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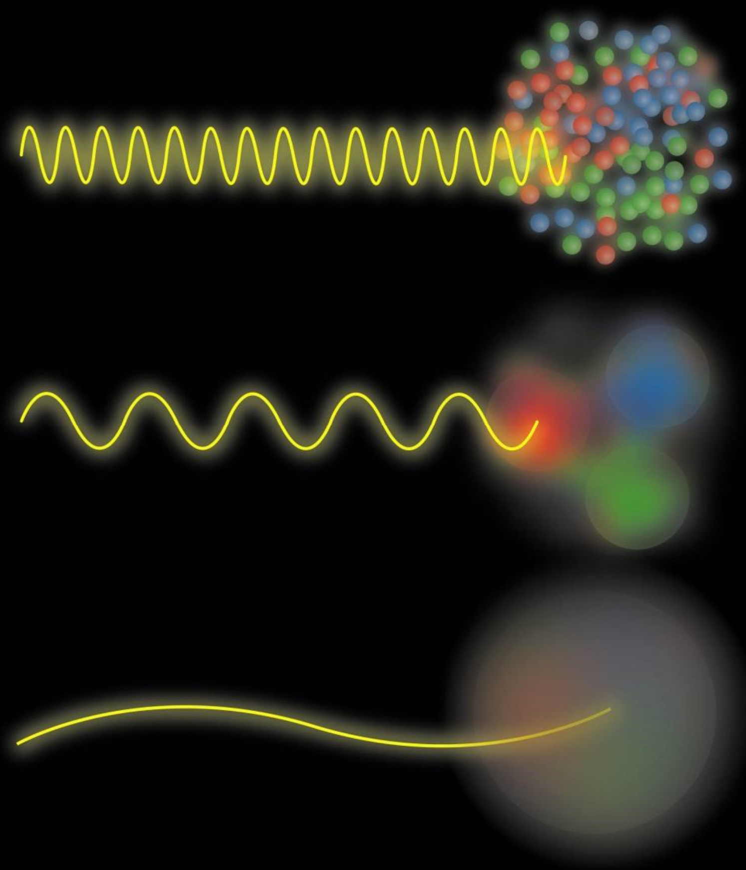
Two-photon exchange from positron Super-Rosenbluth measurements



John Arrington - Lawrence Berkeley National Laboratory

Mikhail Yurov - Mississippi State University

Form factors: unpolarized elastic scattering

Unpolarized elastic cross section depends on charge and magnetic form factors: $G_E(Q^2)$ $G_M(Q^2)$

$$\sigma_R = d\sigma/d\Omega\,[\varepsilon(1+\tau)/\sigma_{Mott}] = \tau\, G_M^2(Q^2) + \varepsilon\, G_E^2(Q^2)$$

$\tau = Q^2/4M^2$

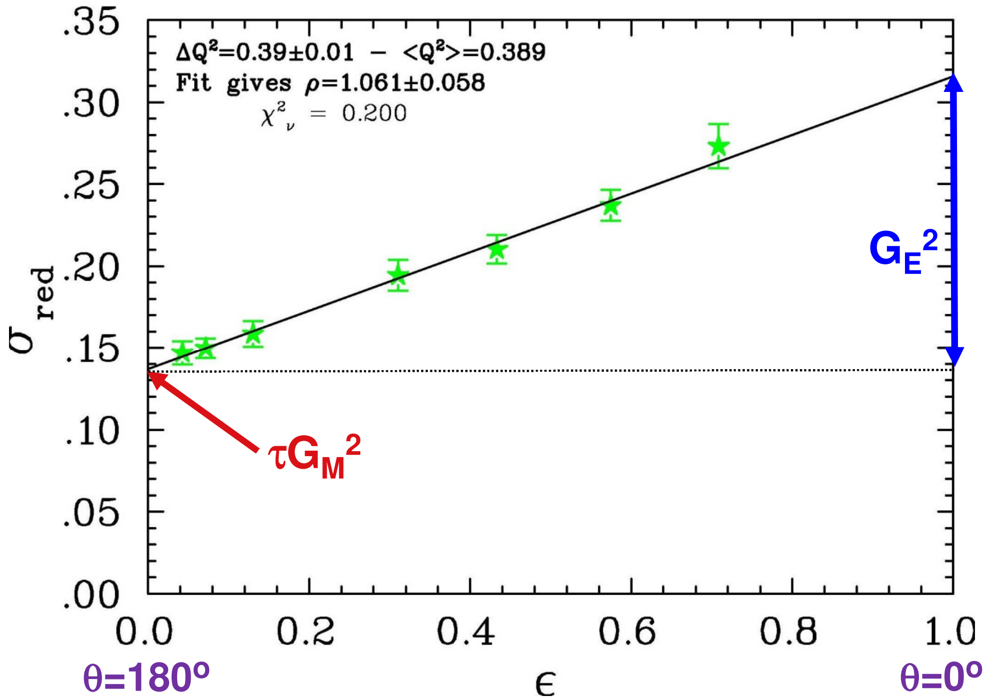
$\varepsilon = [\,1 + 2(1+\tau)\tan^2(\theta/2)\,]^{-1}$

Reduced sensitivity when one term dominates:

- **G_M if $\tau << 1$**
- **G_E if $\tau >> 1$**
- **G_E if $G_E^2 << G_M^2$** (e.g. neutron)

Worlds data give G_M and G_E proportional to dipole form: $(1+Q^2/[0.71\ GeV^2])^{-2}$

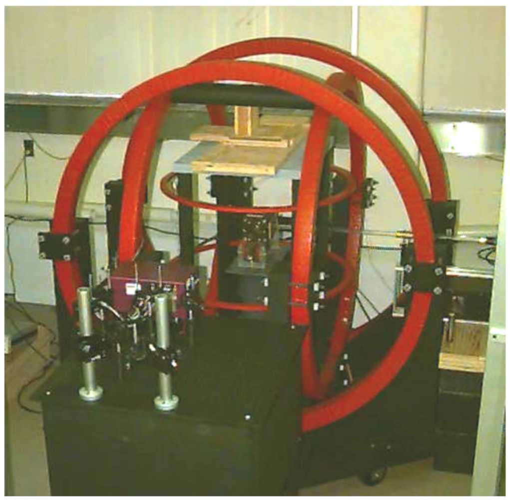
→ **$\mu_p\, G_E(Q^2) / G_M(Q^2) \approx 1$**



Form factors: Recoil polarization, pol targets

Mid ’90s brought measurements using polarization degrees of freedom

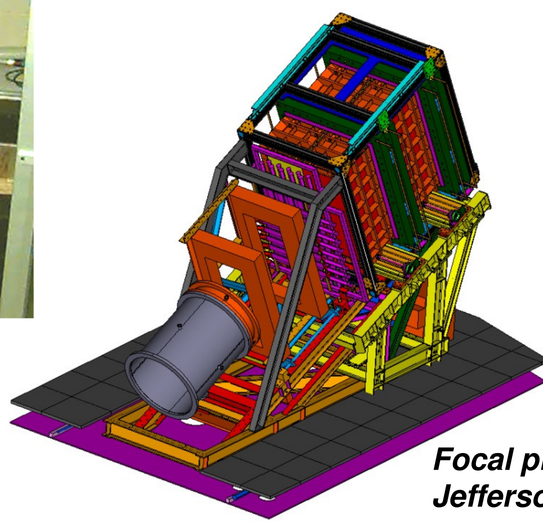
- High luminosity, highly polarized electron beams
- Polarized targets (^1H, ^2H, ^3He) or recoil polarimeters



