Super-Rosenbluth Measurements with Positrons to Study the Two-Photon Exchange

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Positron Working Group Workshop
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Outline

- Elastic form factors: Rosenbluth and Polarization
- Overview of Super-Rosenbluth measurement
- Super-Rosenbluth experiment with positrons
- Summary and Outlook

Form factors from unpolarized elastic scattering

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

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

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

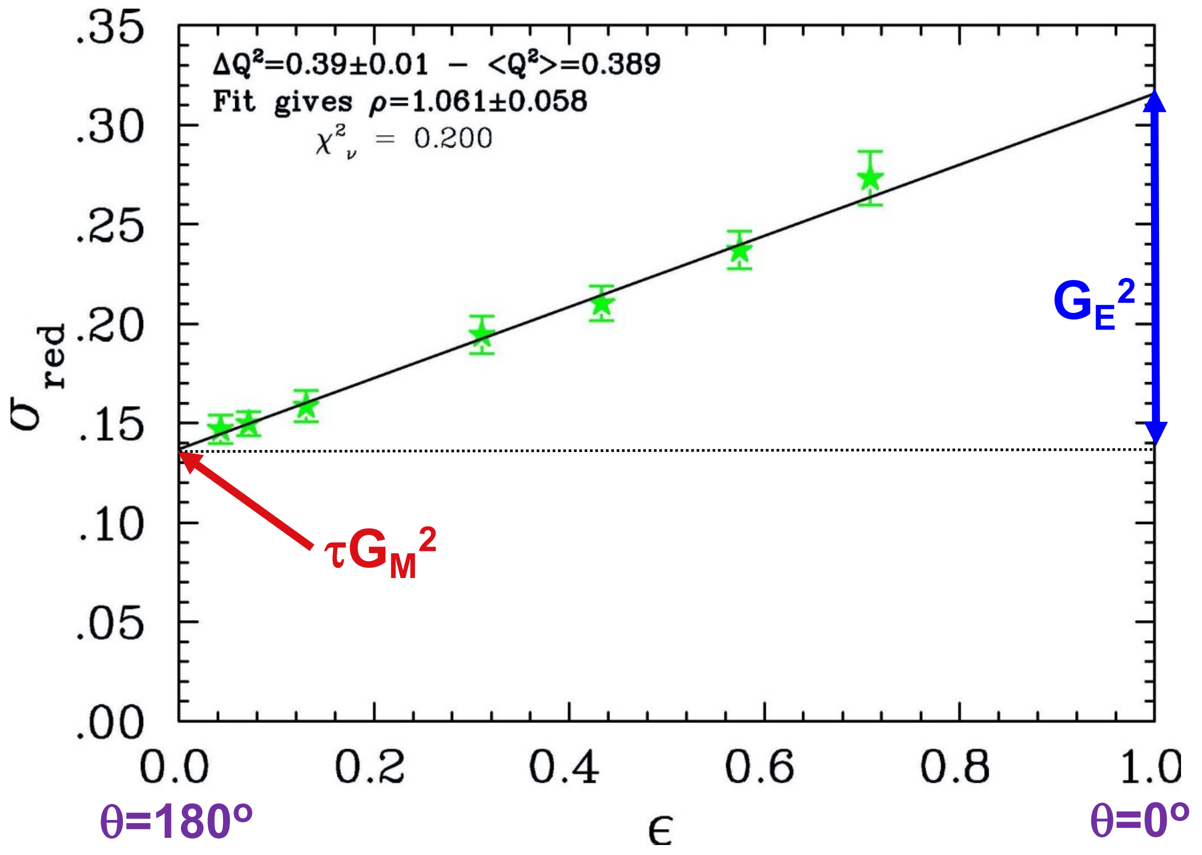
$\varepsilon = [\,1 + 2(1+\tau)\tan^2(\theta/2)\,]^{-1}$

Reduced sensitivity when one term dominates:

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

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

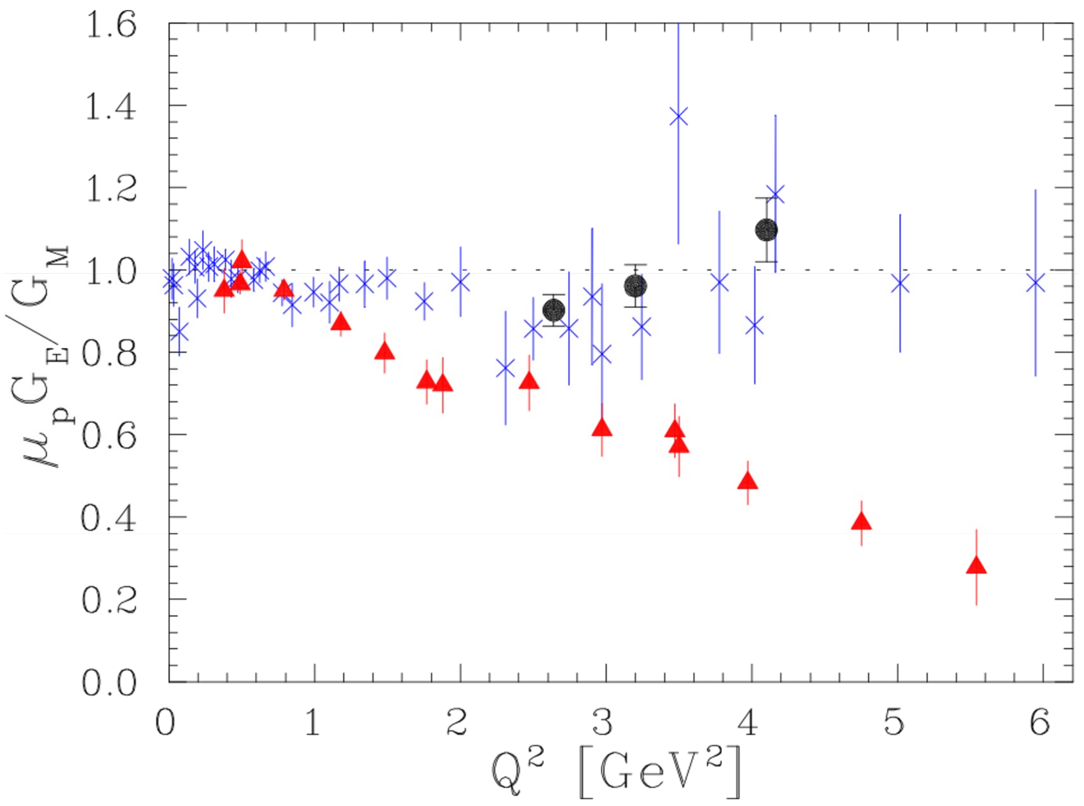
→ **$m_p\, G_E(Q^2)\, /\, G_M(Q^2) \approx 1$**



Form factors: Rosenbluth vs Polarization

Rosenbluth extractions

$$\sigma_R = \frac{d\sigma}{d\Omega}\frac{(1+\tau)\epsilon}{\sigma_{ns}} = \tau G_{Mp}^2 + \epsilon G_{Ep}^2$$



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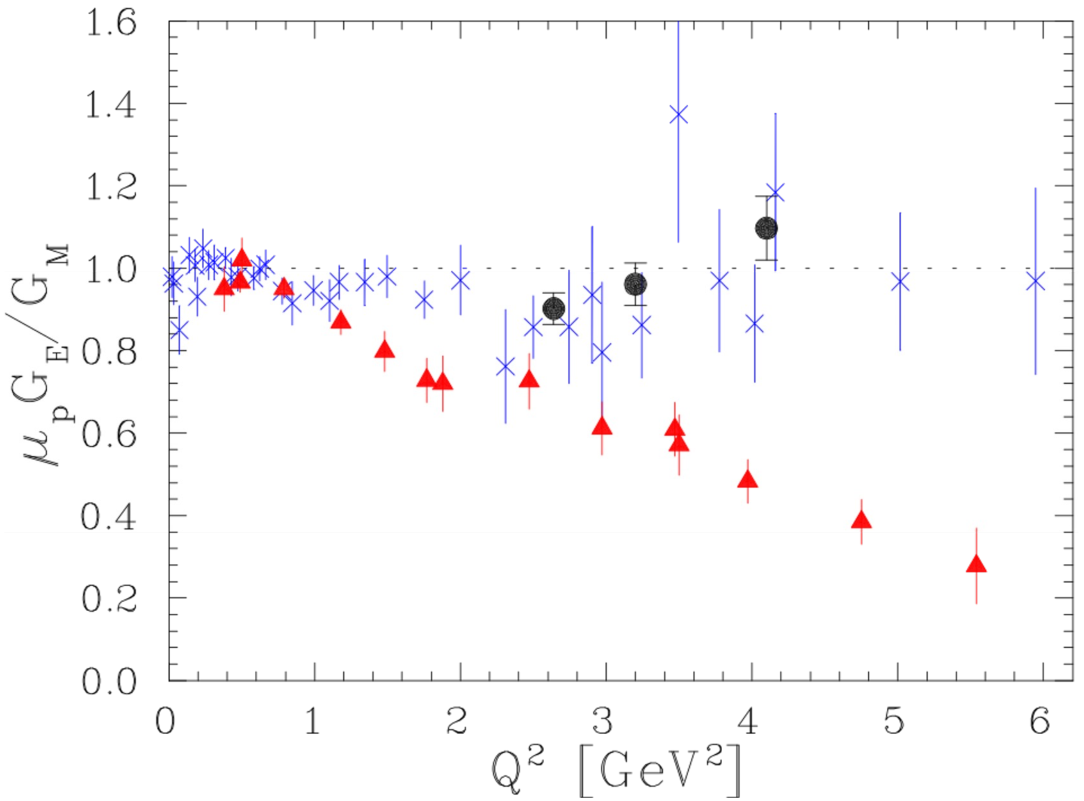
Polarization transfer measurements

$$\frac{G_{Ep}}{G_{Mp}} = -\frac{P_l}{P_t}\frac{E+E'}{2M_p}\tan\left(\frac{\theta_e}{2}\right)$$

