Measurement of the Proton Elastic Form Factor Ratio at Low Q^2

R Gilman, D Higinbotham, G Ron, with 50 colleagues

and the Hall A Collaboration

Hall A Collaboration Meeting, January 3-4, 2007

- 14-day high precision measurement of form factor ratio
- Direct measurement of nucleon structure, with implications for analysis of DVCS, and Zemach radius / hyperfine splitting

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Basic Form Factor Review

- $$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_{point}} \left[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau \tan^2\theta/2 \; G_M^2 \right] = \frac{\tau}{\epsilon(1+\tau)} \frac{d\sigma}{d\Omega_{point}} \left[\frac{\epsilon}{\tau} G_E^2 + G_M^2 \right]$$
- In NRQM, G_E and G_M are Fourier transforms of charge densities: exponential in space <==> dipole form factor has been known to be good to ~10% for ~50 years
- Many theoretical techniques/models: Vector Meson Dominance, constituent quark models, quark-meson coupling models, lattice, pQCD, ... Fits of form factors often use functional forms inspired by these models

Polarization Transfer Review

- $I_0 P_x = -2\sqrt{\tau(1+\tau)}\tan\theta/2\ G_E G_M$ $\qquad I_0 P_z = \frac{E+E'}{m}\sqrt{\tau(1+\tau)}\ G_M^2 \tan^2\theta/2$
- $R = \mu\frac{G_E}{G_M} = -\mu\frac{E+E'}{2m}\cot\theta/2\ \frac{P_x}{P_z}$
- R depends on the form factors, not their squares
- R does not depend on beam polarization, analyzing power, false asymmetries, ... or any of the usual cross section systematics (beam charge, solid angle, target density, radiative corrections, ...)
- The dominating systematic uncertainty is spin transport

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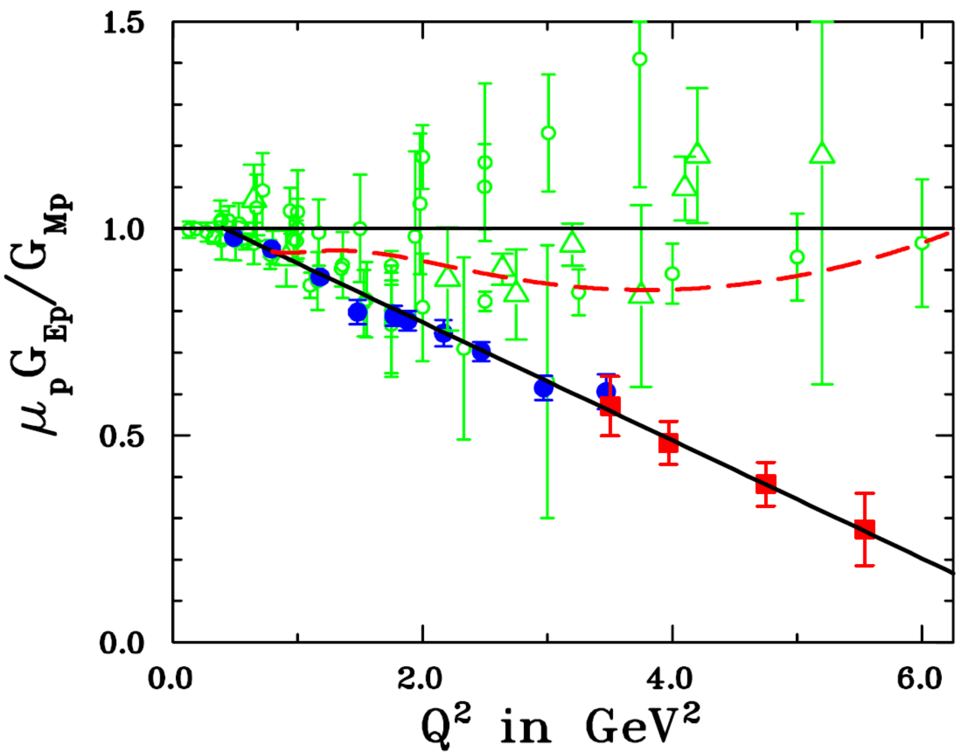
``World'' Data Overview