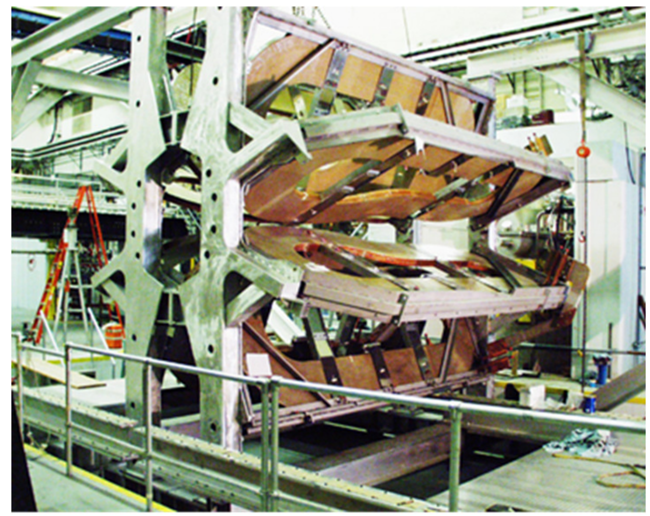
Polarized ^3He target

Unpol: $\tau G_M^2 + \varepsilon G_E^2$

Pol: G_E/G_M



Focal plane polarimeter – Jefferson Lab



BLAST at MIT-Bates

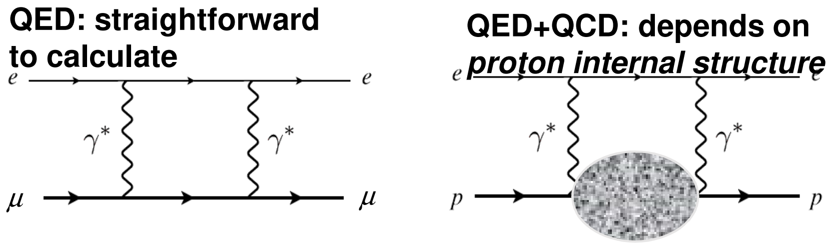
Form factors: Rosenbluth vs Polarization

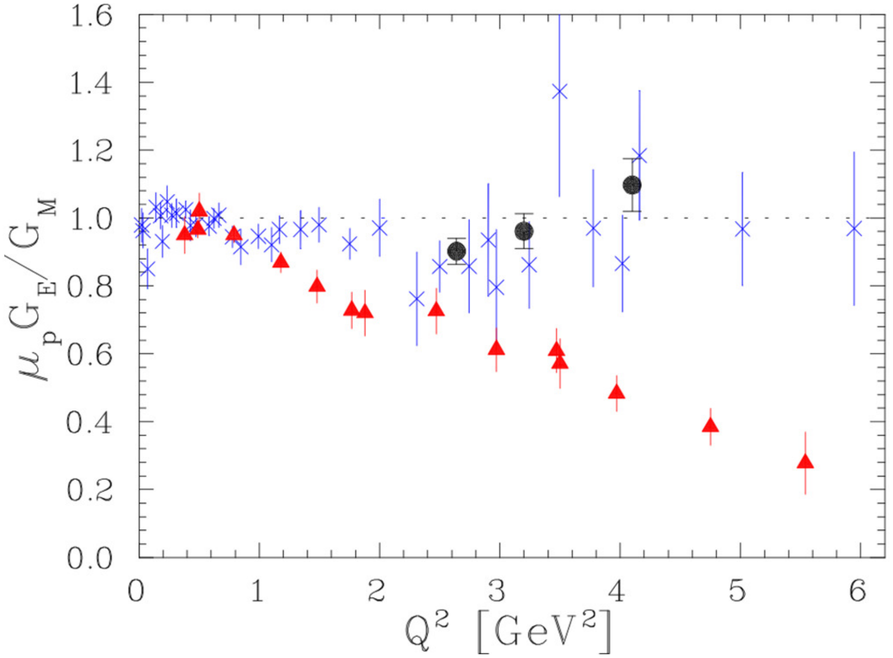
Blue points are global Rosenbluth extractions

Red points are polarization measurements

- Significant difference at high Q^2, where Rosenbluth have large errors, typically limited by systematics

Difference assumed to be caused by two-photon exchange (TPE) corrections





Black points – "Super-Rosenbluth" measurement:
Modified technique that gives significantly smaller uncertainty on the RATIO G_E/G_M

I. A. Qattan, *et al*, *PRL 94, 142301 (2005)*

Super-Rosenbluth technique

Rosenbluth (L/T) measurement: vary ε (θ) at fixed Q^2

Conventional measurement: electron detection

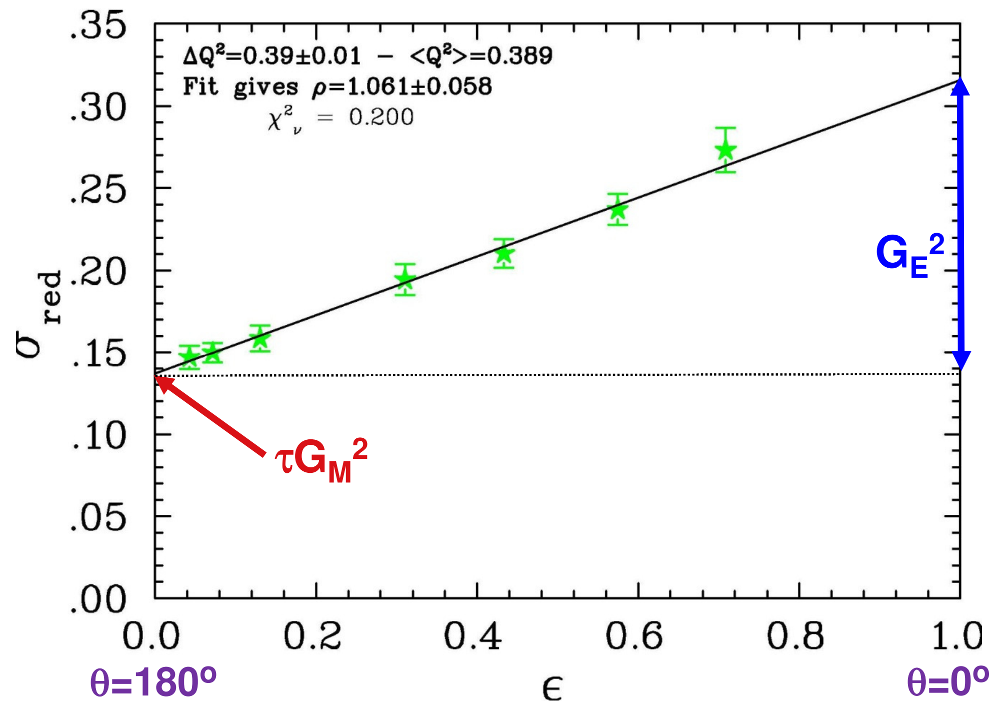
- ε≈1: large beam energy, small scattering angle, large electron momentum, high rates
- ε≈0: small beam energy, large angle, small electron momentum, low rates

