1)**
- **Polarization transfer (PT) shows decreasing ratio**
  - Implies a difference between charge and magnetic distributions
  - Smaller errors at high Q^2

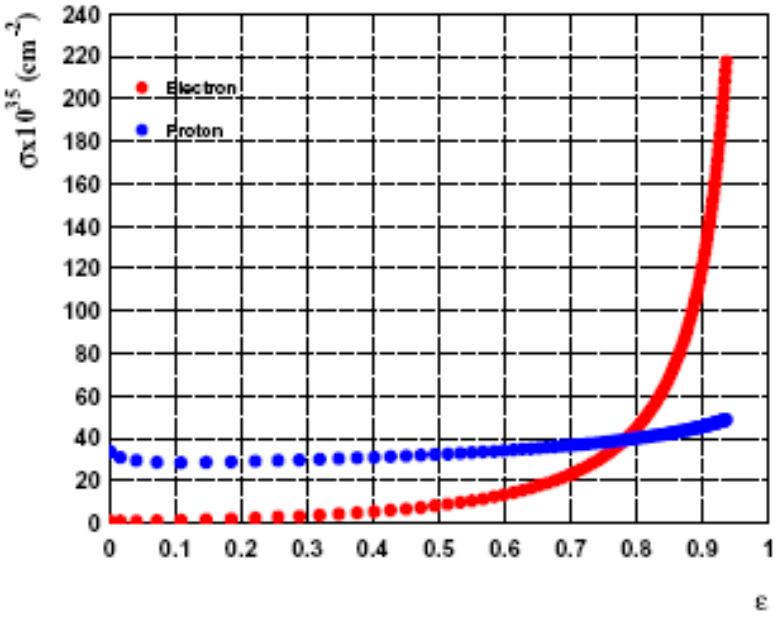


M. Jones *et al*, Phys. Rev. Lett. 84:1398-1402, 2000

O. Gayou *et al*, Phys. Rev. Lett. 88:092301, 2002

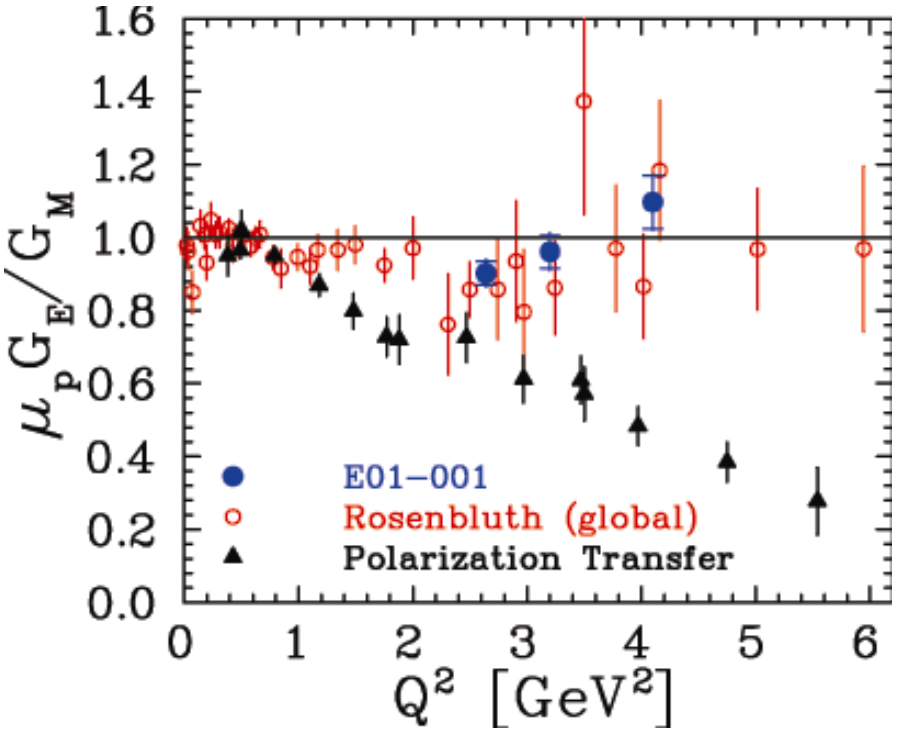
Super-Rosenbluth: Proton detection

- Less cross section variance with angle
  - Important for rate-dependent corrections
- No proton momentum variation with angle
- Can reach smaller electron angles



"Super-Rosenbluth" Results

- E01-001: LT with precision comparable to polarization
- Agrees with electron LT
  - Discrepancy is real physics
  - High-precision measurement of the discrepancy
- E05-007
  - Cover larger Q^2 range
  - Map out ε dependence in more detail: look for nonlinearities