- Linear decrease of polarization data vs. R~1 of Rosenbluth data believed due to 2γ exchange
- Several experiments test this; our focus is the low Q^2 region
- Figure from hep-ph/0612014



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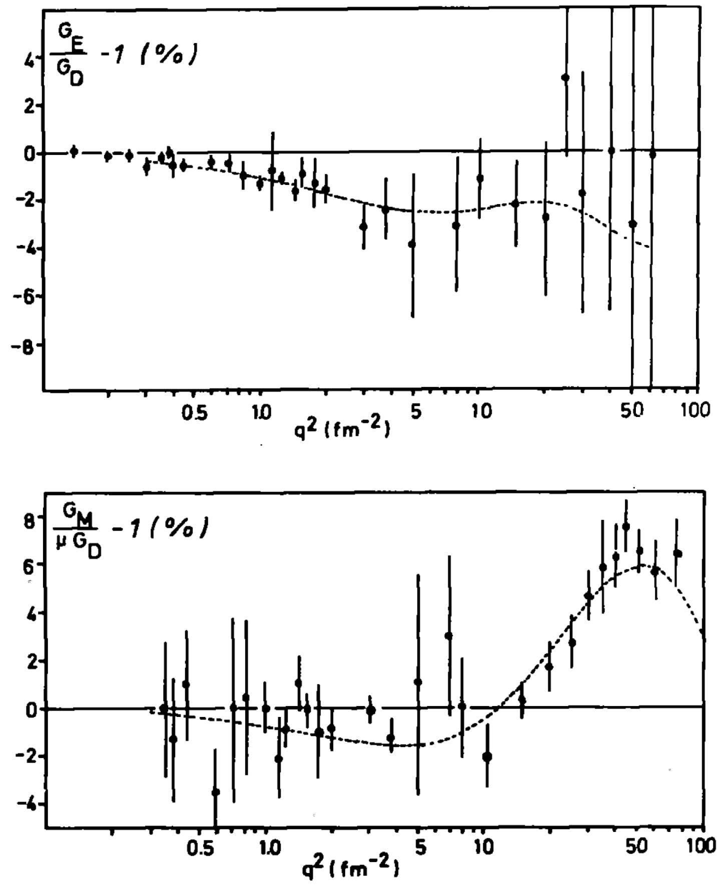
Low Q^2 History Aside

- Detailed deviations from the dipole formulas have been known since the late 1970s
- Figures from Mainz: Simon et al, NPA 333, 381 (1980)



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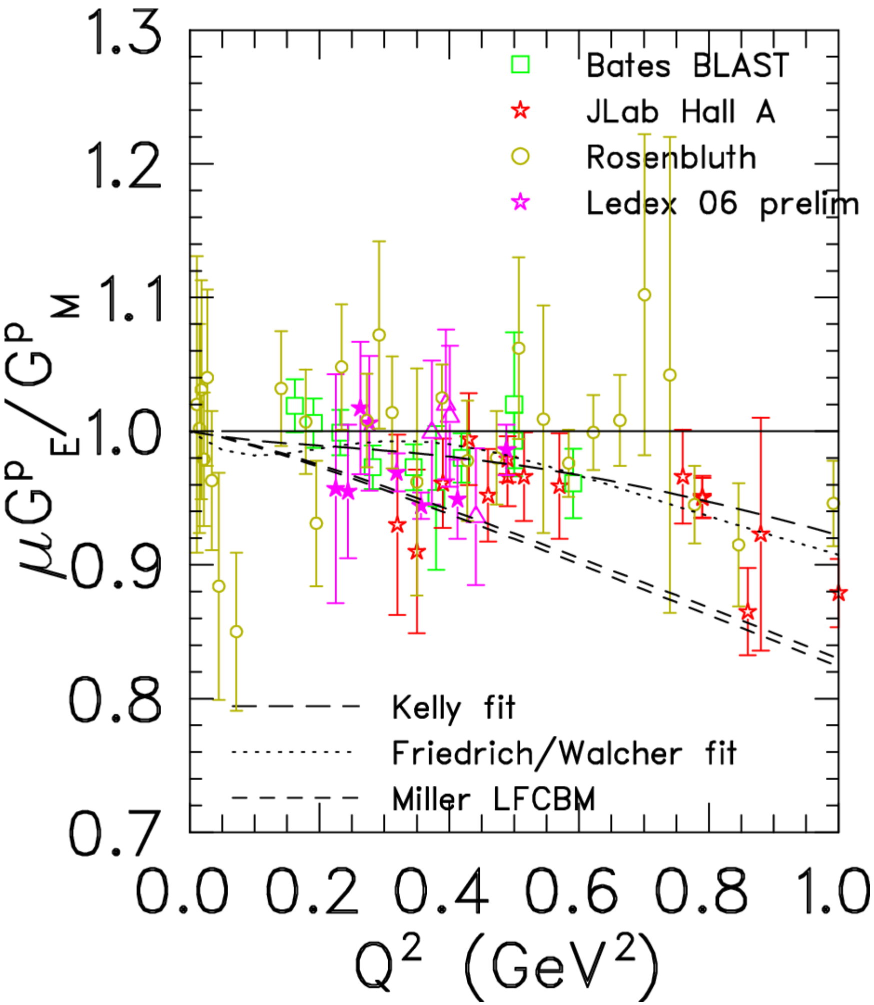
Low Q^2 ``World'' Data