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



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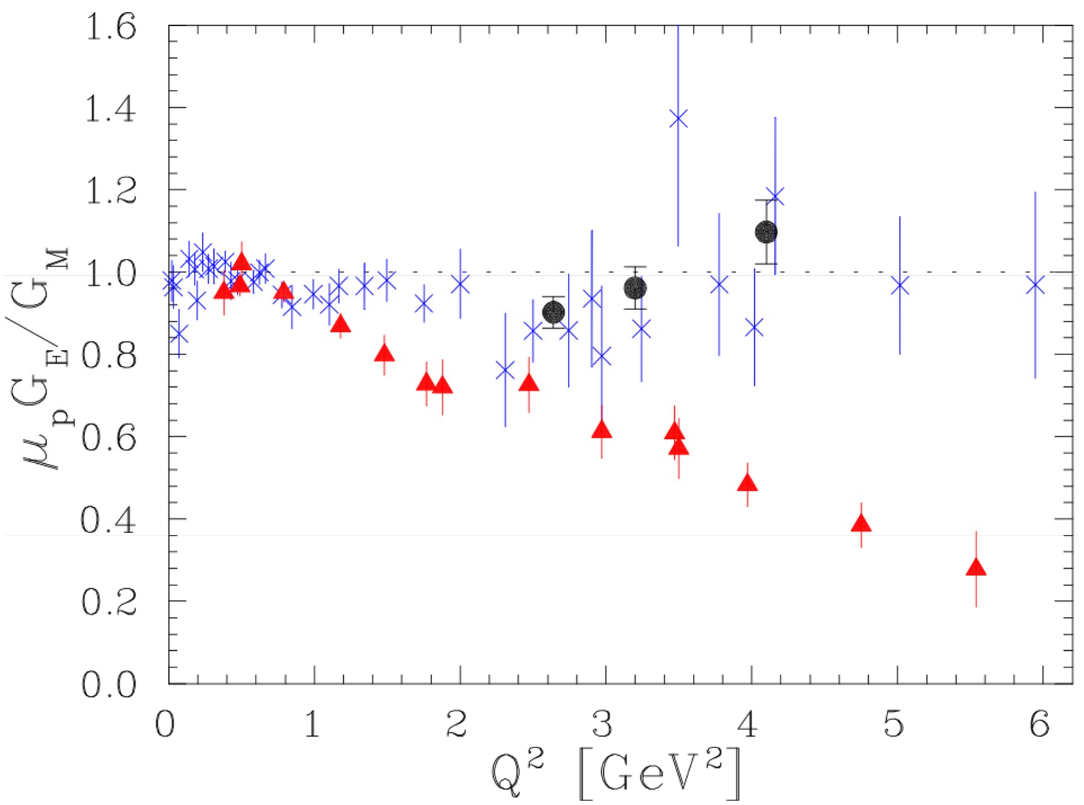

Black points – "Super-Rosenbluth" measurement:
Modified technique that gives significantly smaller uncertainty on the RATIO G_E/G_M

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

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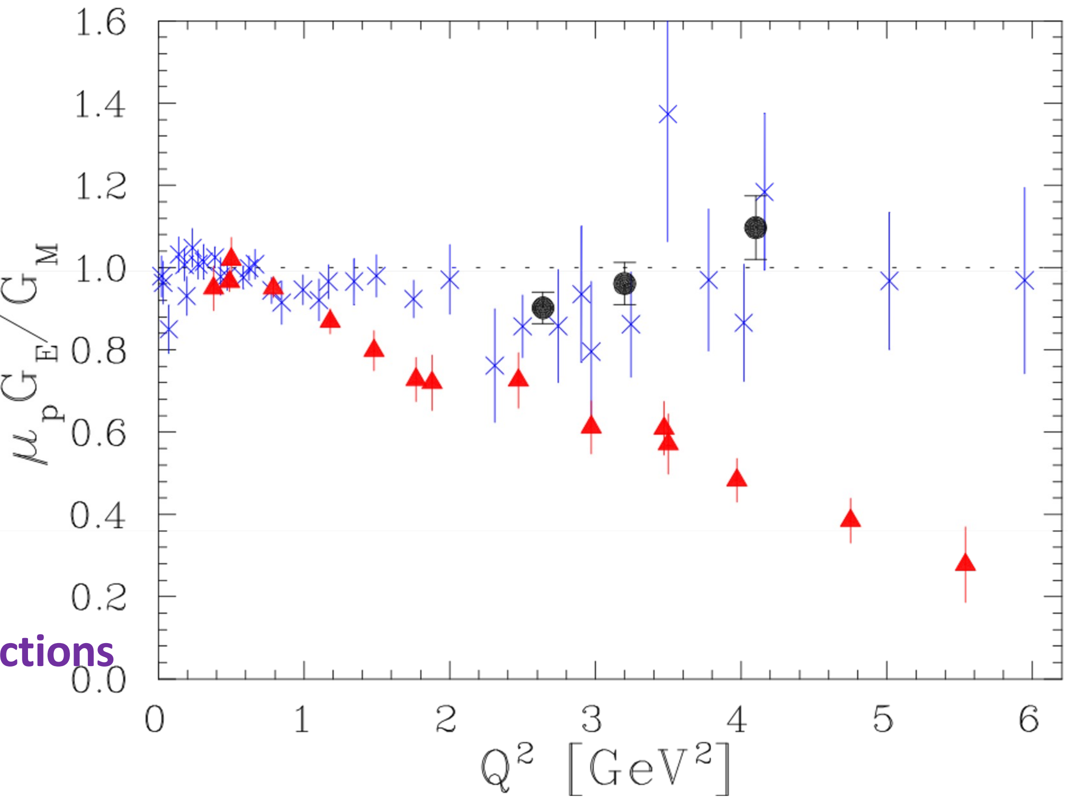
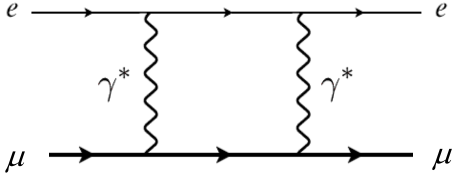
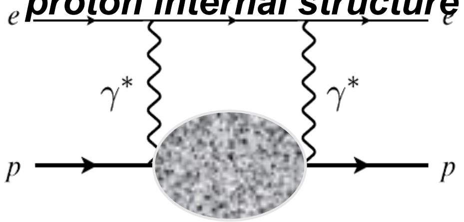


Difference assumed to be caused by two-photon exchange (TPE) corrections

QED: straightforward to calculate



QED+QCD: depends on *proton internal structure*



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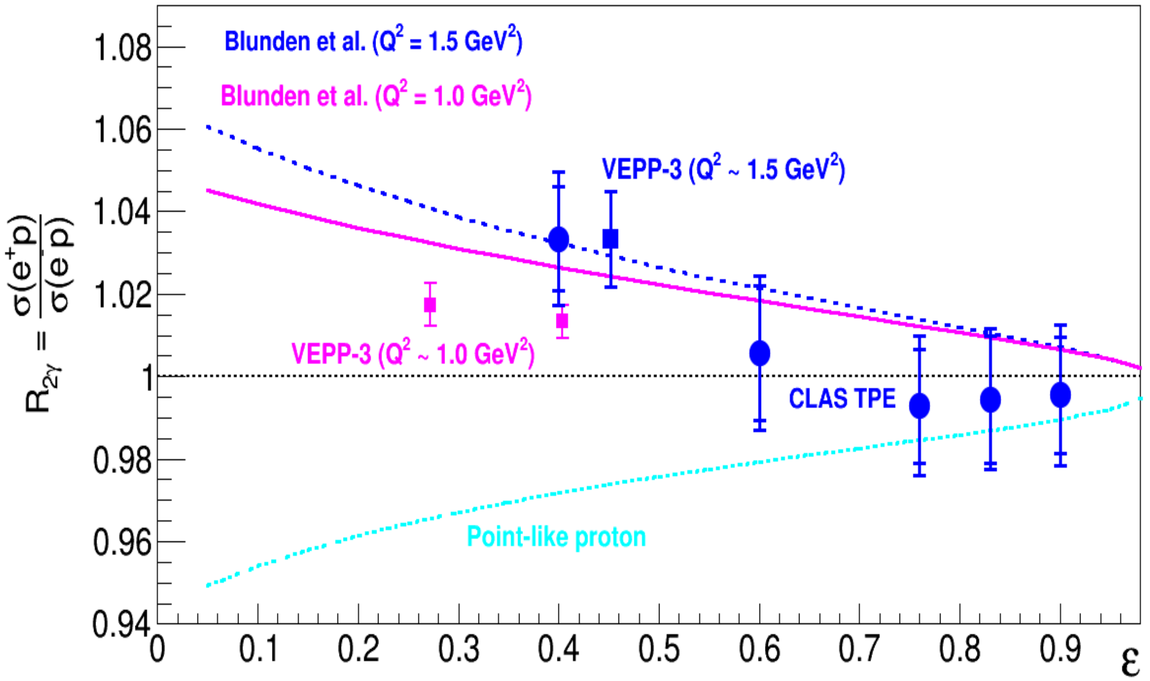
Two-Photon Exchange

- $R = \frac{\sigma(e^+p)}{\sigma(e^-p)}$ $\longrightarrow$ $\boxed{R_{2\gamma} = 1 - 2\delta_{2\gamma}}$



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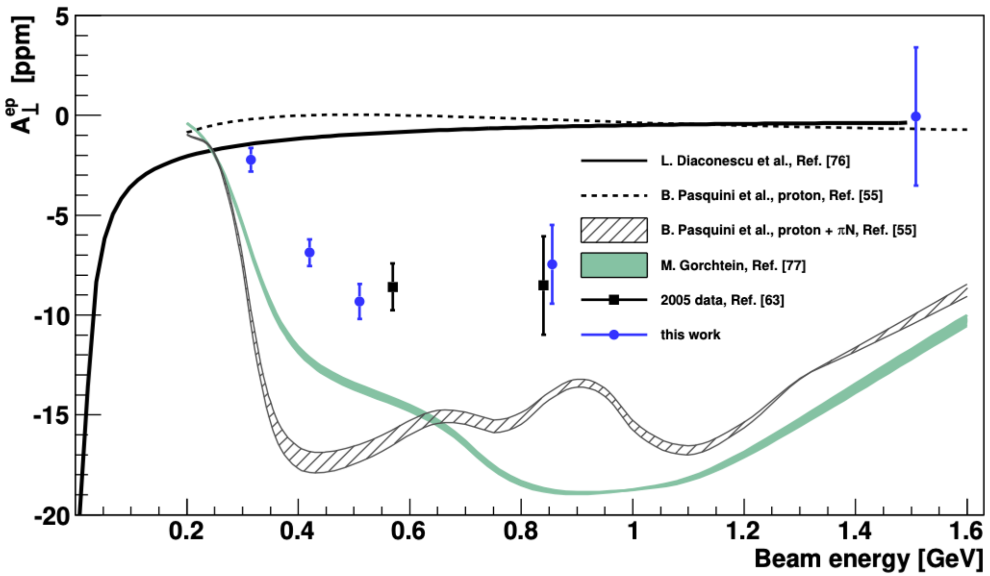
- Target-Normal & Beam-Normal SSA
  - $B_n = \dfrac{\sigma^{\uparrow}-\sigma^{\downarrow}}{\sigma^{\uparrow}+\sigma^{\downarrow}} = \dfrac{2Im(M_{\gamma\gamma}M_{\gamma}^{*})}{|M_{\gamma}|^2}$