➢ Extraction of ε dependence sensitive to momentum- and rate-dependent corrections (including rad corr)

➢ Limited by low cross sections at large scattering angle

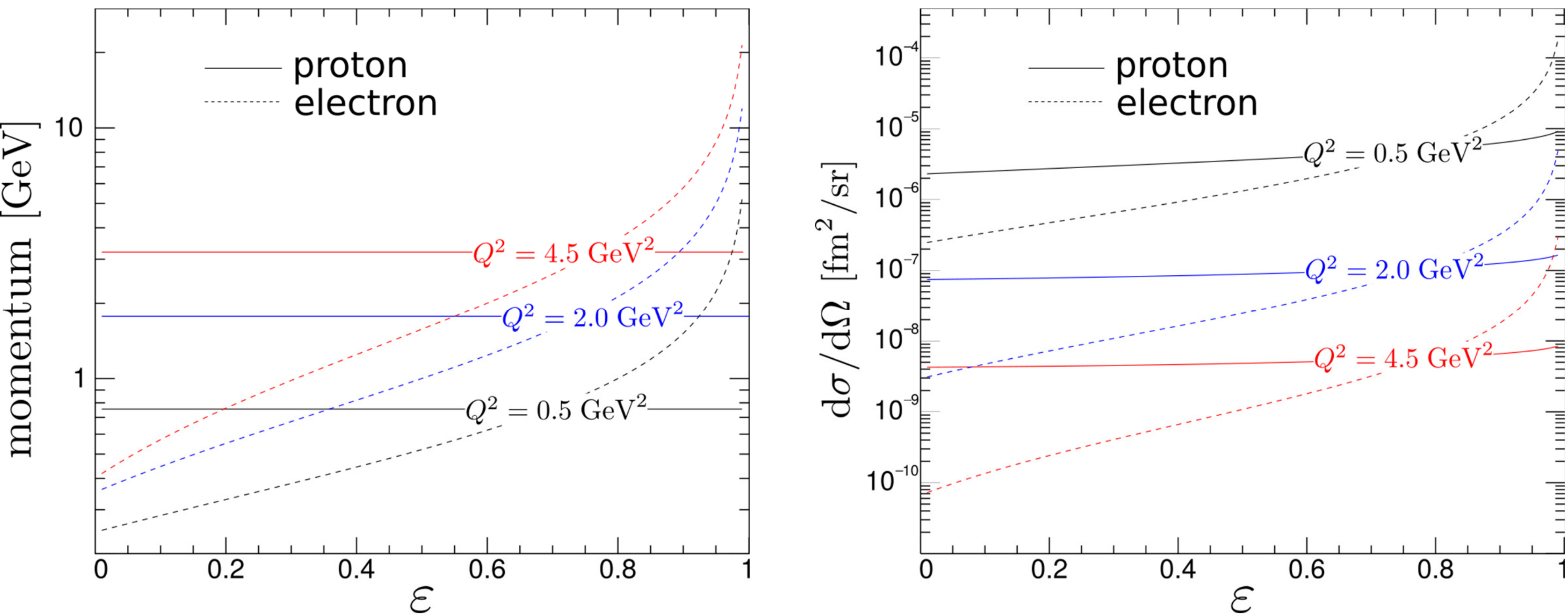
Super-Rosenbluth: Proton detection

- Fixed proton momentum at fixed Q^2
- Cross section, radiative correction have much smaller ε dependence
- Higher cross section for small ε
- Less sensitive to kinematic uncertainties

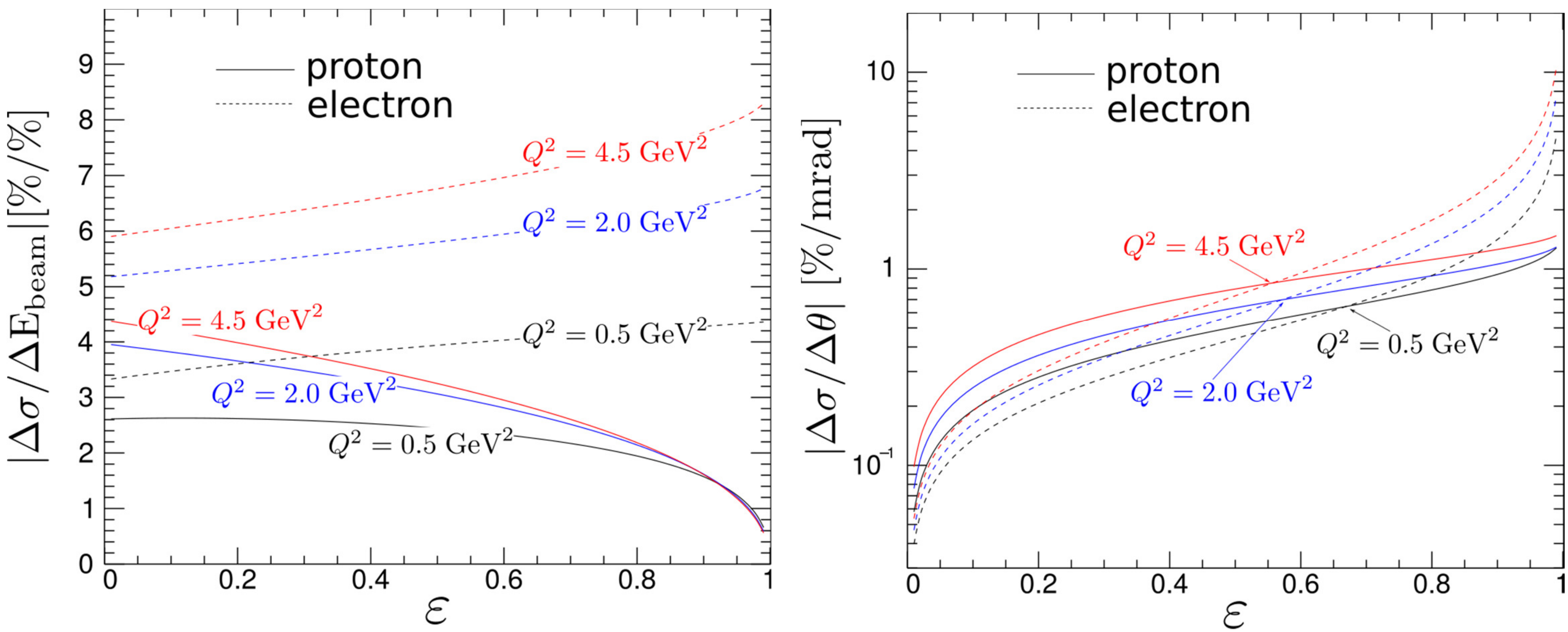


While some uncertainties (e.g. acceptance, proton absorption) have larger absolute uncertainties, they are independent of ε and cancel completely in extraction of G_E/G_M