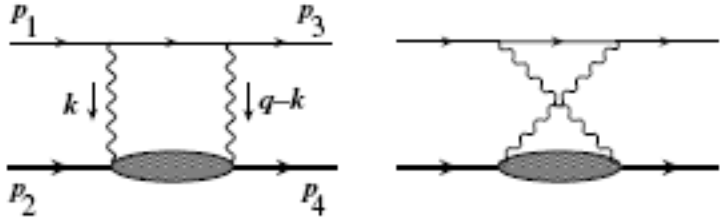


I. A. Qattan *et. al*, Phys. Rev. Lett. 94:142301, 2005

Two-Photon Exchange

- Both techniques account for radiative corrections, but neither considers two-photon exchange

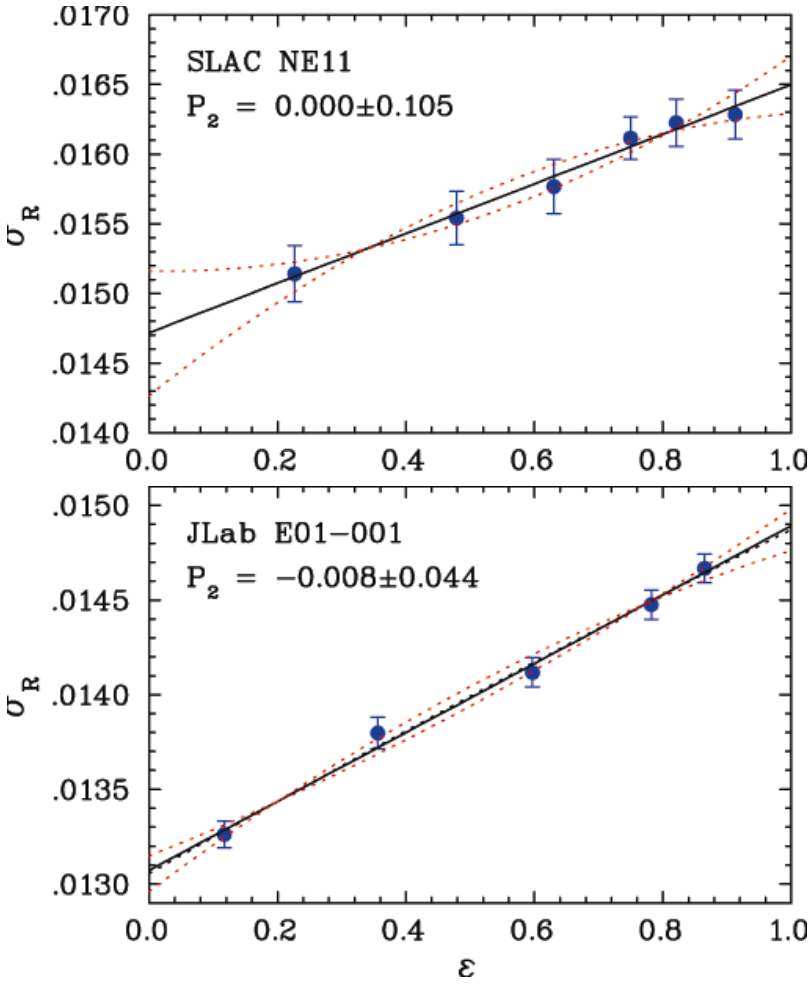
- Box and crossed-box interaction diagrams



- Intermediate state
  can be complicated (proton, excited states, multiple particles); difficult and model-dependent calculations