$A_{\perp}^{ep}$



B.Gou *et al.* Phys. Rev. Lett. 124

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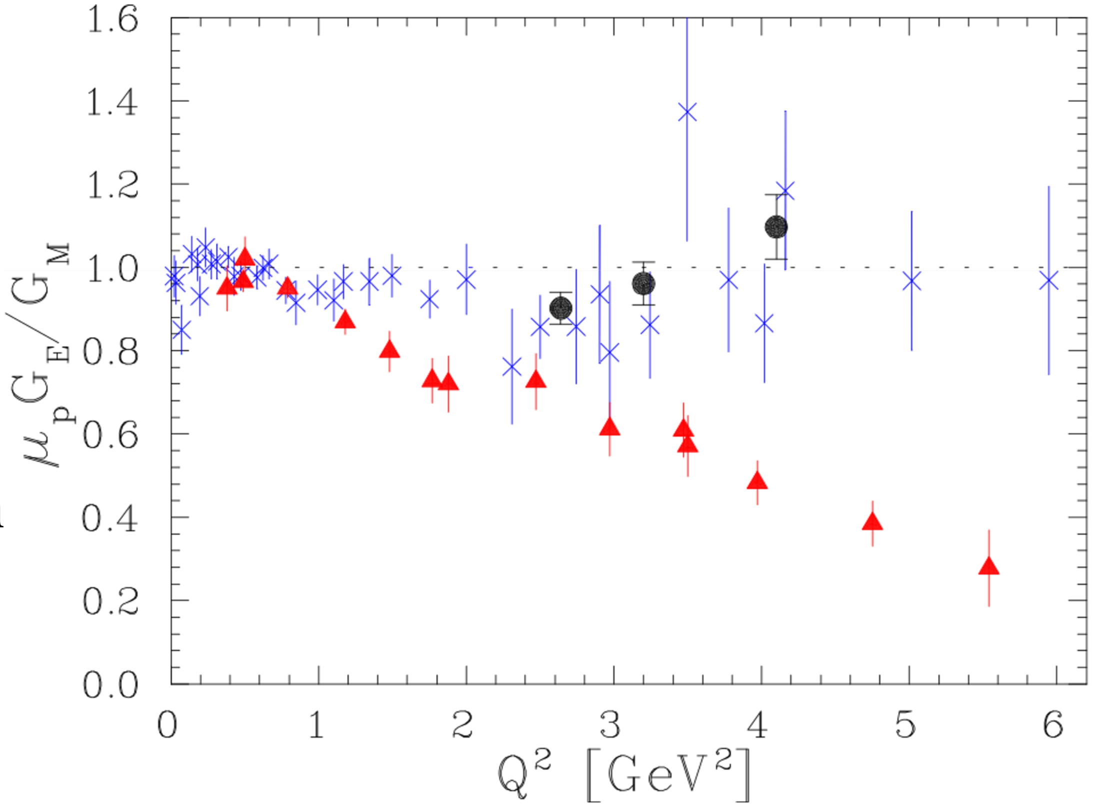
- **Direct comparison between Rosenbluth and polarization measurements**
  - **Super-Rosenbluth provides a way to make high precision measurements at large Q^2**



Two-Photon Exchange Corrections

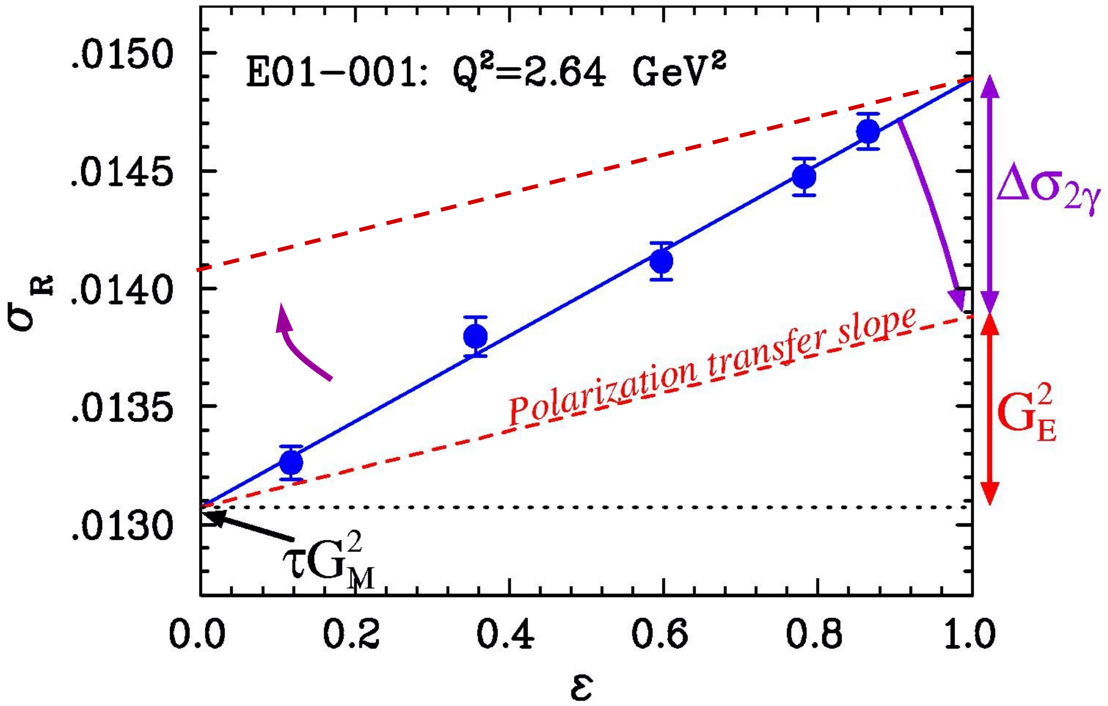
Two-photon exchange effects can explain discrepancy in G_E

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***?

Super-Rosenbluth technique

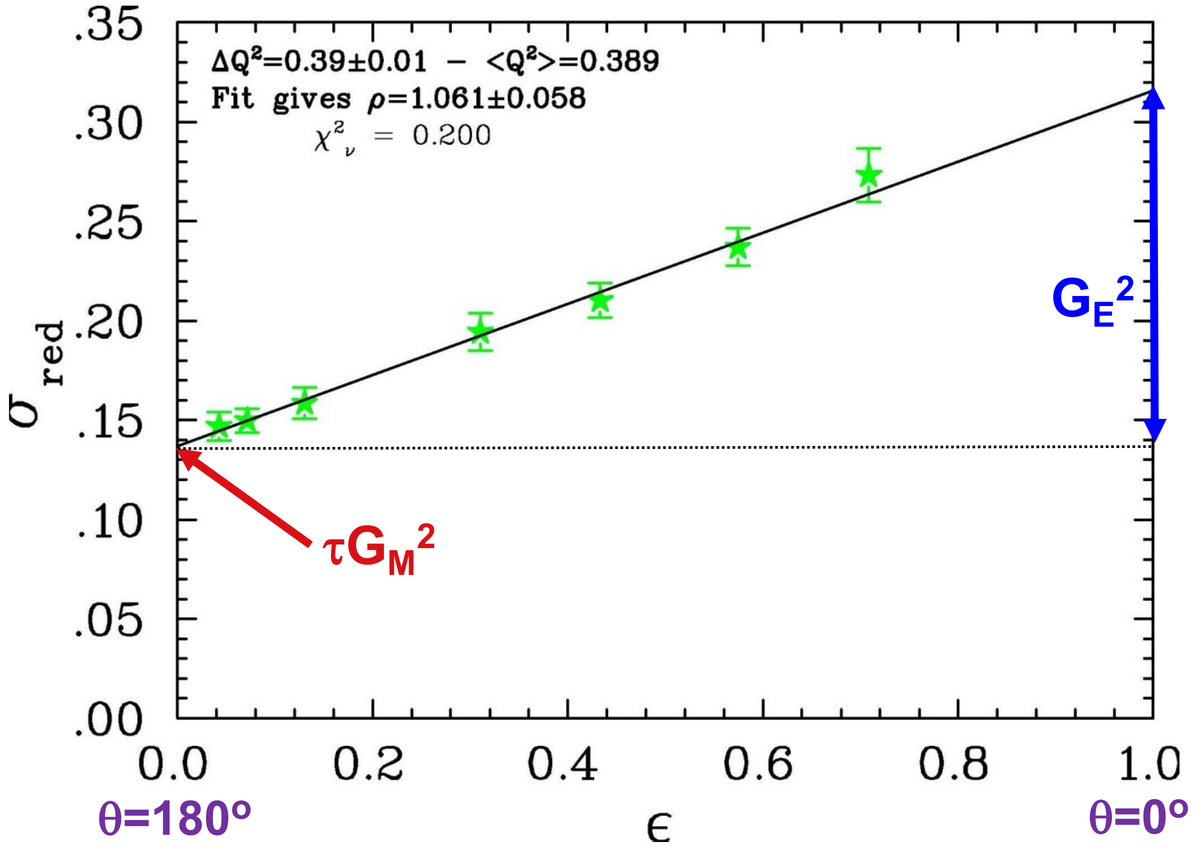
Rosenbluth (L/T) measurement: vary ε (q) at fixed Q^2

Conventional measurement: electron detection

- $\varepsilon \approx 1$: large beam energy, small scattering angle, large electron momentum, high rates
- $\varepsilon \approx 0$: small beam energy, large angle, small electron momentum, low rates