- Many data sets, of varying quality
- General agreement between Rosenbluth and polarization transfer
- Detailed behavior difficult to see



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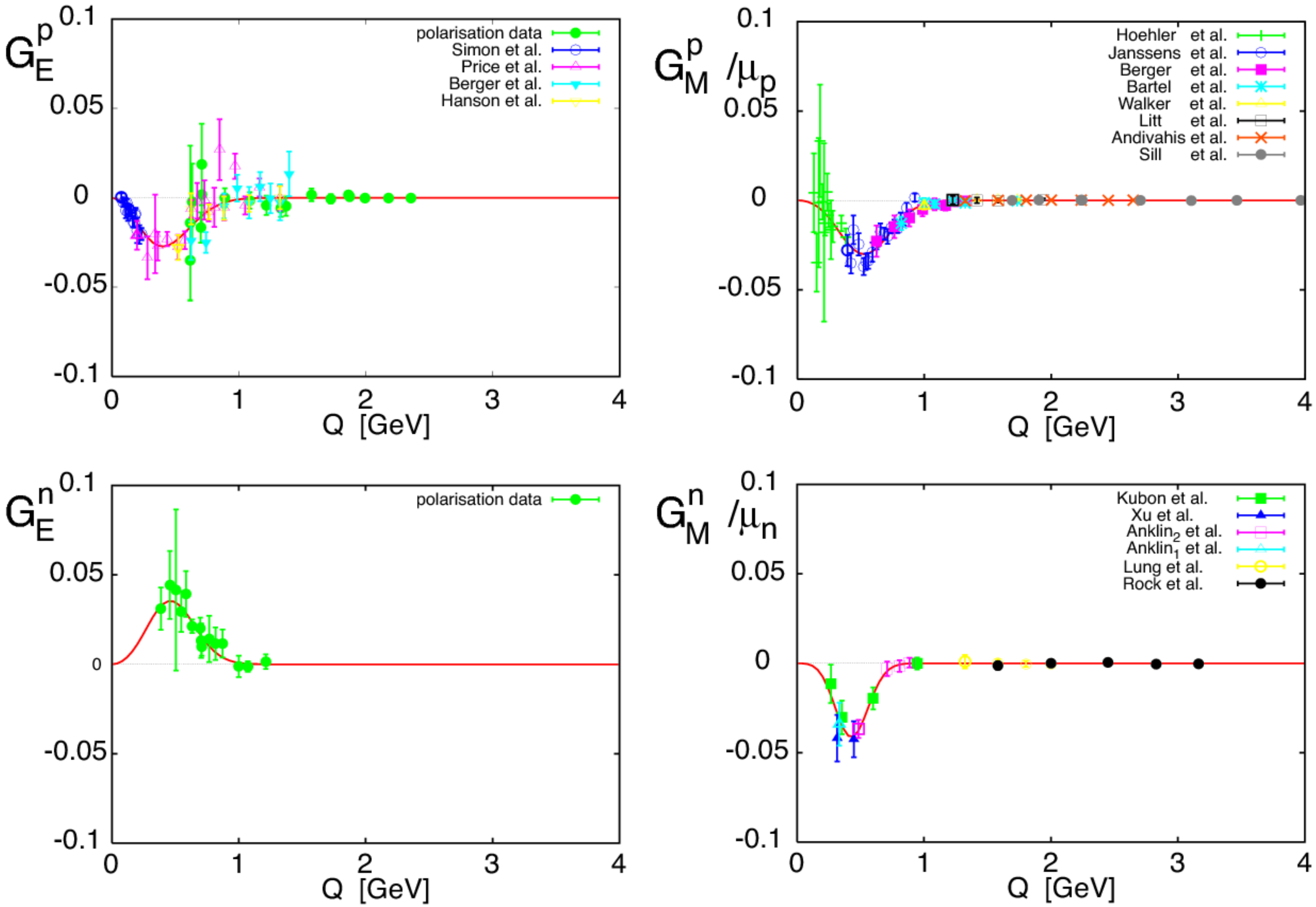
Friedrich / Walcher Fit Residuals