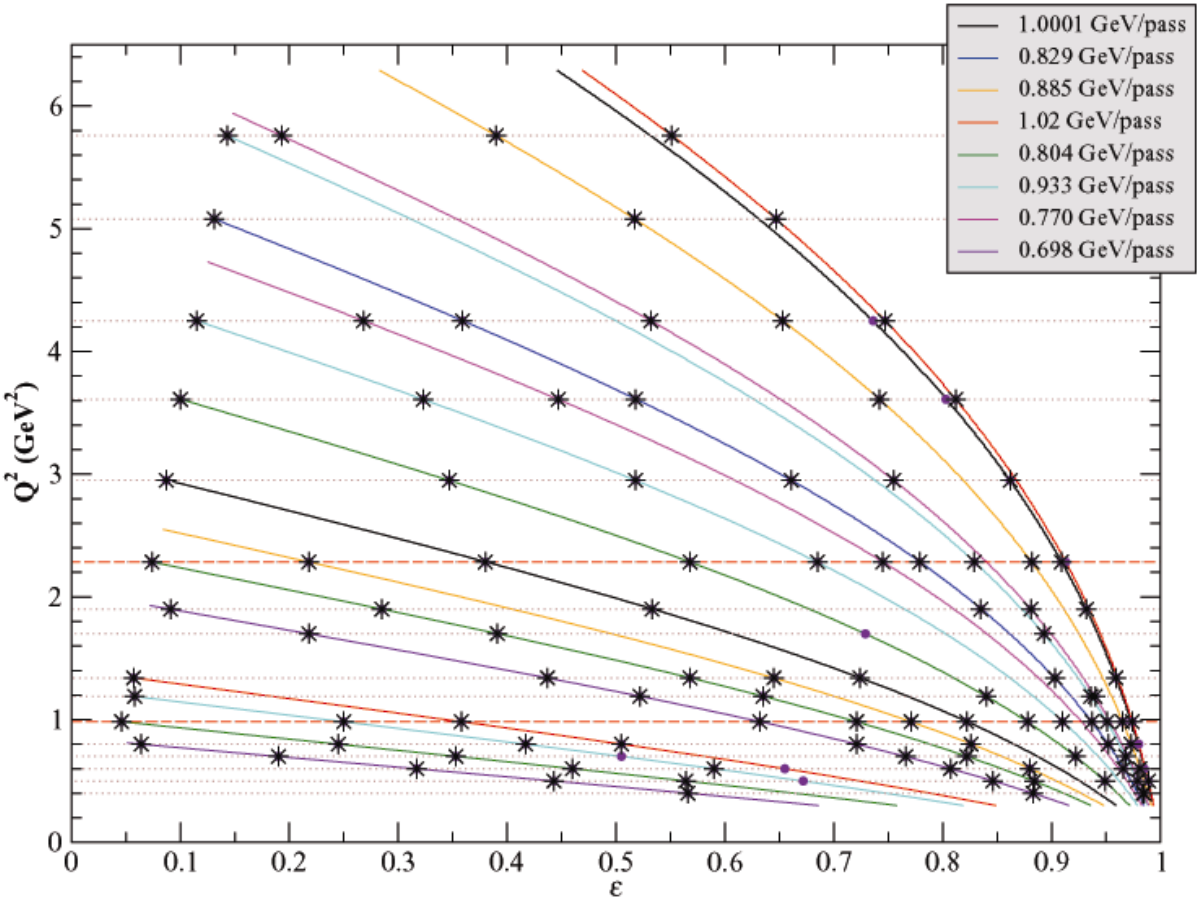
Nonlinearity Tests

- Born (reduced) cross section linear in ε, TPE would cause a deviation
- E01-001 and NE11 show quadratic terms consistent with zero