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

➢ Limited by low cross sections at large scattering angle



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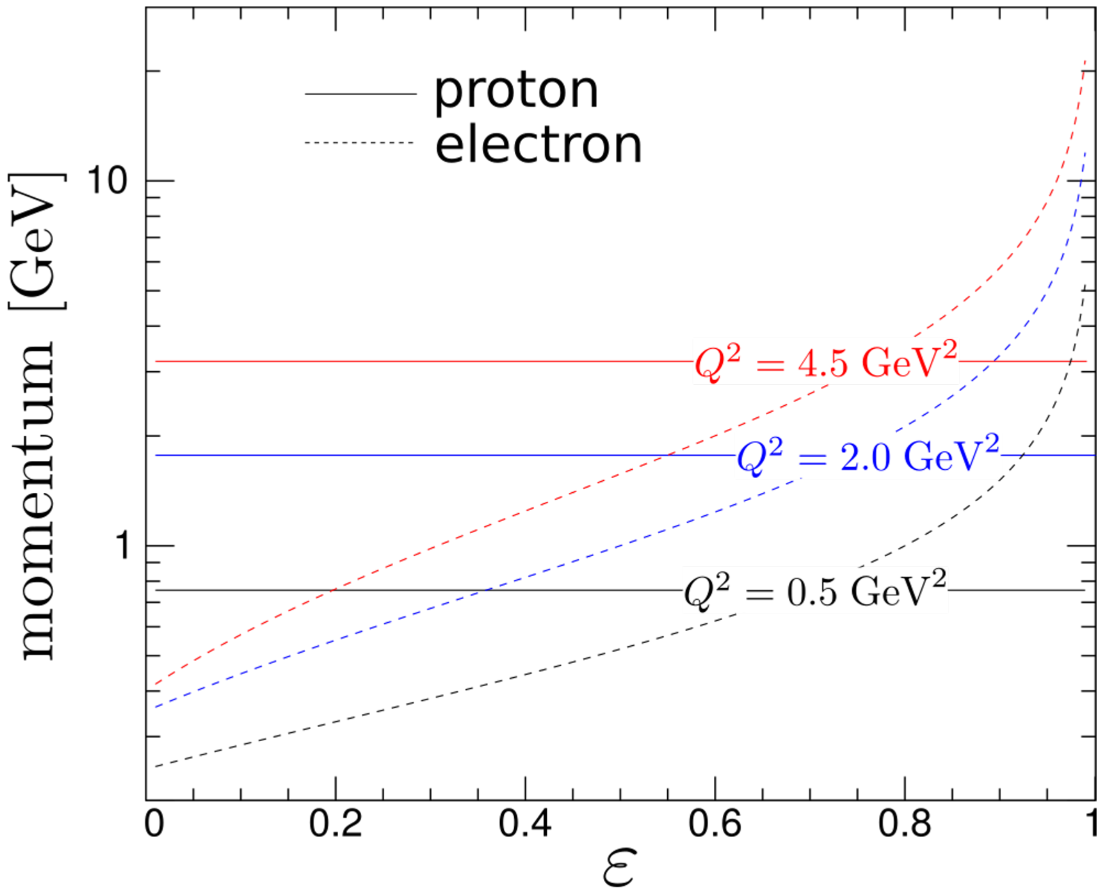

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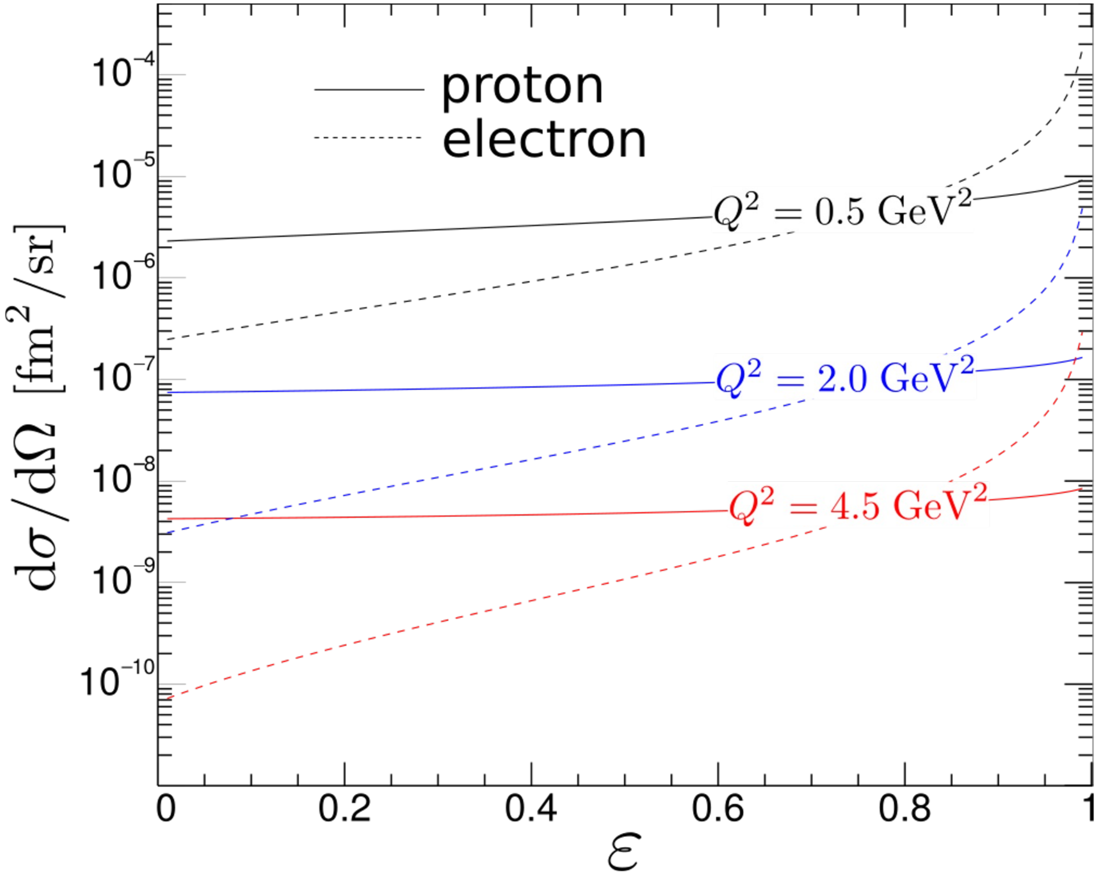

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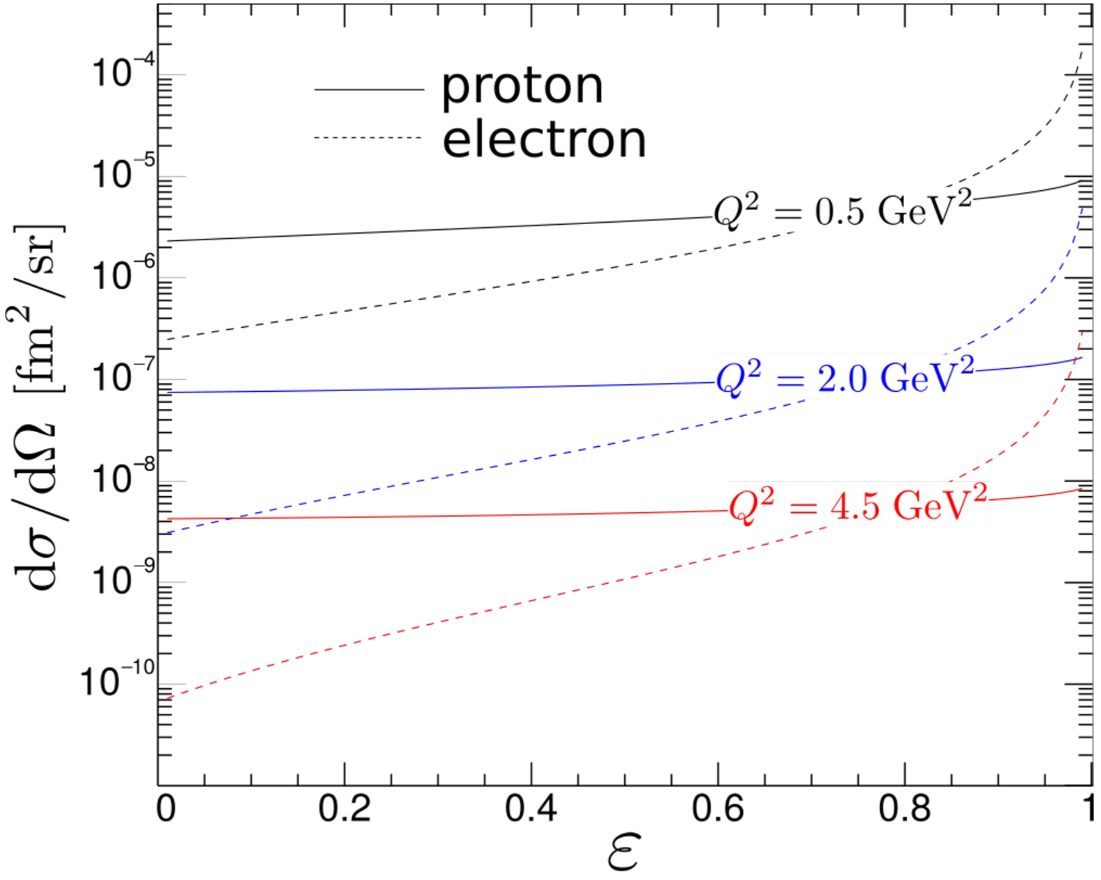