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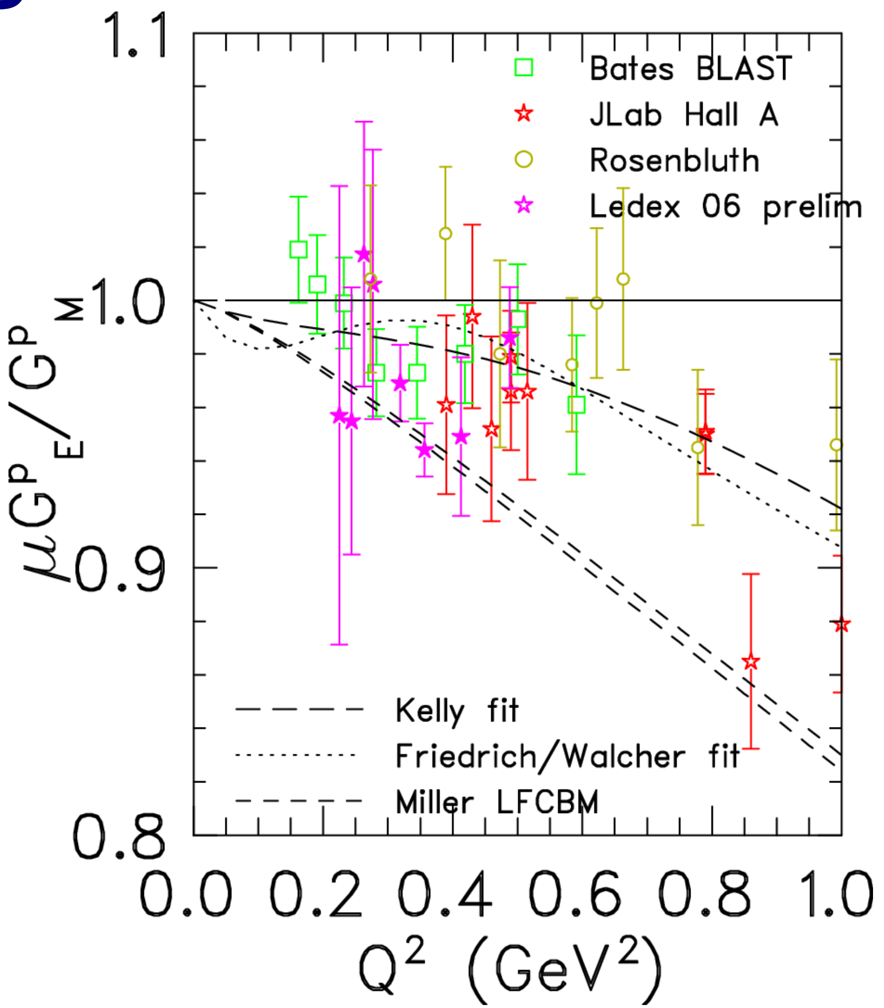
Low Q^2 - High Precision