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

Rosenbluth 2007



102 Kinematics points

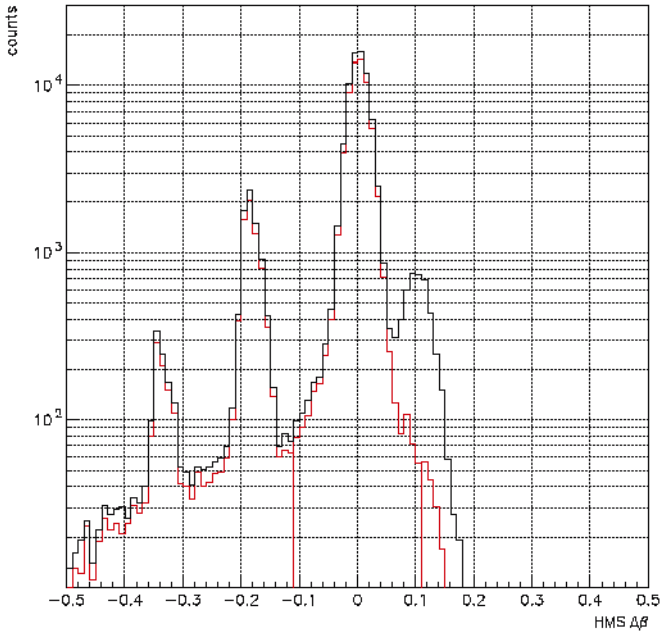
Q^2 0.40-5.76 GeV^2

13 points at Q^2=0.983

10 points at Q^2=2.284

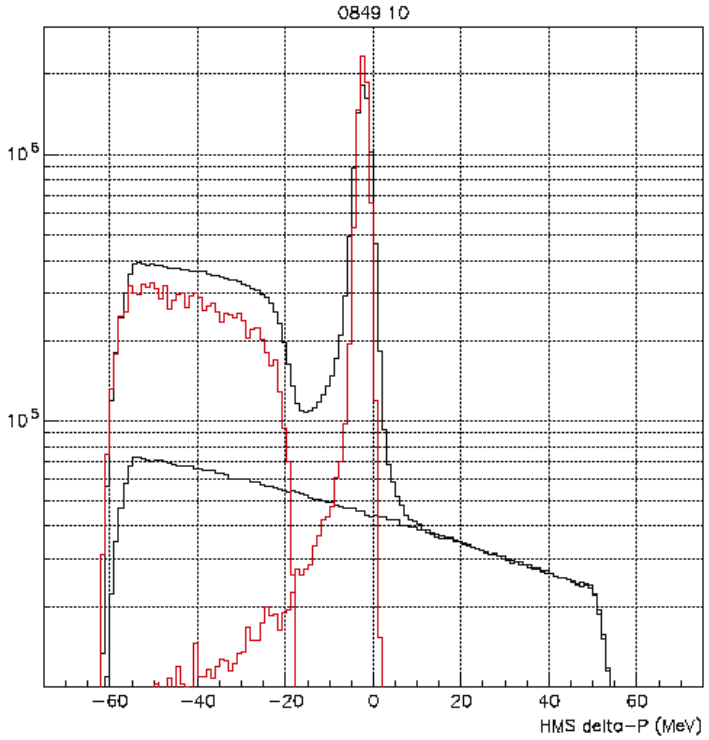
Particle Identification

- Time of Flight for primary particle ID cut
  - Low side: deuterons, tritons
  - High side: pions
- Peaks have tails extending beyond the cuts
  - Important inefficiency



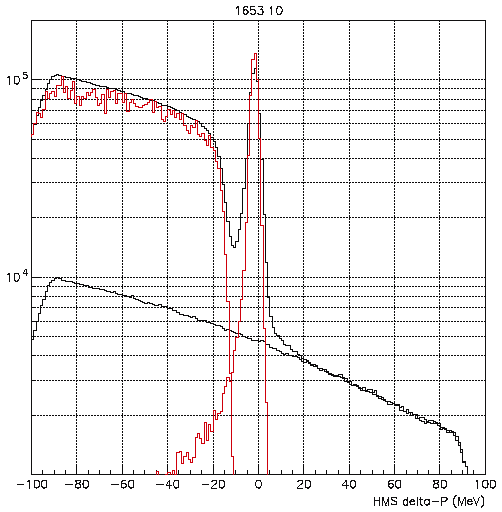
Red curve: aerogel cut to remove pions

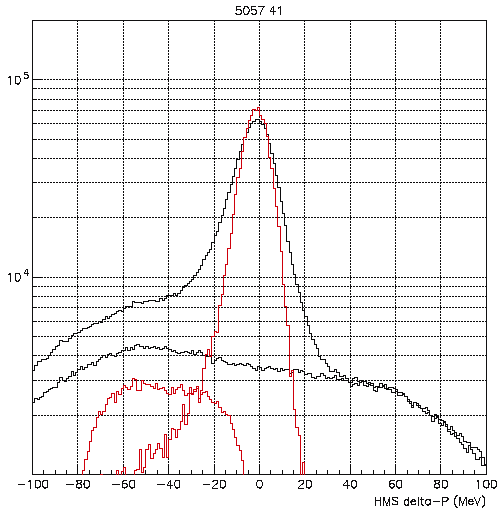
Elastic Spectrum



- Hydrogen elastics
  - Compare to simulated elastics [SIMC]
- Background
  - 'Dummy' runs for endcap subtraction
  - Simulated π^0 photoproduction
- Fit background and elastic normalizations to data-dummy