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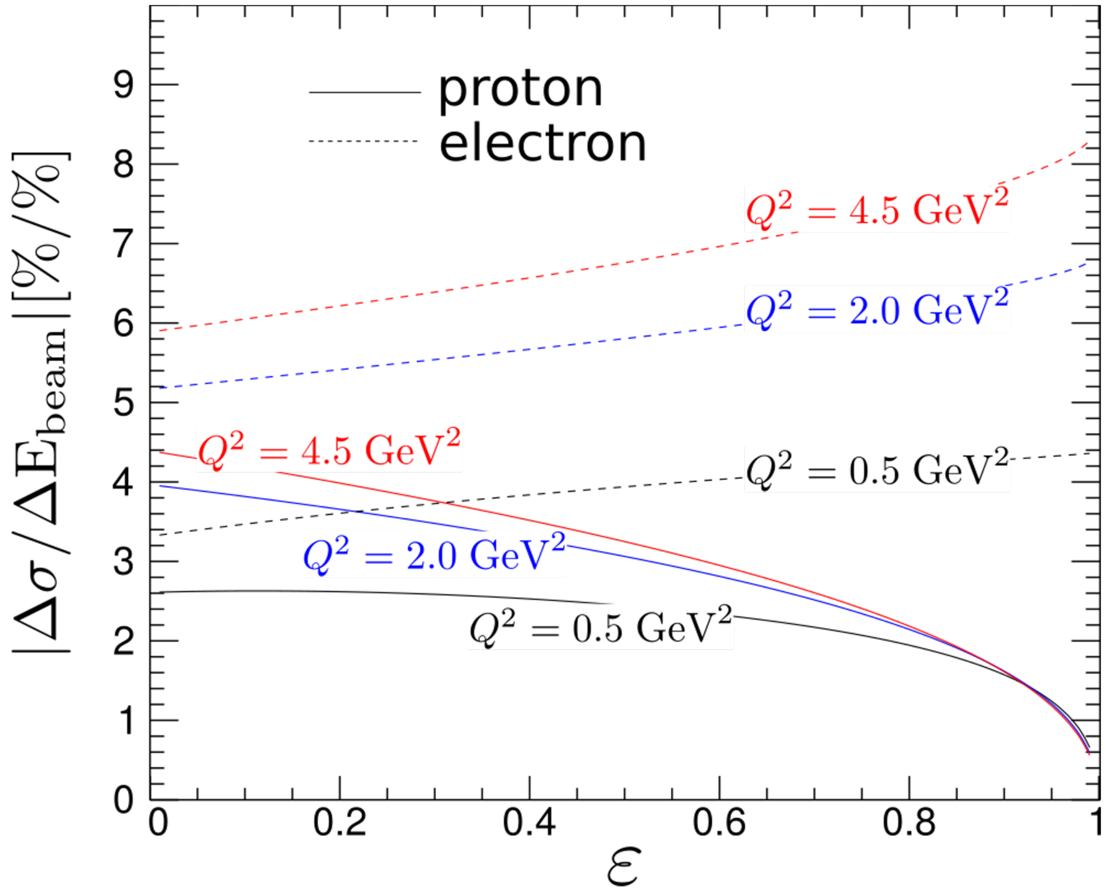

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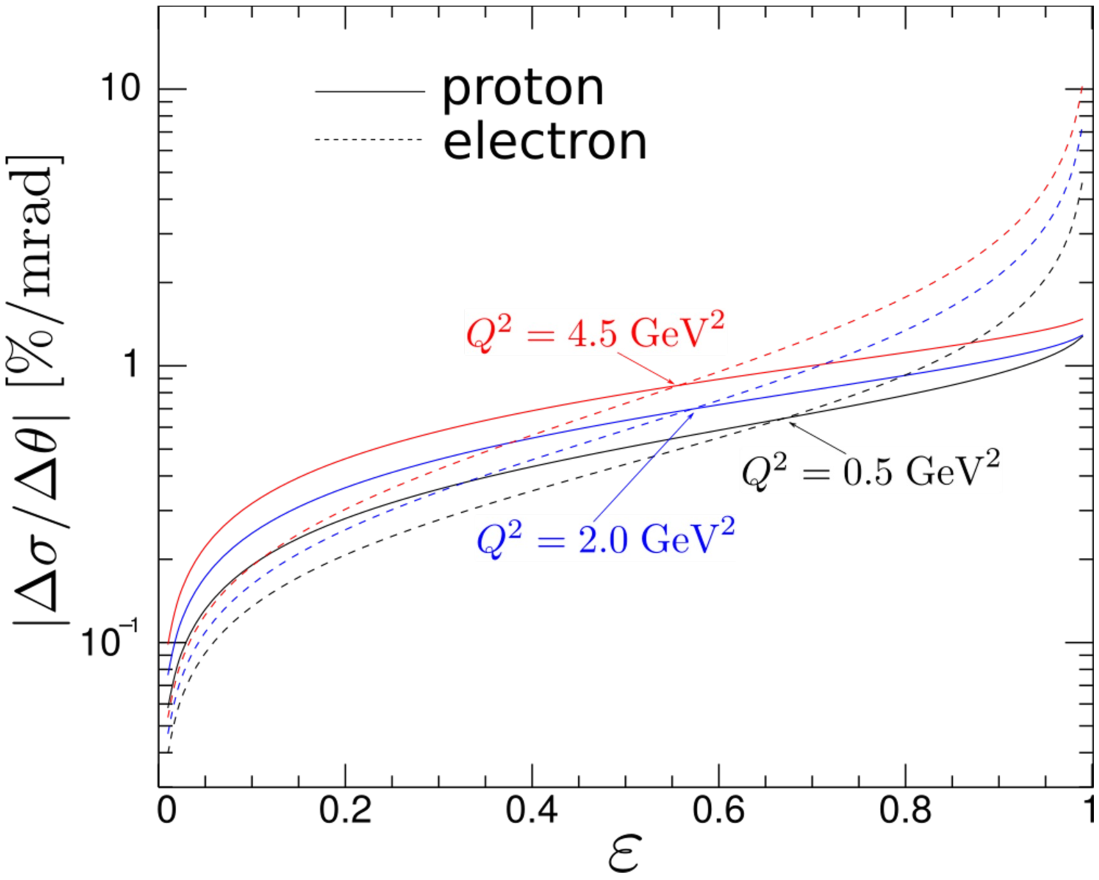

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Super-Rosenbluth with positrons

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

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

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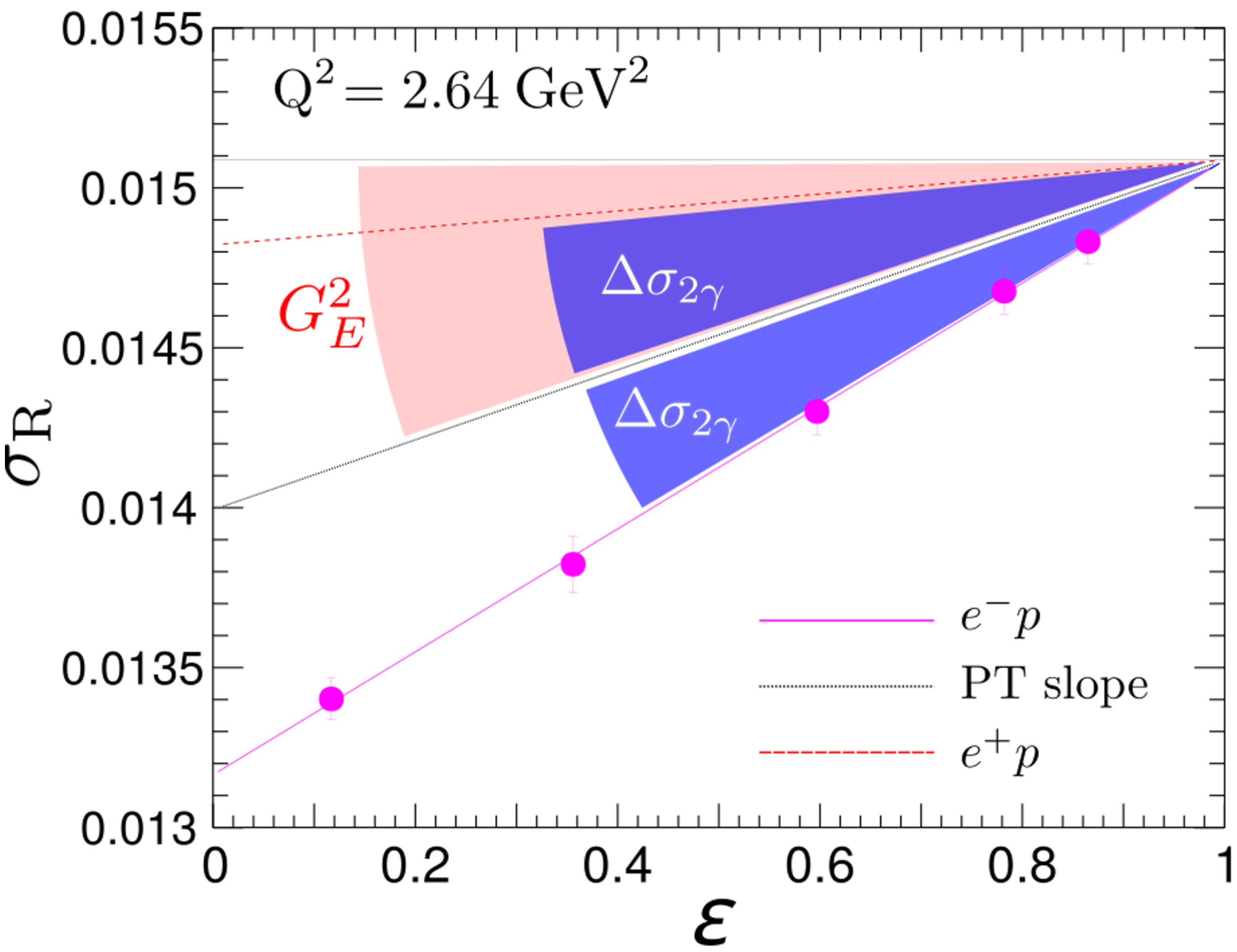
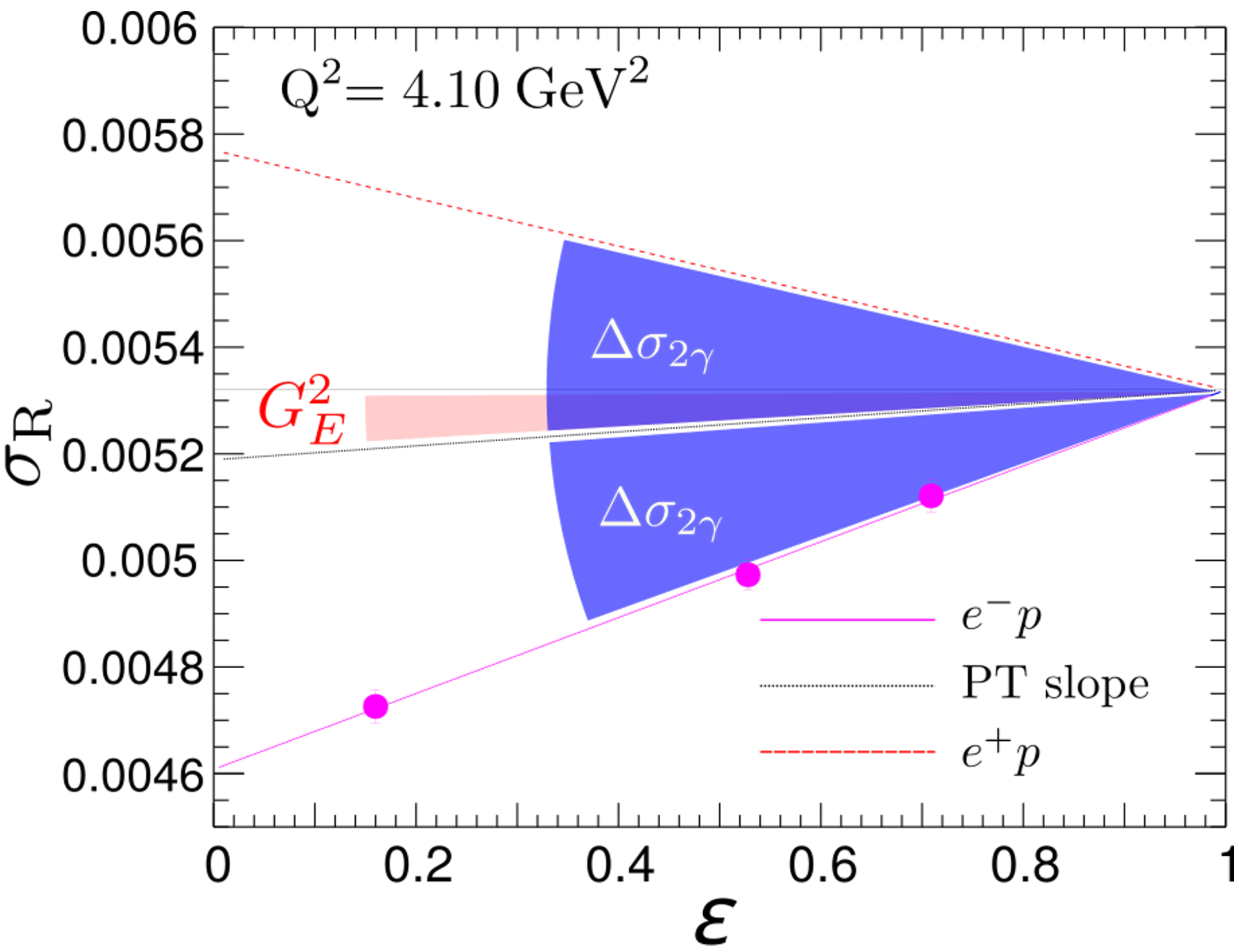
Can perform precise S-R extraction with positrons and S-R with electrons independently.