Proton vs electron detection: kinematics and rate



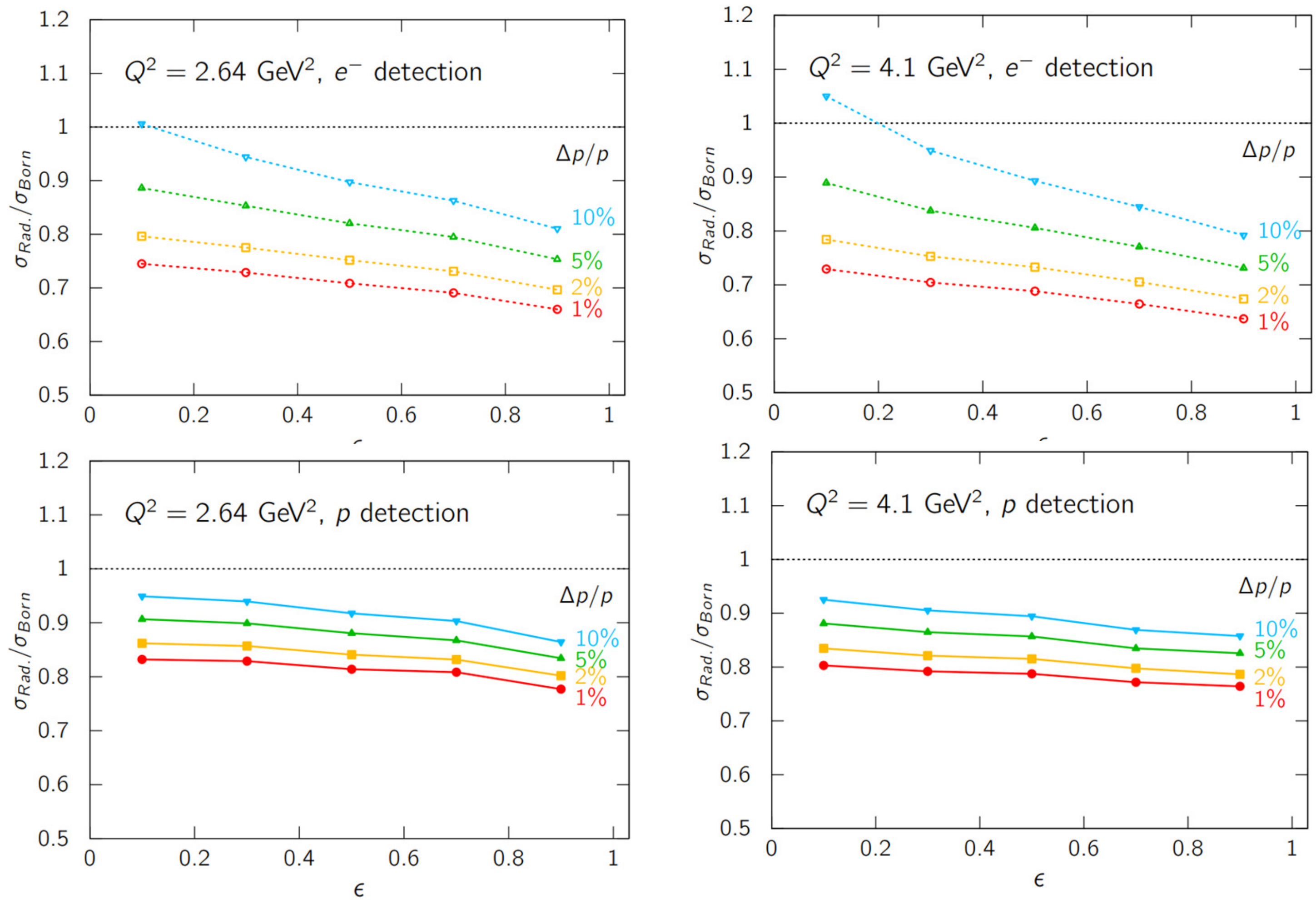
Proton vs electron detection: kinematic sensitivity



Proton vs electron detection – radiative corrections

Radiative corrections for electron and proton detection are similar in size, but proton detection has significantly smaller ε dependence (and less sensitive to cutoff)

Results pilfered from Axel Schmidt – reference?



Super-Rosenbluth with positrons

Conventional positron-electron comparisons limited by positron luminosity (especially at low ε, where TPE are larger) and requirement of significant cancellation between e- and e+ systematics

- Cross section limit most significant at kinematics where TPE are large
- Require frequent changes between e+ and e- beams; similar beam properties

S-R technique enhances cross section at low ε, relies on cancellation between points at different scattering angles (and fixed Q^2)

- Allows precise e+ to e- comparison on the Rosenbluth slope, even for separate e+, e- experiments
- Does not allow direct e+/e- ratio at individual ε, Q^2 points (without normalization at ε=1)

Can perform precise S-R extraction with positrons and S-R with electrons independently.

Does not require rapid beam changes or identical beam characteristics.

Two Photon Exchange Corrections

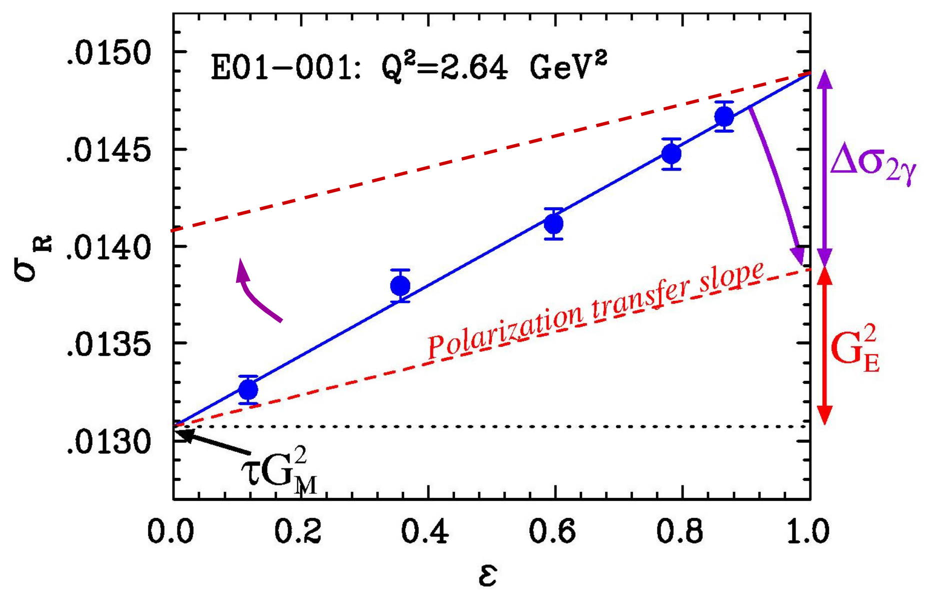
Two-photon exchange effects can explain discrepancy in G_E

Guichon and Vanderhaeghen, PRL 91, 142303 (2003)