Background Separation



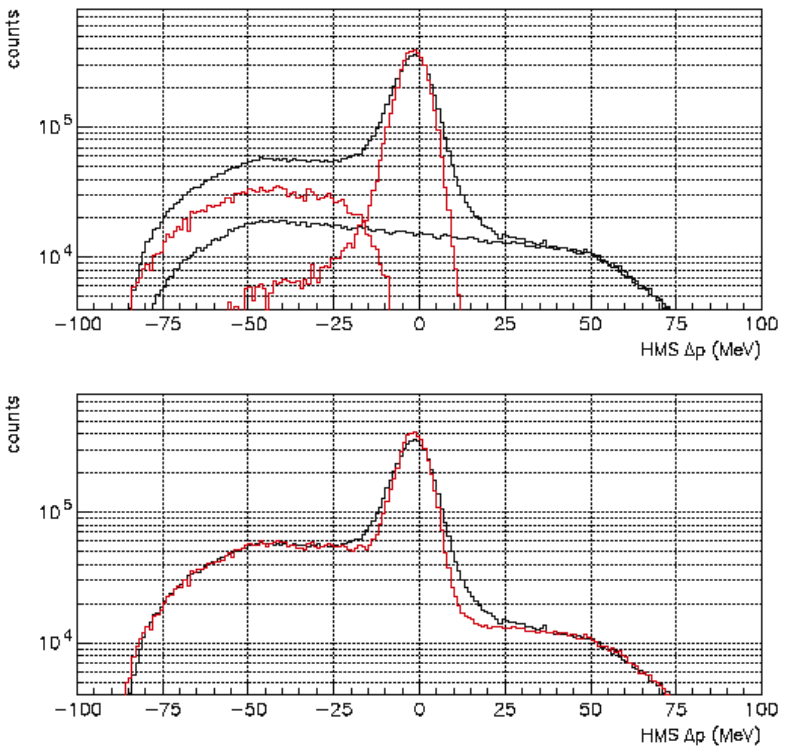


$Q^2 = 2.28\ GeV^2$

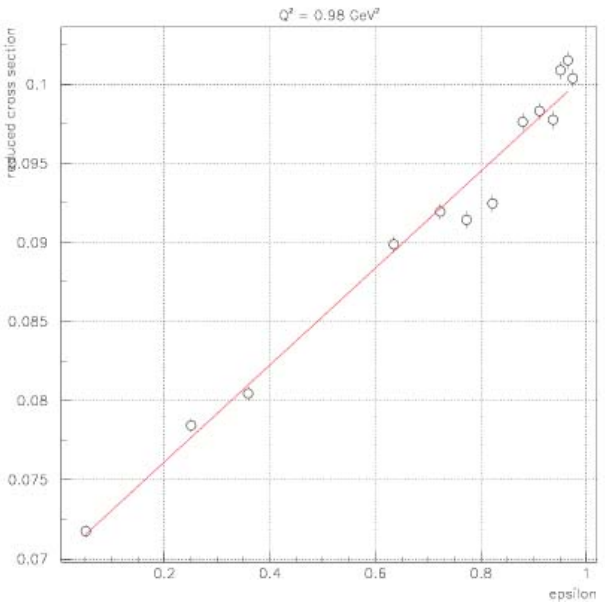
- **Smallest angle – Background larger than peak, but well separated**
- **Largest angle – Background not well separated but much smaller**

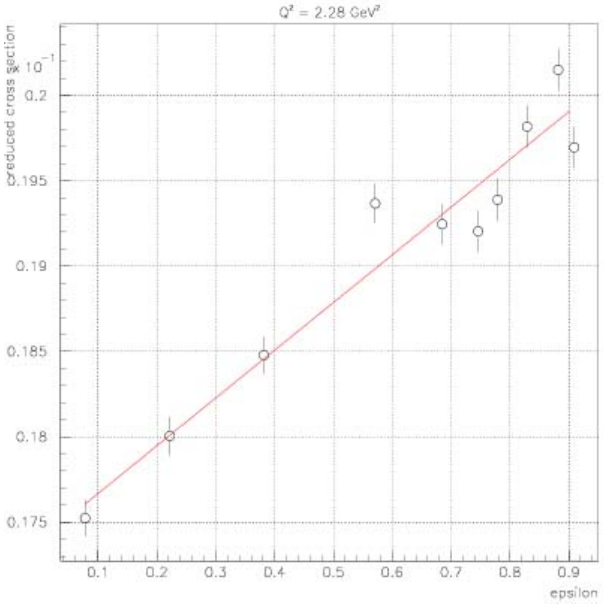
Resolution Mismatch

- Data peak is broader than elastic simulation, show non-gaussian tails
  - **Wider elastic cuts reduce the problem but yield larger background, dummy subtraction**
- Add additional smearing to simulations to better match spectra, use fairly wide elastic cuts