Does not require rapid beam changes or identical beam characteristics.

Rosenbluth separations: e+ vs e-





Kinematics

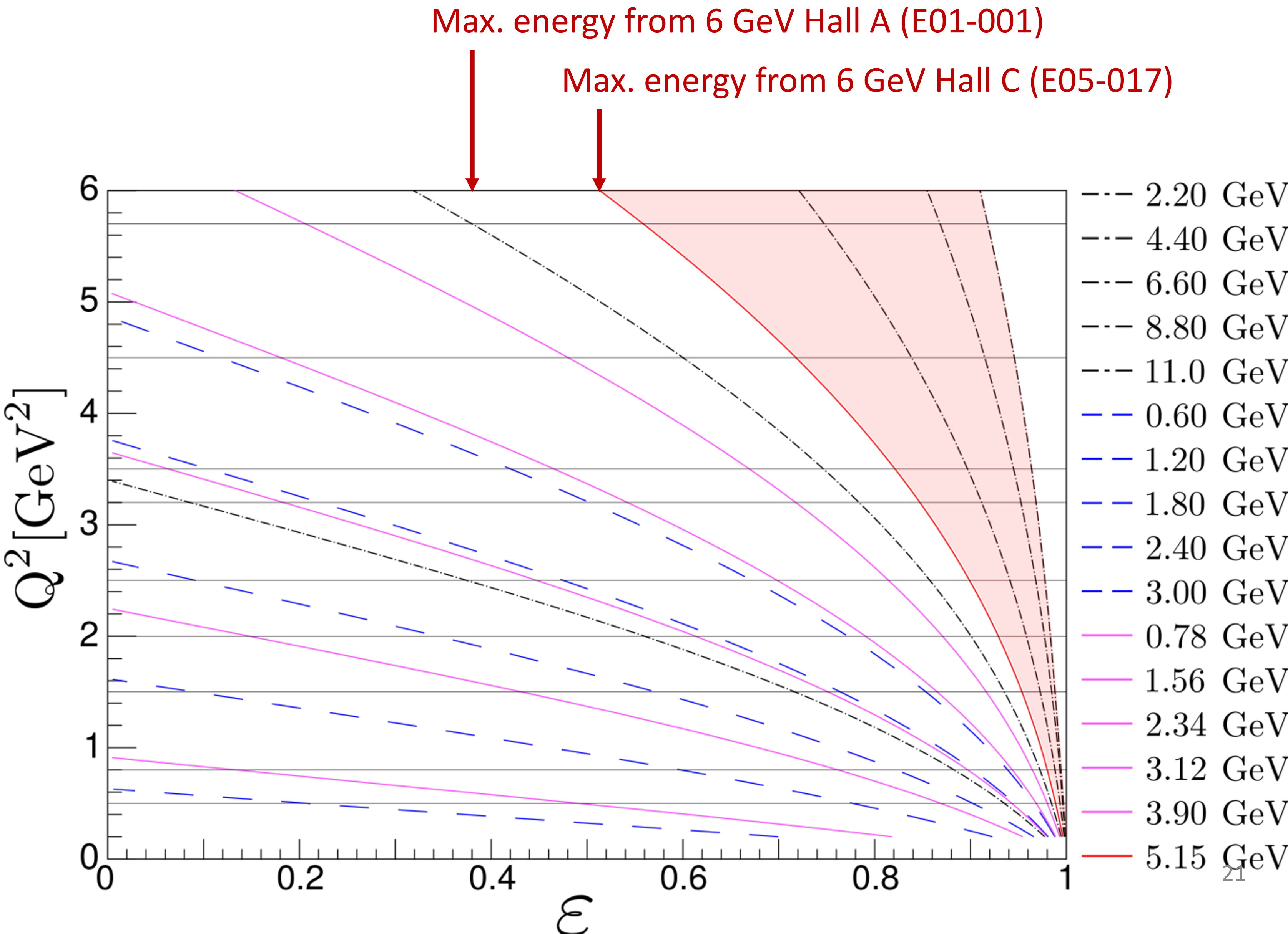
Black: 2.2 GeV/pass

- **2-3 high-epsilon points at each Q^2**
- **Larger e 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

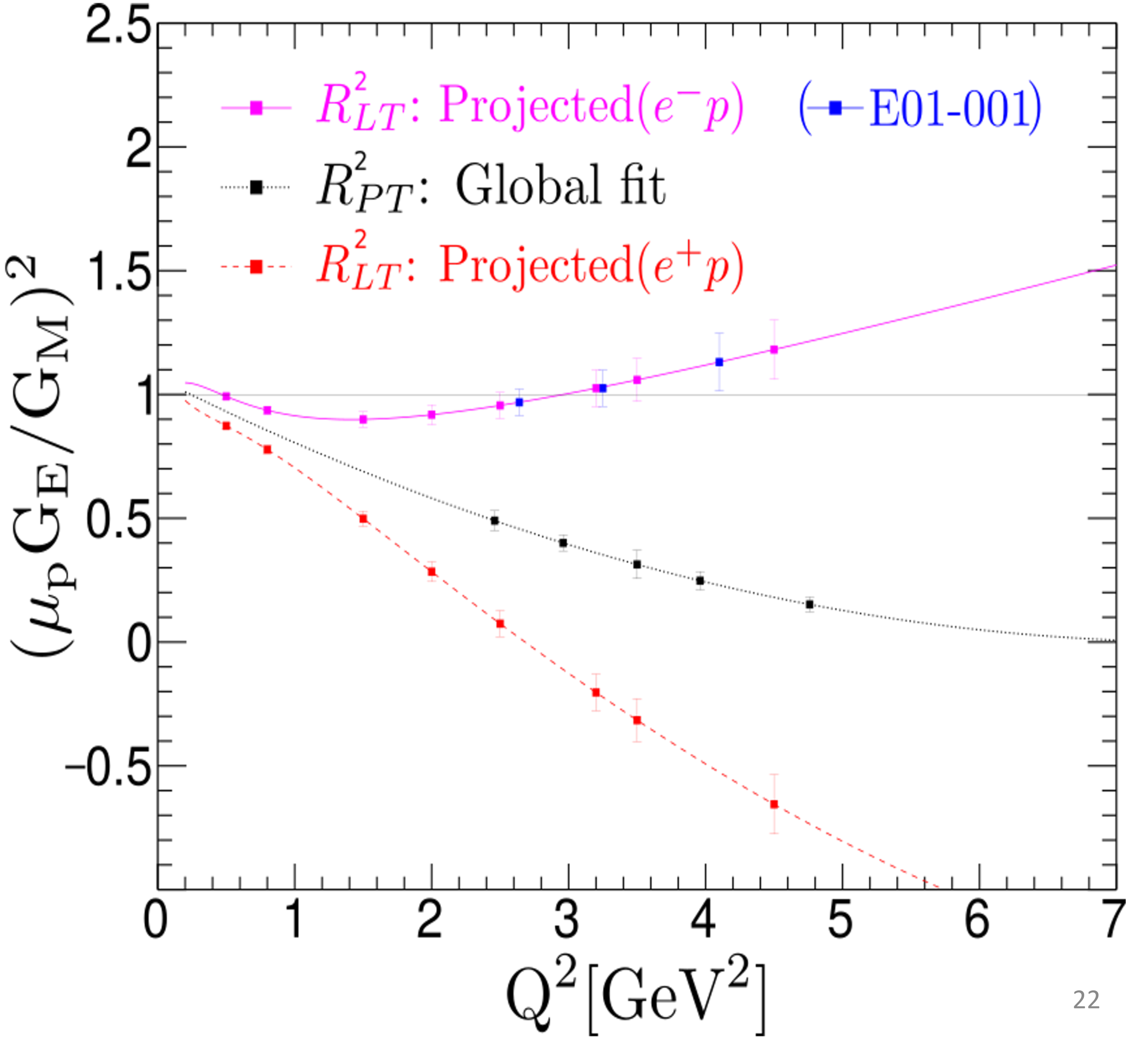
Uses all 3 linac settings from previous plot