- Only data with total uncertainties < 3.5% shown, except for LEDEX preliminary
- Bates + LEDEX give R = 0.951 ± 0.009 at Q^2 ~ 0.35 GeV^2, rising to 0.981 ± 0.010 at 0.5 GeV^2 - structure!? But not Friedrich / Walcher



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New Low Q^2 Experiments

- Suggestions, especially from Friedrich and Walcher, of low Q^2 structure has reignited interest in high precision low Q^2 experiments
- Mainz is currently running a series of ep Rosenbluth separations at several Q^2, attempting to measure 1% cross sections to determine 1% form factors
- We measured precise ep cross sections during LEDEX at 362 and 687 MeV, as part of our ed elastic experiment, E05-004
- Missing is a very precise form factor ratio

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Main Motivation Summary

- Given
  - the suggestion of low Q^2 structure
  - upcoming high precision cross sections from Mainz and LEDEX
  - the behavior of the high (but not high enough) precision polarization measurements of Bates BLAST and LEDEX
  - We conclude a new very high precision form factor ratio measurement is strongly motivated

Deeply Virtual Compton Scattering

- DVCS measurements focus on the high Q^2, small t (small $\theta_{\gamma\gamma'}$) region
- Understanding the DVCS contribution to the cross section / asymmetries relies on precise knowledge of the proton form factors at Q^2_{ep} = -t to calculate the Bethe-Heitler contribution
- Knowledge of form factors can be a limiting uncertainty, especially in kinematic regions in which BH >> DVCS (DVCS collab. interested, but supplied no estimates for any particular experiment)

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Zemach Radius: $r_z = -\frac{4}{\pi}\int_0^\infty \frac{dQ}{Q^2}\left[G_E(Q^2)\frac{G_M(Q^2)}{1+\kappa}-1\right]$

- A topic of much recent discussion:
  - FS: Friar, Sick, PLB 579, 285 (04)
  - BCHH: Brodsky, Carlson, Hiller, Hwang, PRL 94, 022001 (05)
  - NCG: Nazaryan, Carlson, Griffioen, PRL 96, 163001 (06)

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- In hydrogen atom, HF splitting known to ~ 10^{-12}
- Leading correction is: $\Delta E_Z = -2Z\alpha m r_Z E_{Fermi}$
- r_Z ~ 1 fm leads to elastic correction Δ_Z ~ 40±~1 ppm
- NCG: HF + 1.3±0.3 ppm Δ_{pol} -> -39.9±0.3 ppm Δ_Z vs:
  - FS: -41.7±0.5 ppm, Kelly fit: -41.0±0.5 ppm
  - BCHH: Arrington fit gives -39.7 / -40.8 ppm
- -> Need ~1% form factor precision over broad range

The Proposed Measurements

- Hall A FPP, E_e ~ 0.85 GeV
- Existing LEDEX data took 12-18 hours with P_e=40%, we request 1 day (2 days at 0.25 GeV^2) with P_e=80%
- Systematics ~ 0.4% at 0.5 GeV^2, better at low Q^2