Requires ~6% ε-dependence, weakly dependent on Q^2, roughly linear in ε

JA, PRC 69, 022201 (2004)

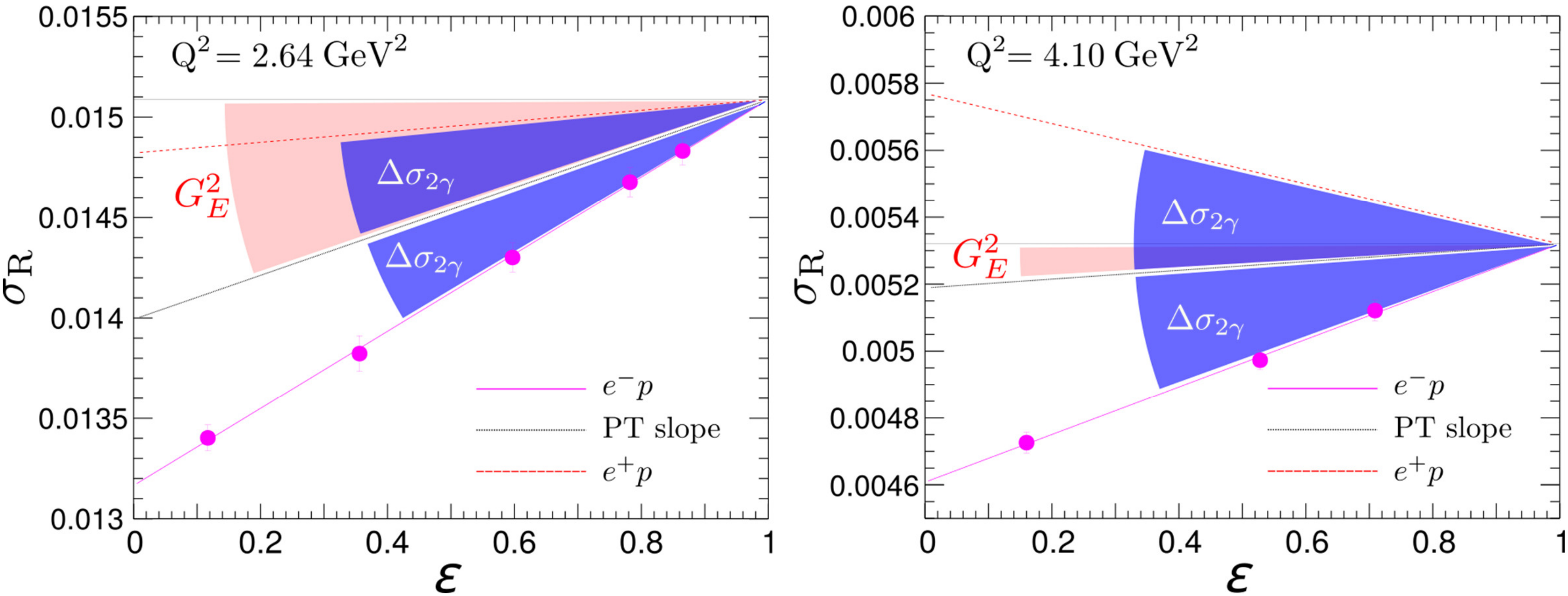
If this were the whole story, LT would give G_M, PT gives G_E/G_M



There are other issues to be addressed

- Constraints (~1%) from positron-electron comparisons
- TPE effects on ***polarization transfer***?

Rosenbluth separations: e+ vs e-



Kinematics

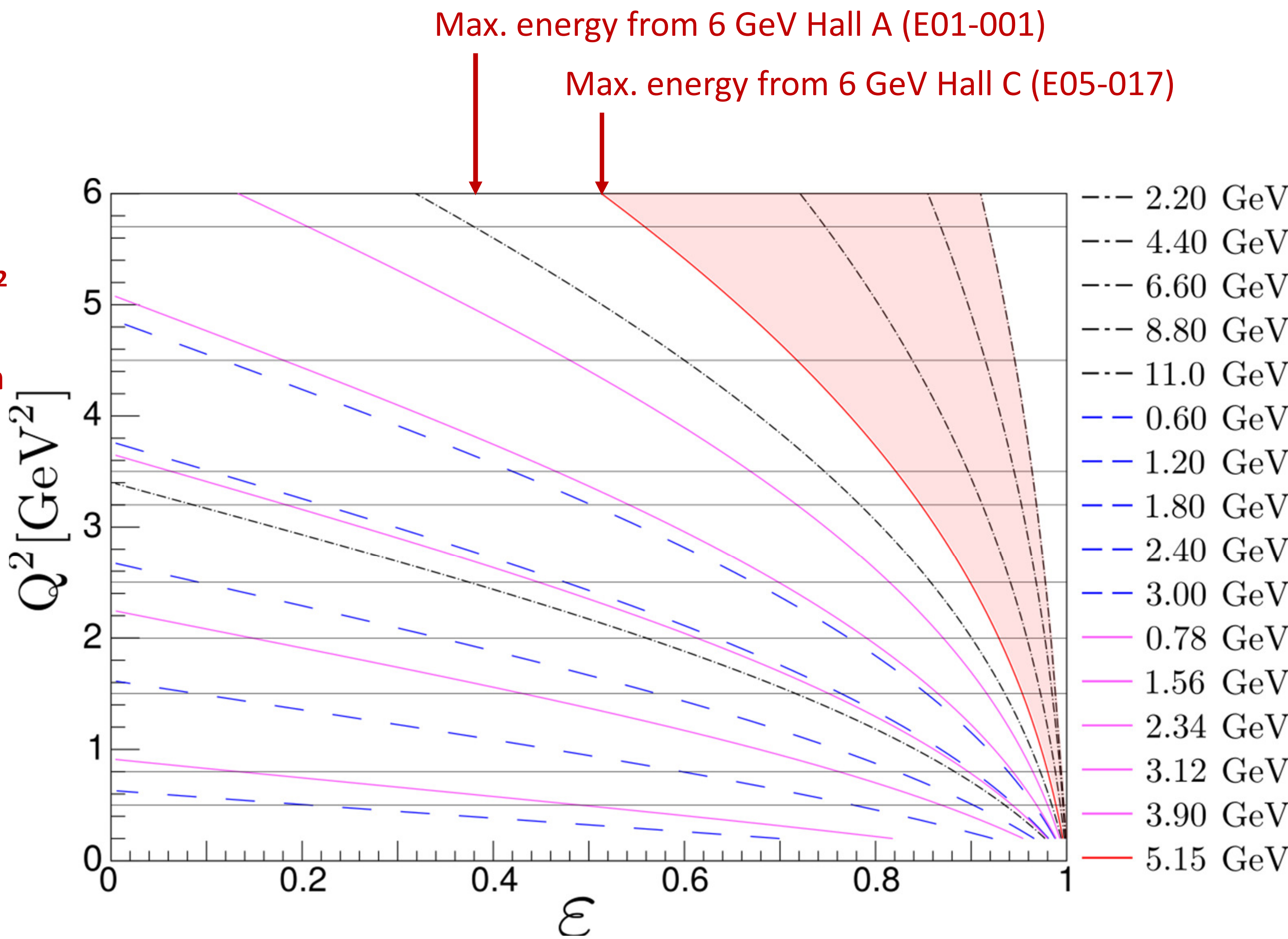
Black: 2.2 GeV/pass

- **2-3 high-epsilon points at each Q^2**
- **Larger ε range for higher Q^2 points**