Assumes 2 μA for positrons, 10cm LH2 target

Electron data in separate run: 20-50 μA

→ **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

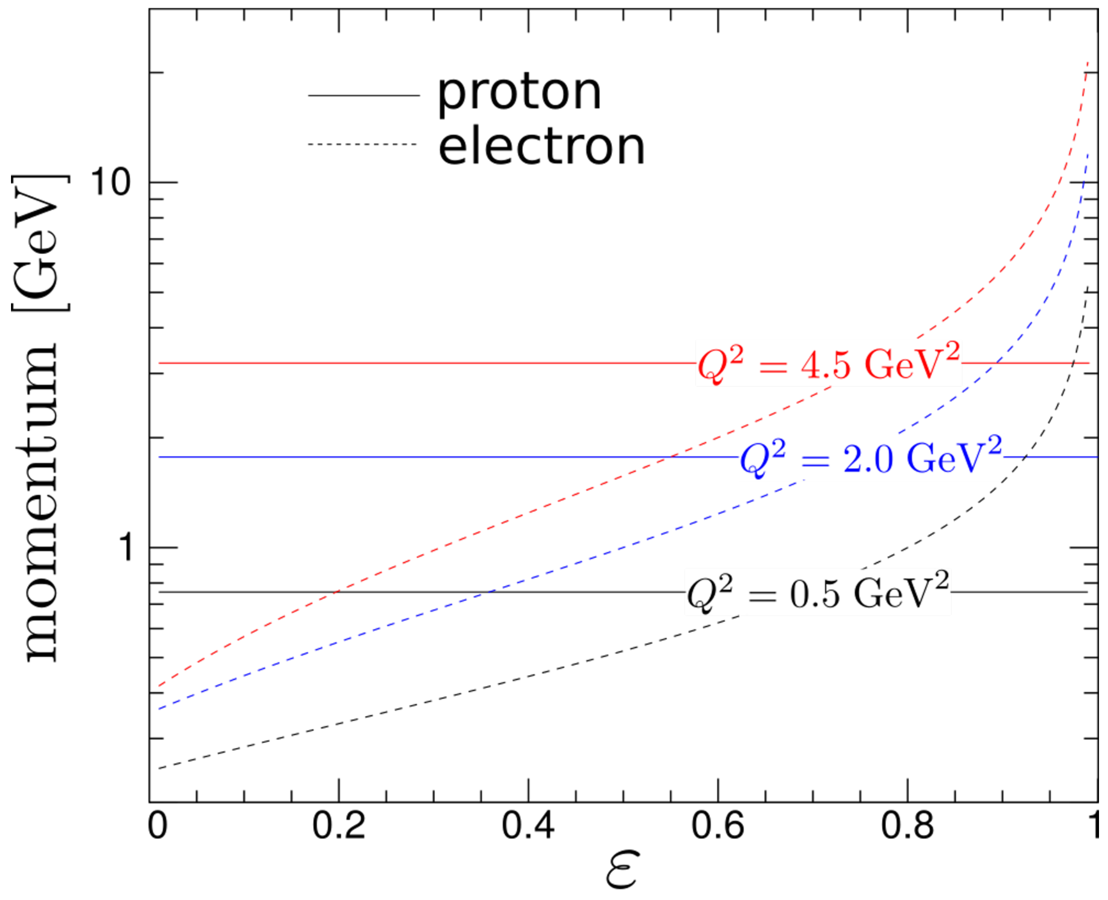


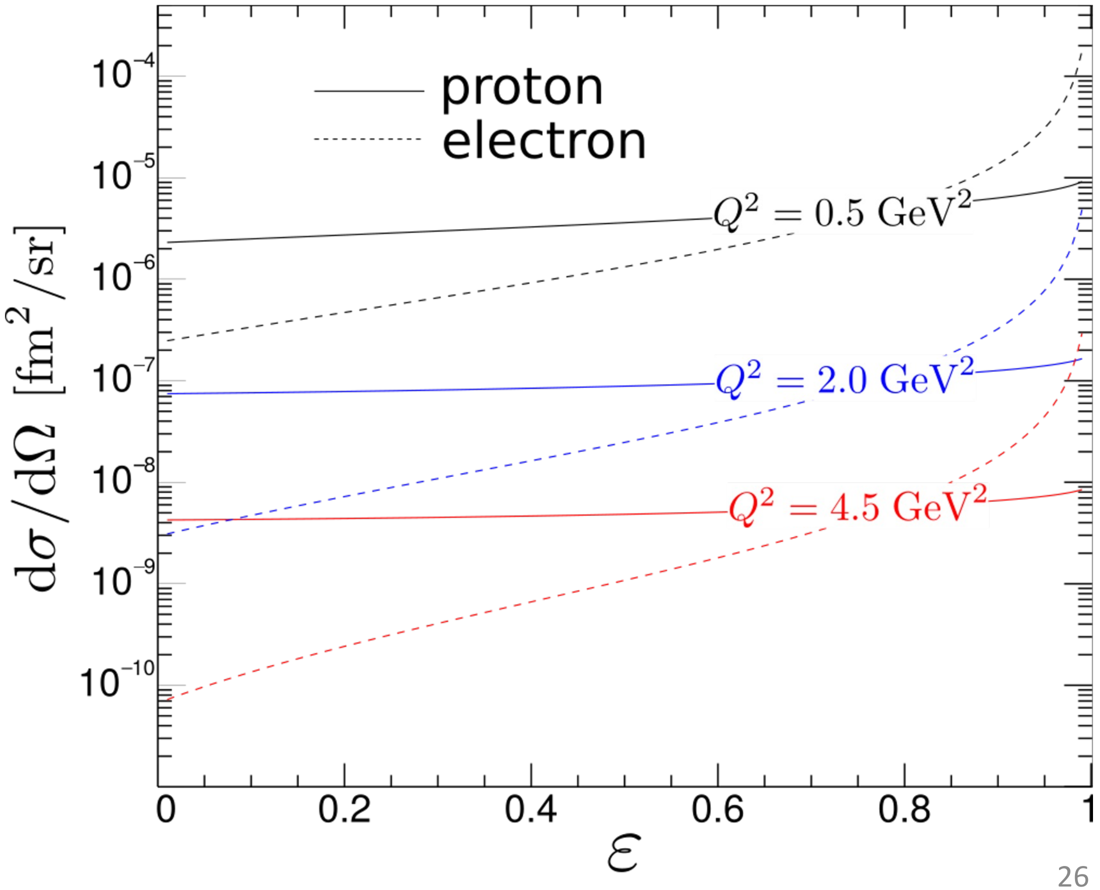
Summary and Outlook

- Contribution of TPE effects causing difference in Rosenbluth and Polarization measurements still not well constrained
  - Measurements investigating TPE at large Q^2 are challenging
  - Differing theoretical predictions
  - High precision data to understand TPE
- **Super-Rosenbluth measurement using positrons**
  - Precision extraction of G_E/G_M
  - Compare with polarization measurements to determine magnitude of two-photon corrections as a function of Q^2
- Optimize kinematic for positrons Super-Rosenbluth measurement
  - Can make complimentary e^- Super-Rosenbluth measurement
  - Doubles the sensitivity
- Updating and optimizing kinematics
- Proposal in progress
  - John Arrington, Mikhail Yurov, Nathaly Santiesteban and Michael Nycz
  - Currently updating and optimizing kinematics + reformatting proposal