Q^2 (GeV^2)	ΔR/R (%)
0.25	1.00
0.3	0.73
0.35	0.46
0.4	0.32
0.45	0.28
0.5	0.37
0.55	0.34
0.6	0.32
0.7	0.52

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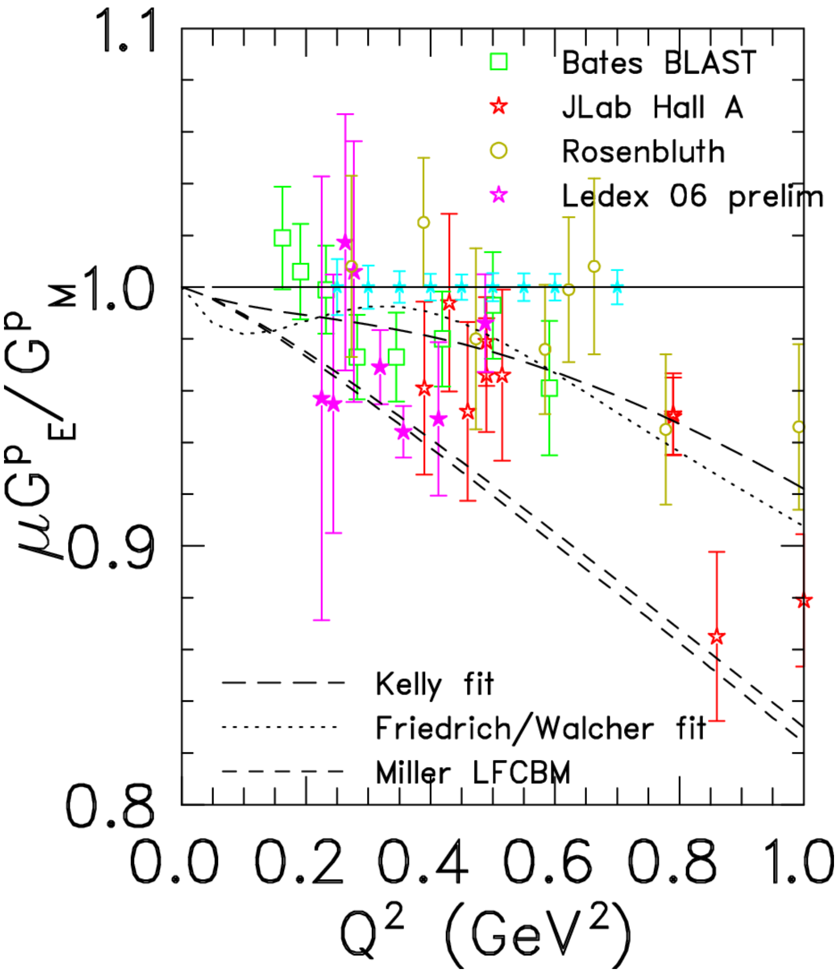
The Proposed Measurements

- Expected results with total uncertainties
- Might adjust Q^2's to match Mainz/LEDEX cross sections



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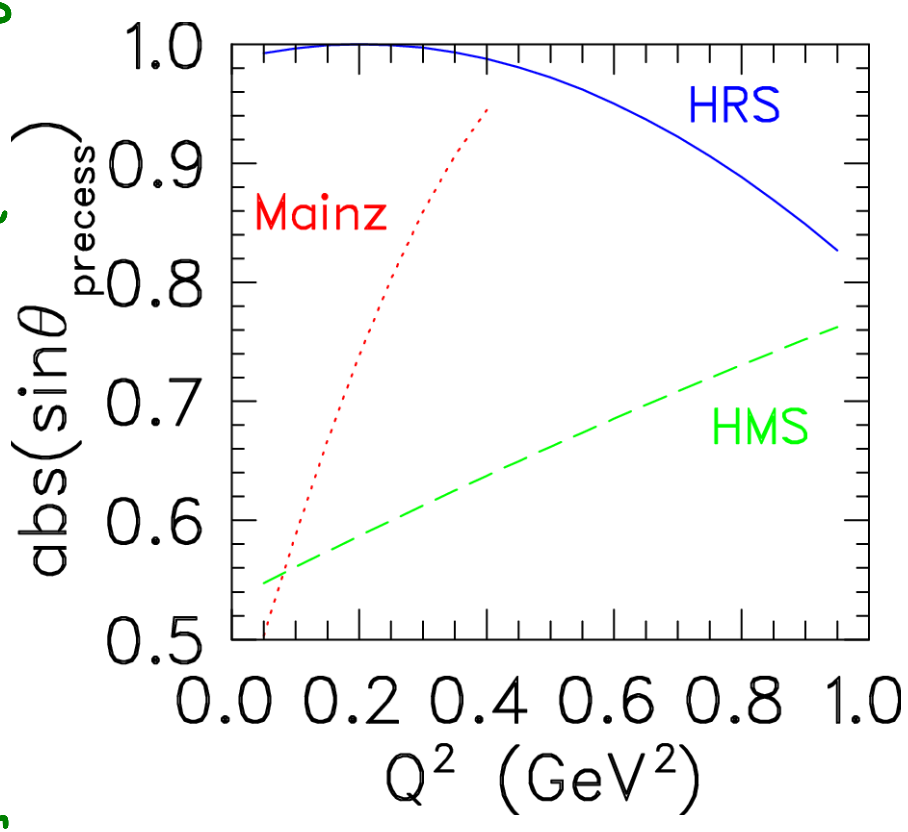
Could This Be Done Elsewhere?