Preliminary Results – Extractions



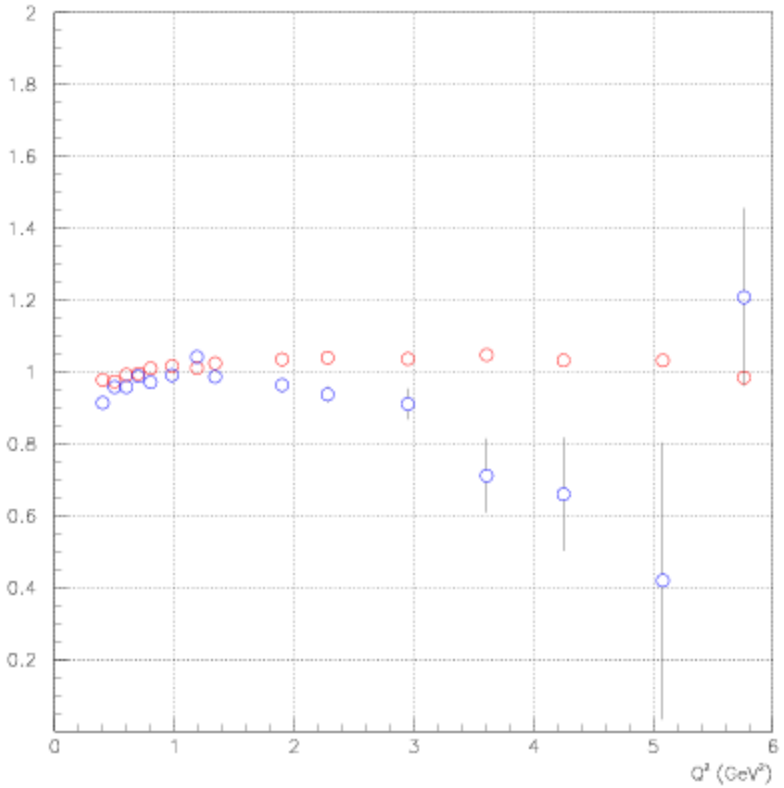


- Figure shows statistics only, cuts not finalized
- Can reliably extract form factors up to 2.28 GeV^2
  - Corrections, uncertainties at high Q^2 require more study

Preliminary Results – G_E & G_M

G_E/G_D and $G_M/(\mu_p G_D)$

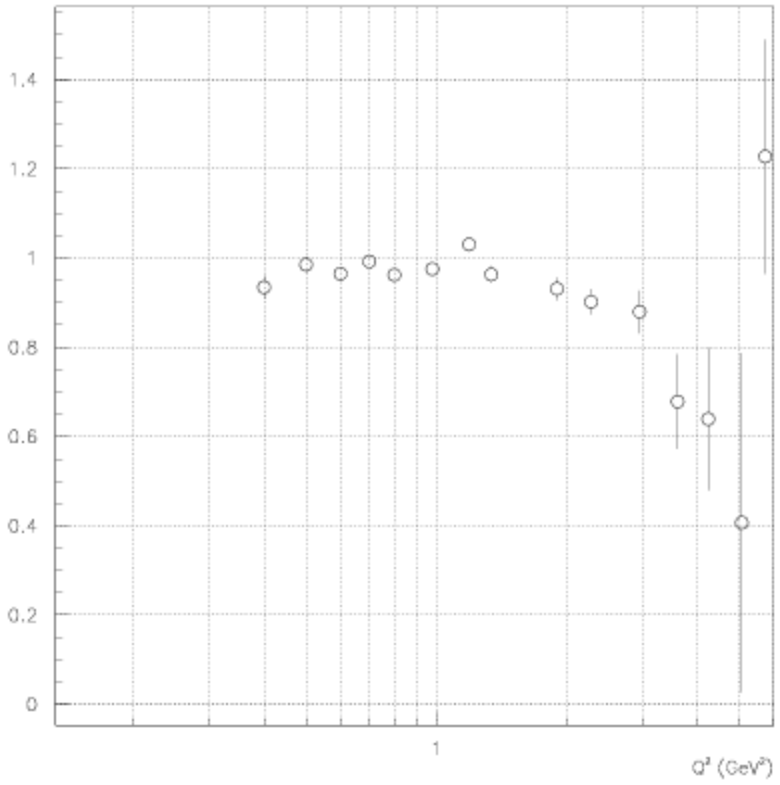
- Systematic uncertainties are not finalized
- Results above 2.5 GeV^2 not yet reliable



Preliminary Results – Ratio

$G_E/(\mu_p G_M)$

- Systematic uncertainties are not finalized
- Results above 2.5 GeV^2 not yet reliable
- Pretty good agreement with previous LT up to 2.5 GeV^2
  - *Lowest Q^2 point anomalously low, but larger uncertainties (on G_M)*



Efficiencies

- Proton absorption: Target, windows, detector
  - "Large" correction and uncertainty, but no θ dependence
- Tracking, Triggering, Deadtime, Tgt boiling
  - Under control
- Particle Identification
  - Loss due to ToF cut shows unexpected θ dependence
    - Small at low-to-moderate Q^2 (up to ~2.5 GeV^2)
    - Significant but acceptable uncertainty if we have to apply half of observed θ dependence with 100% uncertainty to cover bases
    - Would yield some correlated uncertainties at high Q^2, want to resolve the issue
  - D, π^+ contamination issue at very largest Q^2

To Do

- Finalize efficiencies, systematics for data up to 2.5 GeV^2
- Continue work on high Q^2 corrections
- Extract photoproduction cross sections from the π^0 background (we have data covering extreme CM angles)
- Mikhail Yurov (UVa student) will be joining the effort in the next few months