Thank You

Advantage of Detecting the Proton





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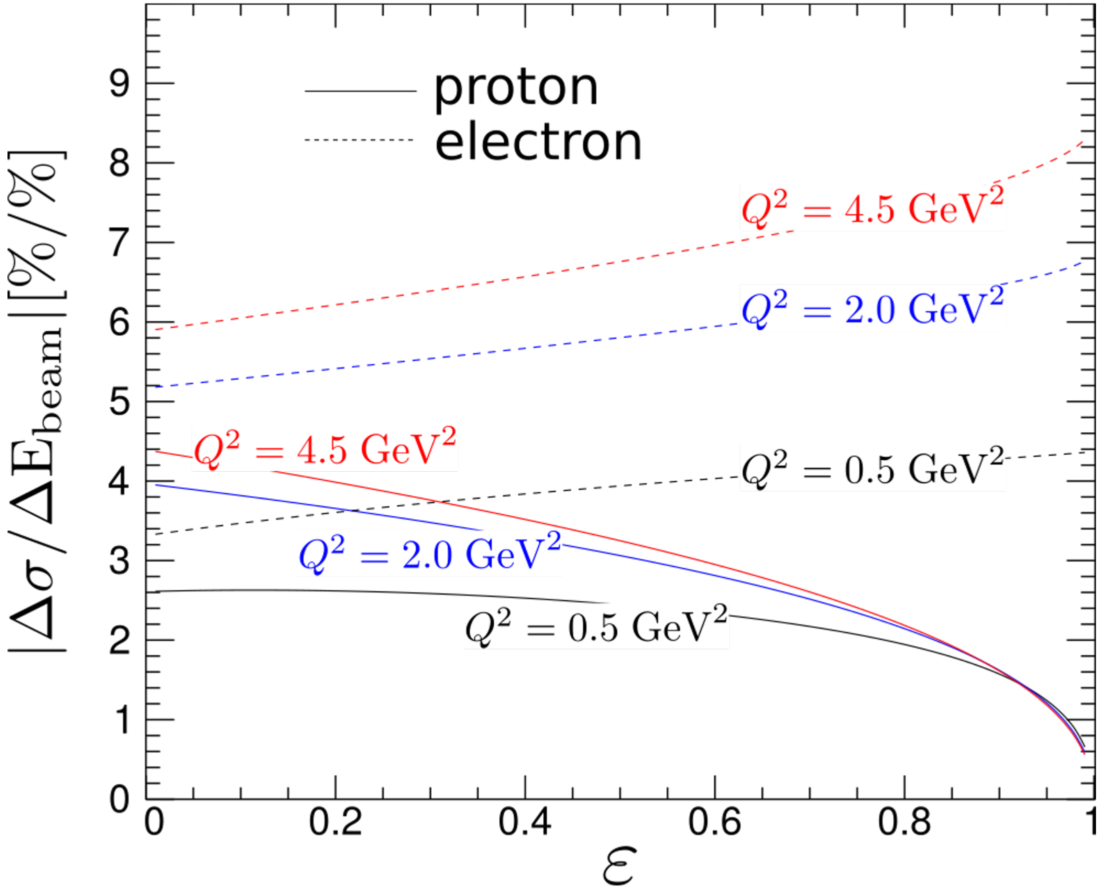
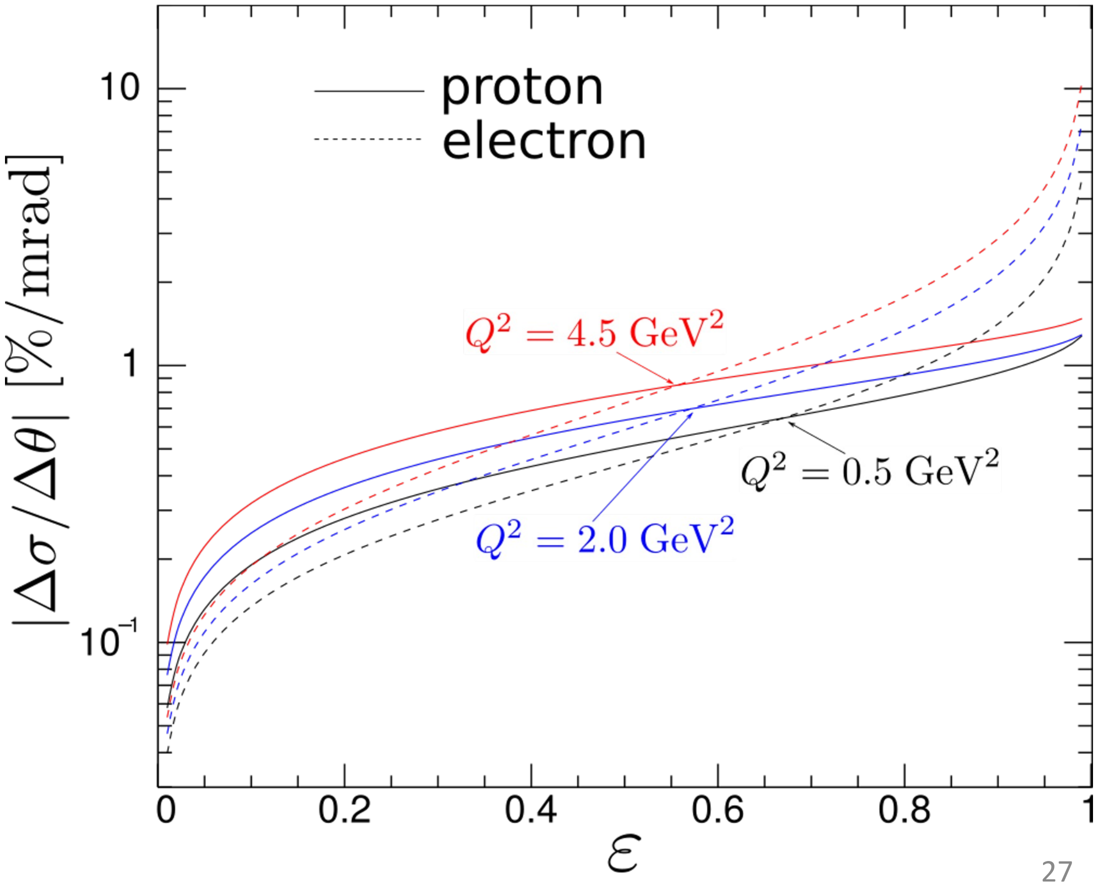




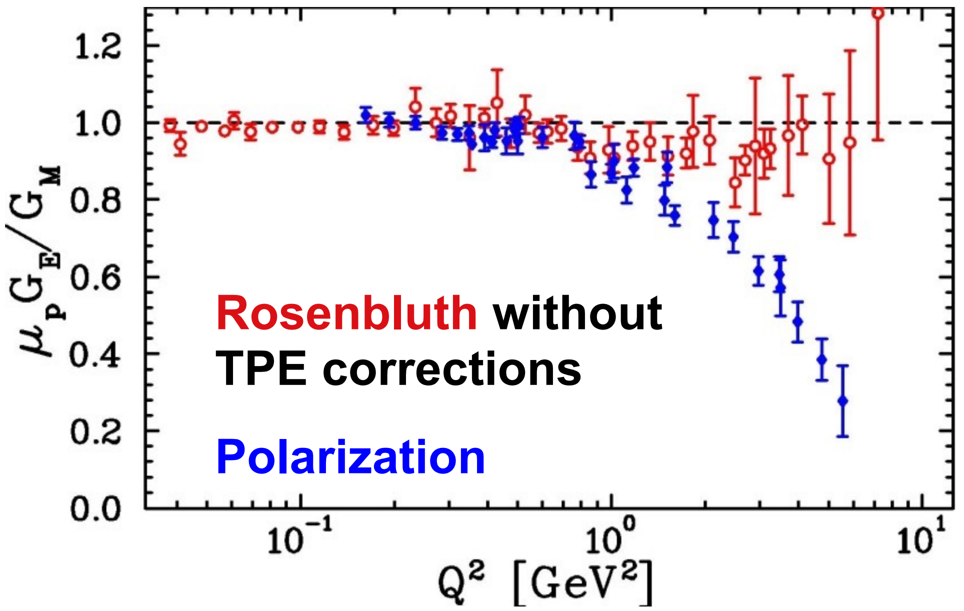
Two Photon Exchange?

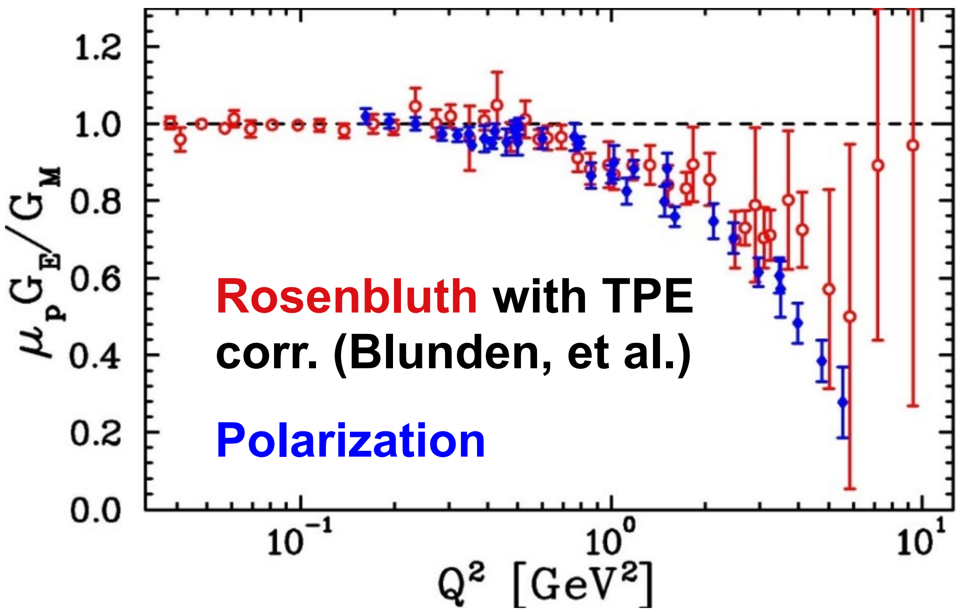
Limits set for non-linear (non-Born) contributions: *V. Tvaskis, et al., PRC 73 (2006) 025206*

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……]*

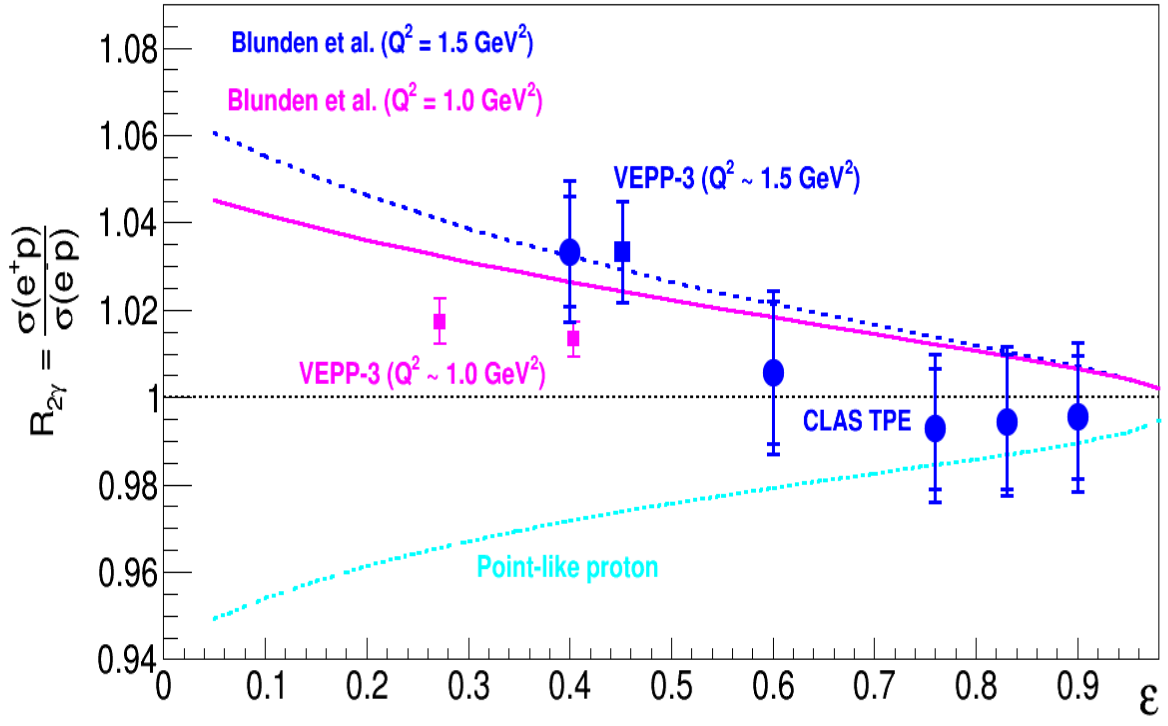




JA, W. Melnitchouk, J. Tjon, PRC 76, 035205 (2007)

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]