- Our proposed uncertainties on R are 0.5% - 1.1%
- Mainz cross sections give ~ 1.4%
- Mainz FPP systematics ~ 4%
- Spin transport favors Hall A; ultimate systematics for Hall C HMS are unclear



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Checks of Systematics

- Measurements with quadrupoles turned off
- Measurement of R at $Q^2 \sim 2.2$ GeV^2, in the ``spin hole''; variation of spin direction in focal plane very sensitive to spin transport here
- Done previously with HRS-R for G_E^p-I; never done for HRS-L – since we request very high precision measurements, we plan to redo these tests
- Also considering methods to decrease the systematic uncertainties

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Summary

- We request 14 days for a very high precision, low Q^2 measurement of the proton form factor ratio
- Implications for nucleon structure:
  - structure (pion cloud?) vs. smooth fall-off
  - Zemach radius
  - ultimate DVCS uncertainties

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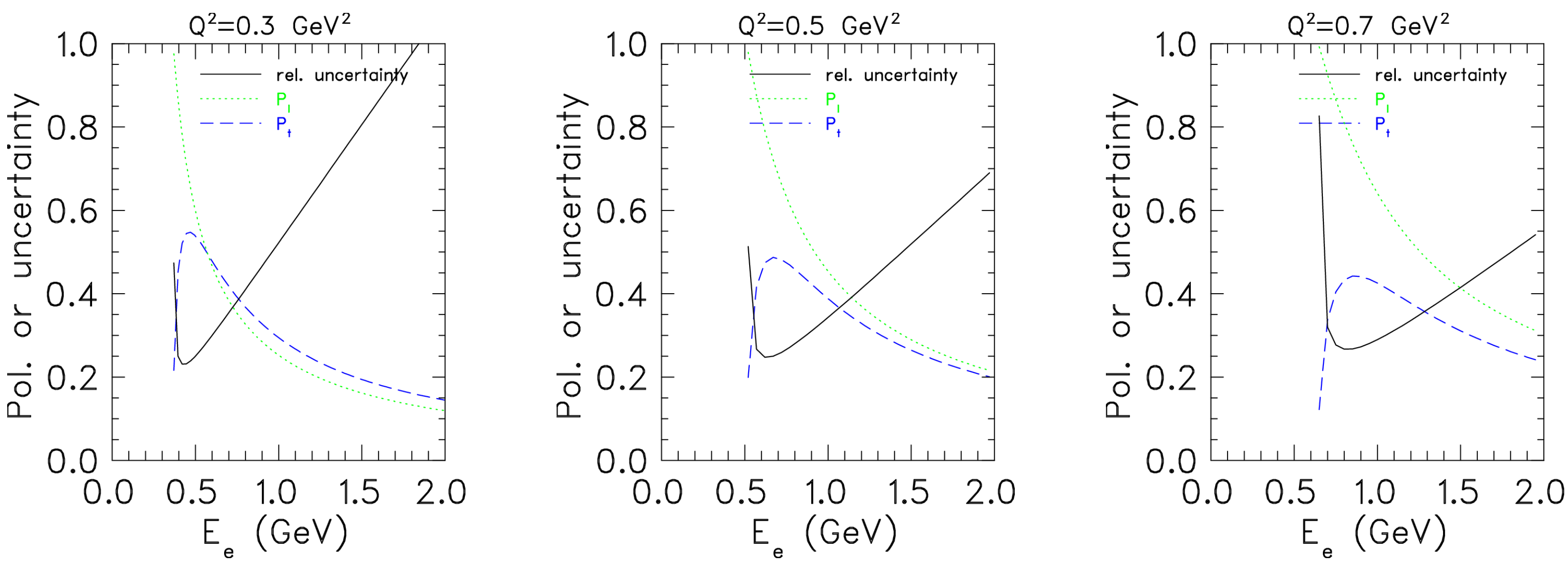
Backup: What is optimal E_e?

- Optimal energy depends on Q^2, ~ 400 - 800 MeV



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