Backups

Rosenbluth

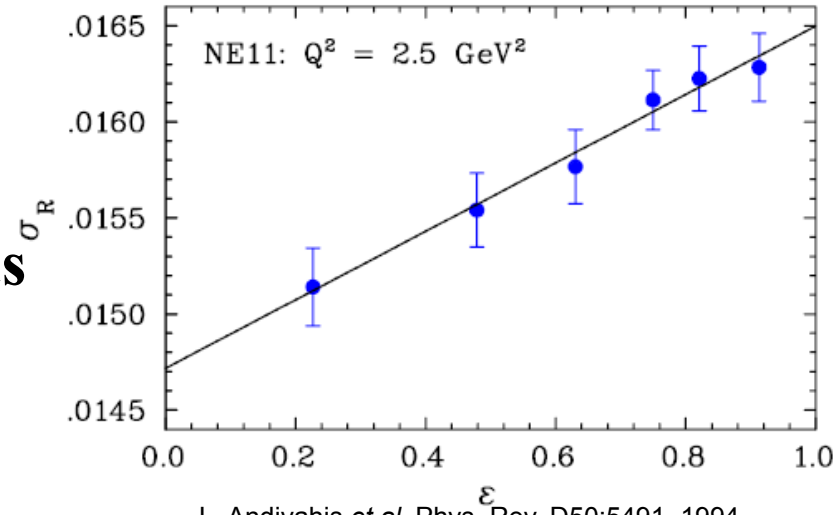
- **Rewrite in terms of σ_{ns} and form factors**

$$\frac{d\sigma}{d\Omega} = \sigma_{ns}\frac{1}{1+\tau}\left(G_E^2(Q^2) + \frac{\tau}{\varepsilon}G_M^2(Q^2)\right)$$

- **Factor out σ_{ns} to get reduced cross section**

$$\sigma_R = \left(\frac{d\sigma}{d\Omega}\right)\frac{(1+\tau)\varepsilon}{\sigma_{ns}} = \left(\tau G_M^2(Q^2) + \varepsilon G_E^2(Q^2)\right)$$

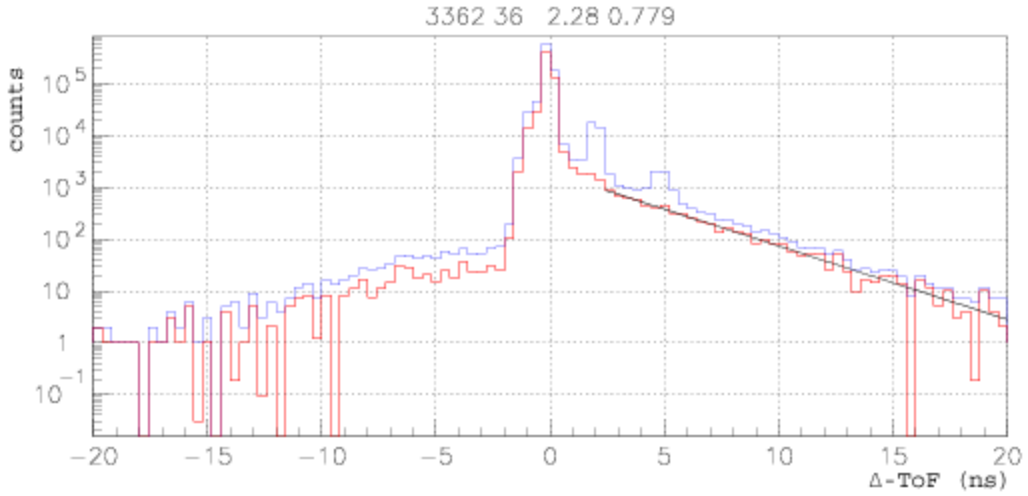
- **At fixed Q^2, plot σ_R vs ε**
  - **G_M^2 from intercept**
  - **G_E^2 from slope**
- **Sensitivity to G_E decreases as Q^2 increases**