Blue or magenta: 0.6 or 0.78 GeV/pass

- **Each linac setting gives five different Q^2 values with large lever arm in epsilon**
- **Intermediate Q^2 with smaller lever arm**

Can run with positrons only, compare to polarization → should see opposite discrepancy than electrons



Projected uncertainties

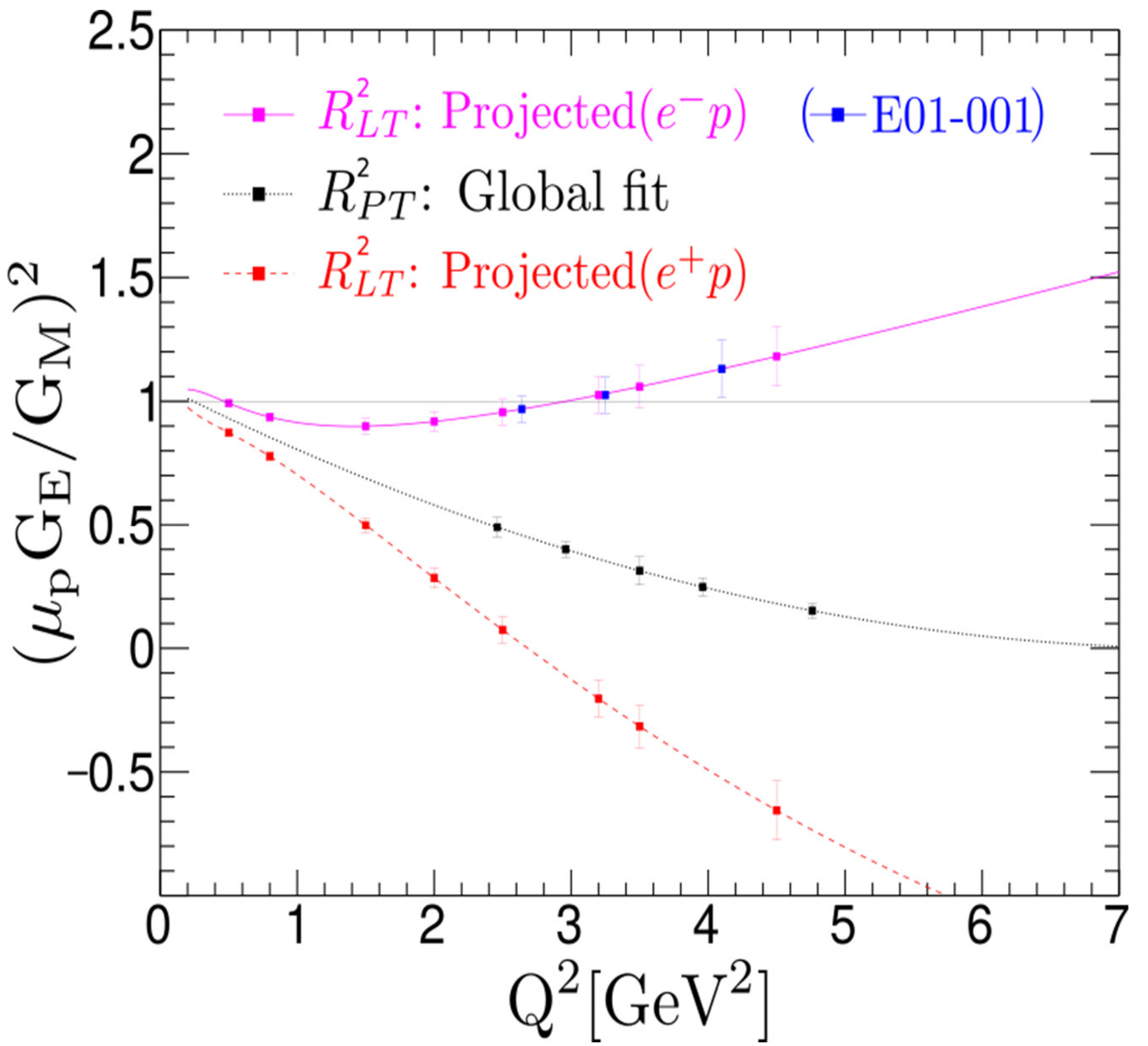
Uses all 3 linac settings from previous plot

Assumes 2 uA for positrons, 10cm LH2 target

Electron data in separate run: 20-50uA

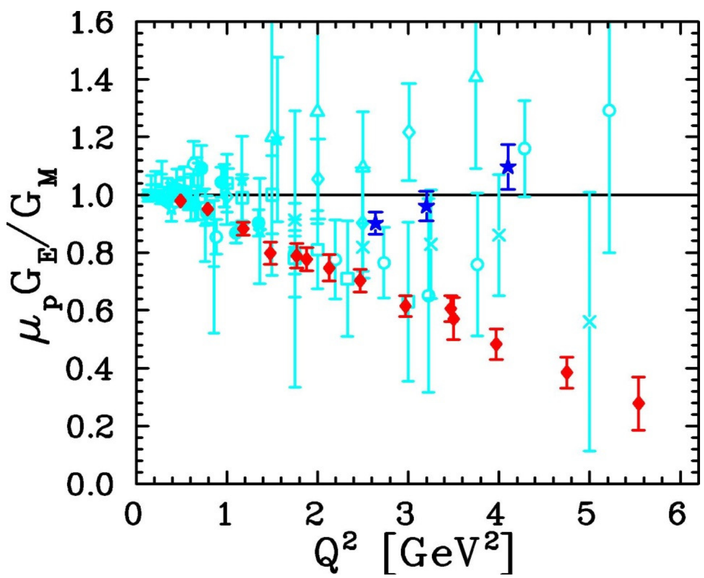
→ 35-40 days using 2 HRSs in Hall A OR using the HMS in Hall C (twice the solid angle)

Comparison doubles size of observed TPE contributions, is independent of potential TPE to polarization measurements