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

ToF Low Tail

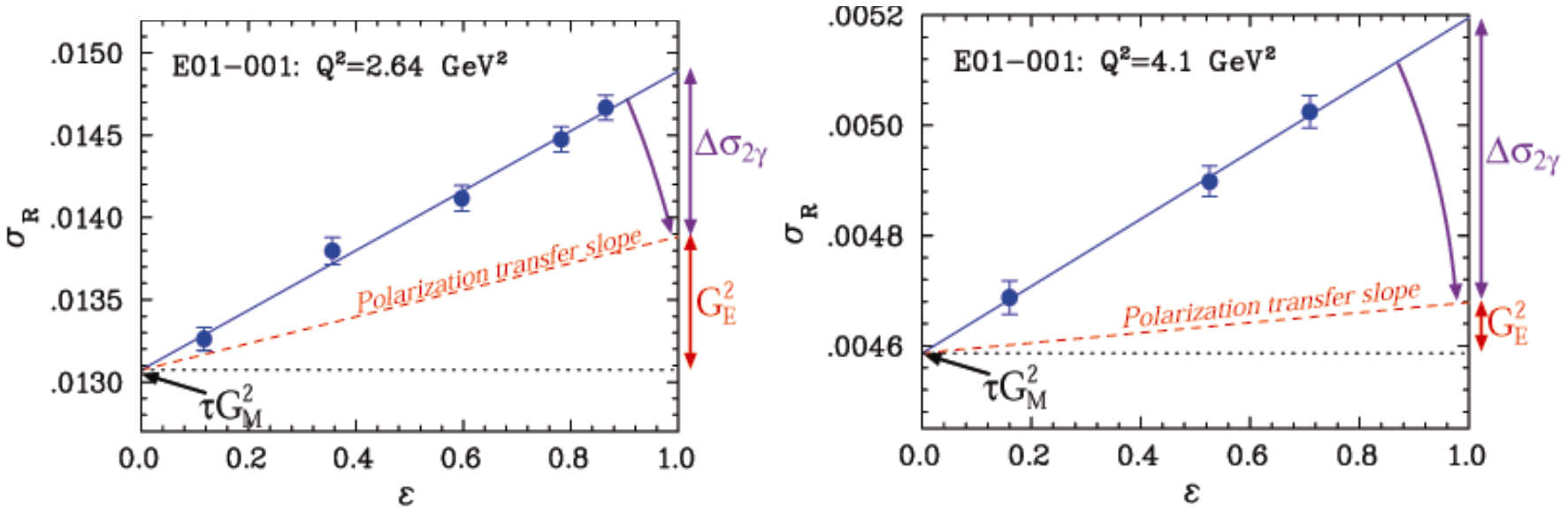
- Look at exponential tails in dummy-subtracted Δ-ToF
  - Dummy subtraction minimizes effect of deuterons, tritons
  - Expect same tails at fixed Q^2
  - Found small angle dependence
- Pion tail expected similar to proton
  - Too little gap to fit
- At high Q2, possibly no cut needed
  - Deuterons suppressed



Elastic Simulation

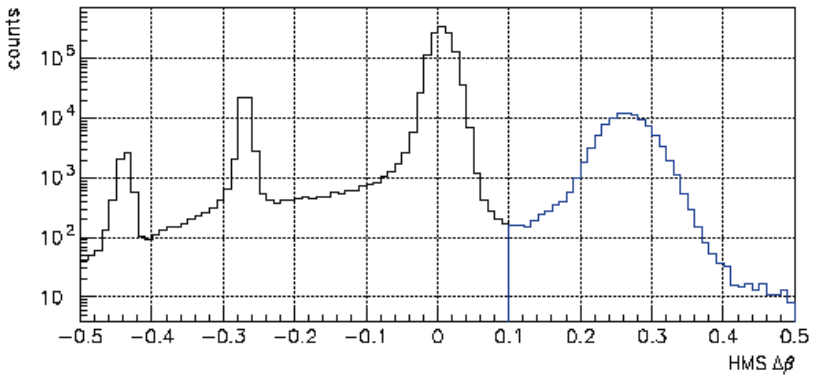
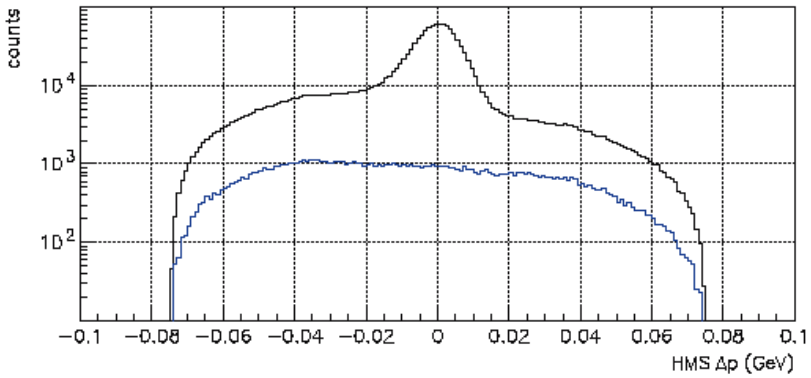
- Incoming beam on LH2
- Generate scattered proton
  - Energy, angle, scattering position
- Propagate into detector
  - COSY matricies
  - Multiple scattering, energy loss in target, windows
- Apply radiative effects
- Normalize based on luminosity, cross section

Magnitude of the Discrepancy



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

Dashed line – taken from polarization transfer ratio

ToF High Side

- Excluding pions, faster than protons
- Elastic protons disappear quickly
- Cut just above proton peak
- Pion tail may extend underneath proton peak