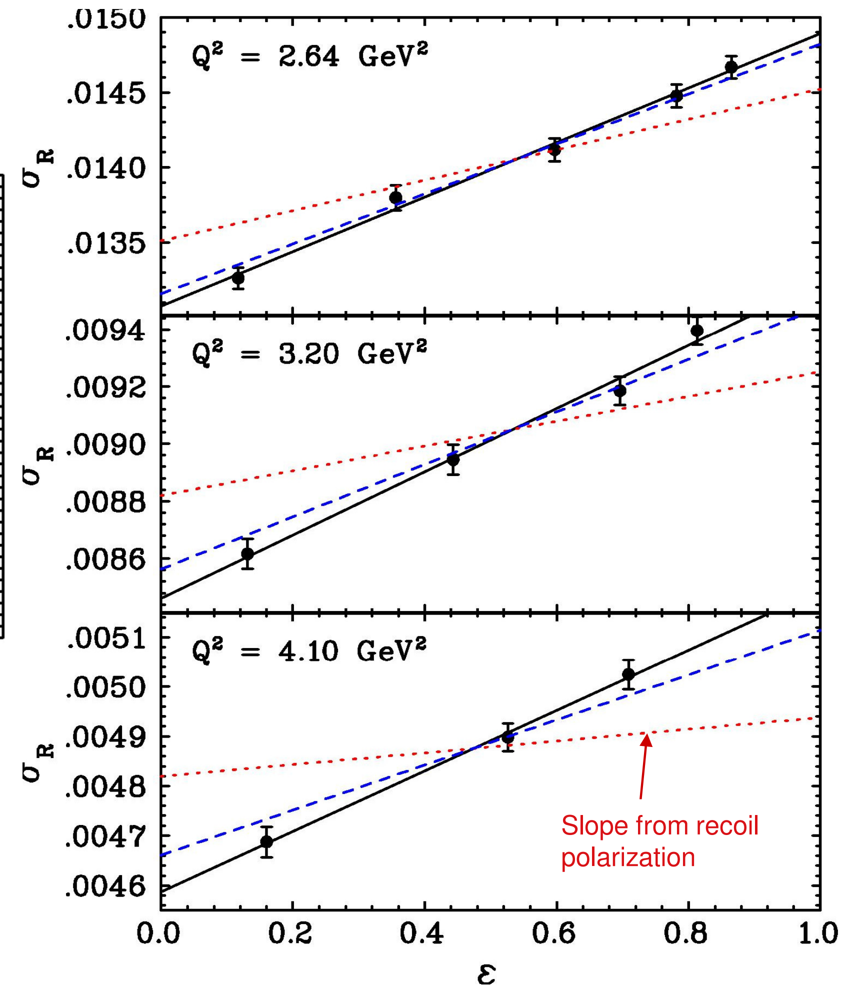
Polarization vs. Rosenbluth: G_E/G_M

$\mu_p G_{Ep}/G_{Mp}$ from Rosenbluth measurements



New data: Recoil polarization and p(e,p) "Super-Rosenbluth"

JLab Hall A: *M. Jones, et al.; O. Gayou, et al.*
I. A. Qattan, *et al, PRL 94, 142301 (2005)*



Two Photon Exchange

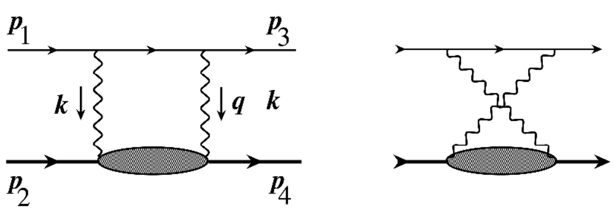
❑Proton form factor measurements

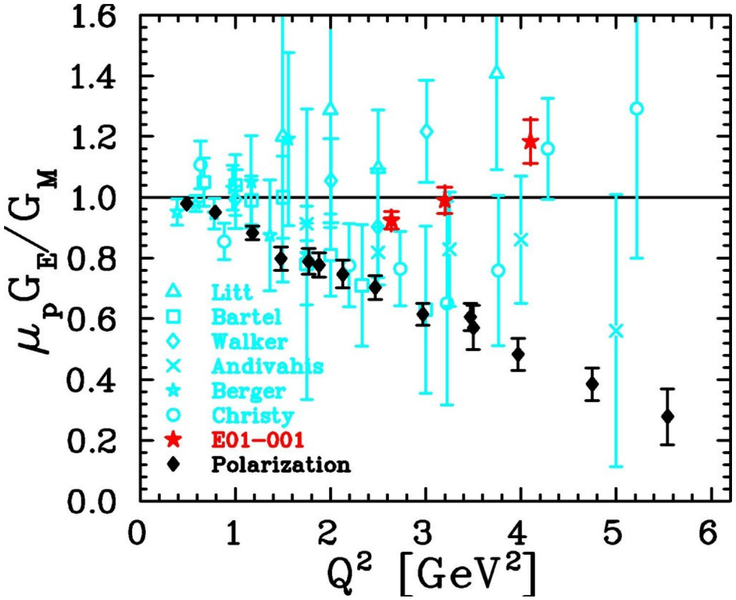
- **Comparison of precise Rosenbluth and Polarization measurements of G_{Ep}/G_{Mp} show clear discrepancy at high Q^2** *I.A.Qattan, et al., PRL 94 (2005) 142301*

❑Two-photon exchange corrections believed to explain the discrepancy

- **Minimal impact on polarization data**

P.A.M.Guichon and M.Vanderhaeghen, PRL 91, 142303 (2003)





*M.K.Jones, et al., PRL **84**, 1398 (2000)*
*O.Gayou, et al., PRL **88**, 092301 (2003)*
*I.A.Qattan, et al., PRL **94**, 142301 (2005)*

❑ **Active program to confirm, calculate, and understand TPE**

P. G. Blunden et al, PRC 72 (2005) 034612
A.V. Afanasev et al, PRD 72 (2005) 013008
D. Borisyuk, A. Kobushkin, PRC 78 (2008) 025208
C. Carlson, M. Vanderhaeghen, Ann. Rev. Nucl. Part. Sci. 57 (2007) 171
JA, P. Blunden, W. Melnitchouk, PPNP 66 (2011) 782
+ several completed or ongoing experiments

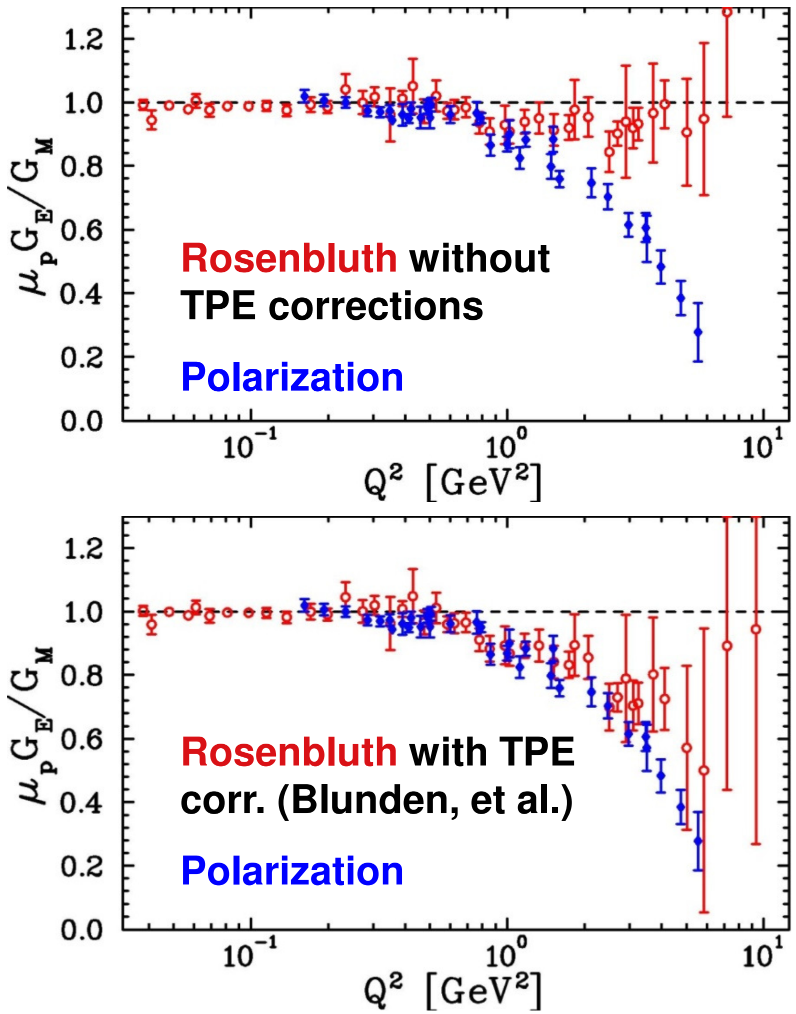
Two Photon Exchange?

Limits set for non-linear (non-Born) contributions: ***V. Tvaskis, et al., PRC 73 (2006) 025206***

Limits set for θ-dependent (non-Born) PT contributions: ***M. Meziane, PRL 106 (2011) 132501***

Evidence (3σ) for TPE in existing e+/e- comparisons (TPE changes sign with lepton charge)***: JA, PRC 69 (2004) 032201***

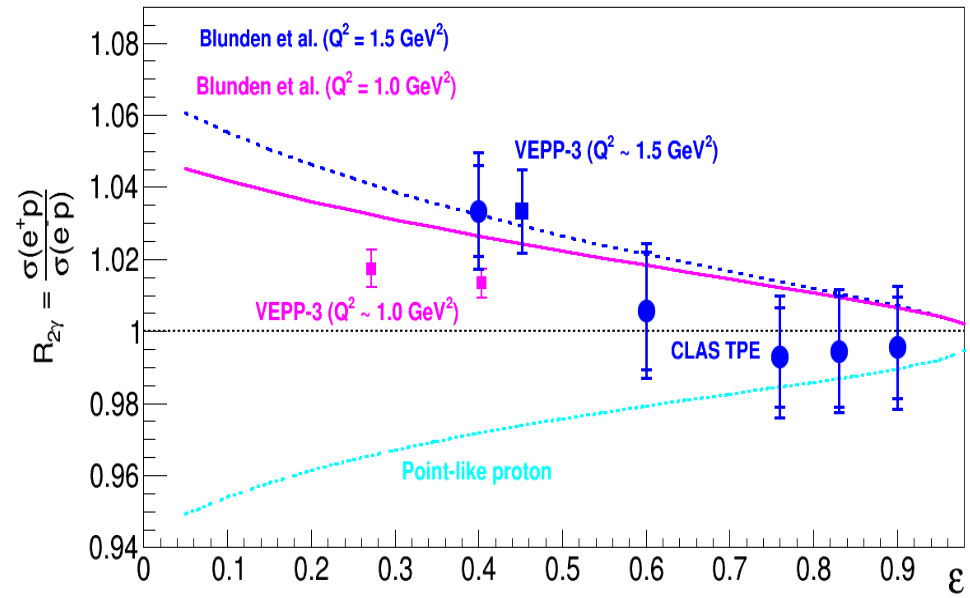
Many model-dependent TPE calculations - generally good qualitative agreement with observed discrepancy: ***[Afanasev, et al.; Blunden, et al.; Borisyuk and Kobushkin; Chen, et al.; etc……]***



JA, W. Melnitchouk, J. Tjon, PRC 76, 035205 (2007)

Snapshot of new e+/e- comparisons

- Results in from JLab(CLAS) and Novosibirsk(VEPP-3) experiments



JLab: D. Adikaram, et al., PRL 114 (2015) 062003
D. Rimal, et al., arXiv:1603.00315

VEPP-3: I.A.Rachek, et al., PRL 114 (2015) 062005

Good agreement with hadronic TPE

Point proton (~Q^2=0 limit) has opposite sign from data at Q^2 = 1-1.5 GeV^2

OLYMPUS: up to Q^2~2 GeV^2, ~1% uncertainties [talk by J. Bernauer]

- If Olympus also agrees with calculations, very strong overall case for TPE as culprit
  - Hadronic calculations appear to be reliable at low Q^2, where they should be most reliable, and where many of the extremely high-precision data are taken
  - Other improvements to radiative corrections still being investigated

e.g.., Gramolin and Nikolenko, PRC 93 (2016) 055201 [arXiv:1603.06920]

Issues in extracting the radius: TPE corrections

Blunden, Melnitchouk, Tjon, hadronic calculation *[PRC 72, 034612 (2005)]*

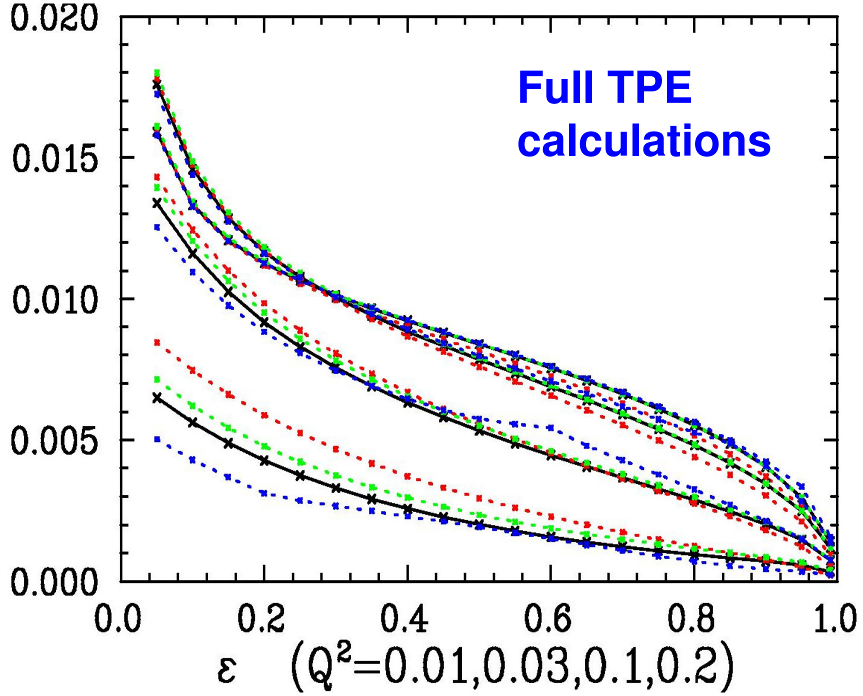
Borisyuk & Kobushkin: Low-Q^2 expansion, valid up to 0.1 GeV^2 *[PRC 75, 038202 (2007)]*

B&K: Dispersion analysis (proton only)

[PRC 78, 025208 (2008)]

B&K: proton + Δ *[arXiv:1206.0155]*

B&K proton only: (same as Blunden)



JA, arXiv:1210.2677