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# The experimental study of nucleon form factors

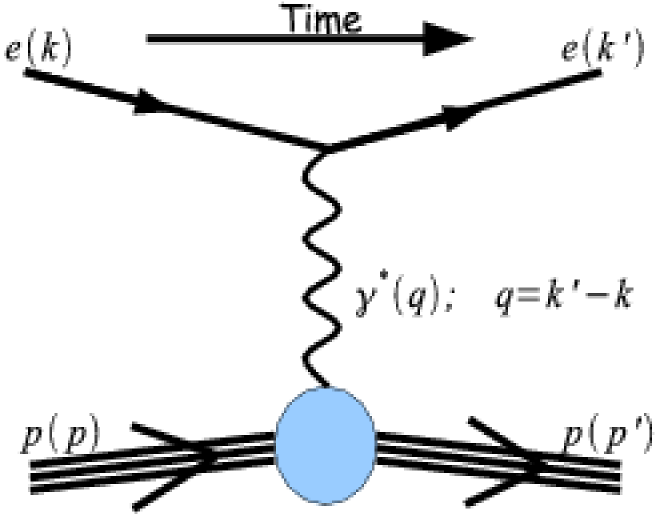
R. Gilman, Rutgers University

*Lattice QCD and Experiment:*
*Revealing the Structure of Hadrons*
Jefferson Lab
21-22 November 2008

# The Experimental Study of Nucleon Form Factors

- Ground Rules
  - Since this is the first form factor talk, to a knowledgable audience, I will go quickly over the usual introductory material, but quickly
  - Bias towards space-like form factors, measured at JLab
  - Largely ignore 2$\gamma$ exchange, theories/fits/interpretations
- Basics and Techniques
- Existing Data
- Expected Data
- Summary

# Basics: EM Current



- Simple leading-order picture
- Spin-½ proton 2s+1=2 terms in its EM current
- Form factors (FF) are the $Q^2$-dependent coefficients that describe the internal structure of the proton

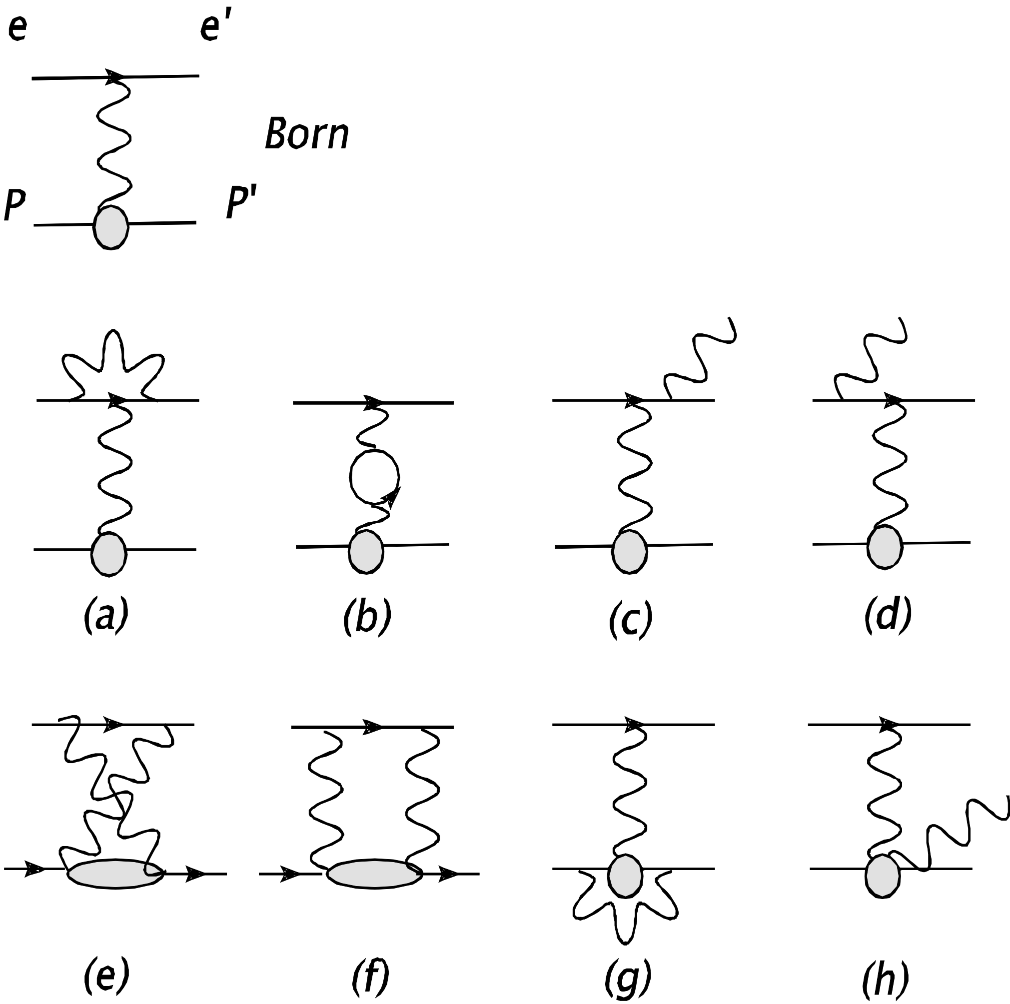
EM currents are:

$$J_e^\mu = \bar{u}(p)[\gamma^\mu]u(p)$$

$$J_p^\mu = \bar{u}(p)[F_1(Q^2)\gamma^\mu + i\frac{\kappa}{2M}F_2(Q^2)\sigma^{\mu\nu}q_\nu]u(p)$$

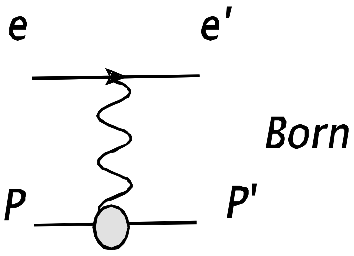
# Basics: Problem with 1γ Exchange Picture

- EM coupling is too strong: radiative corrections
- (c) and (d) off other target nucleons as well
- Two γ exchange, (e)+(f), responsible for Rosenbluth / polarization disagreement
- "Coulomb correction": beam electron accelerated by 1/r potential inside atomic e

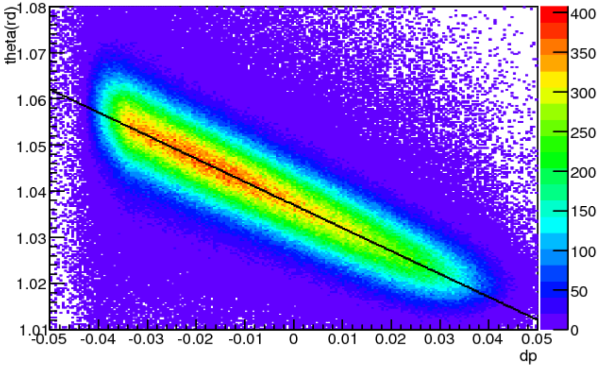


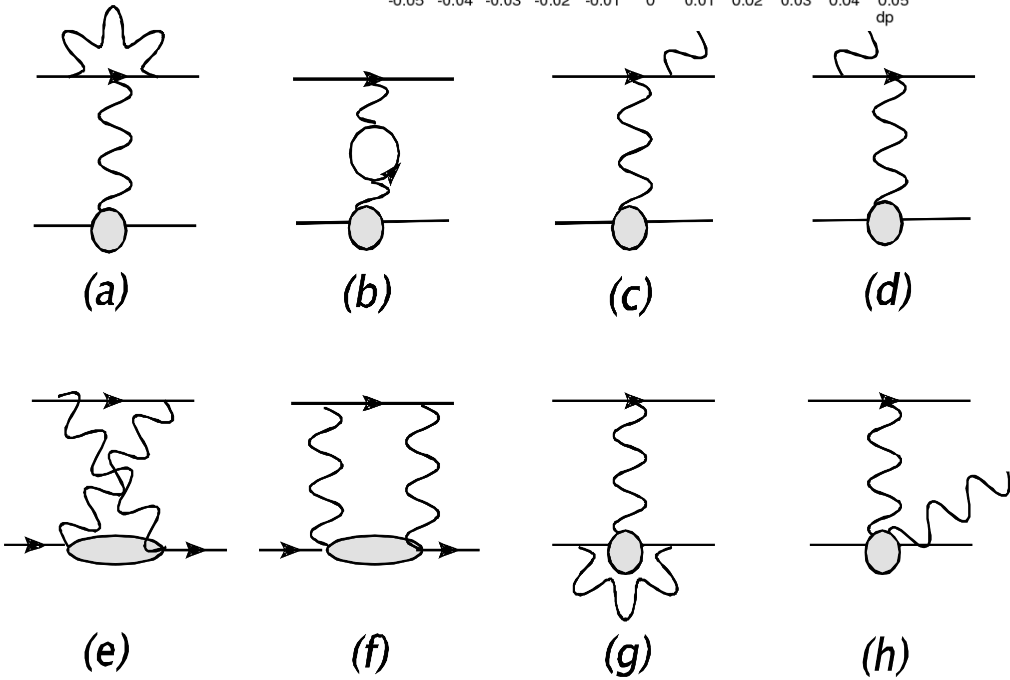
# Basics: Problem with 1γ Exchange Picture

- Corrections depend on kinematics, acceptance
- Cross section experiments do standard “Mo + Tsai” corrections, but watch out for old data
- Two γ exchange, (e)+(f), under active investigation
- For more, try http://www.jlab.org/RC/ or talk with Andrei Afanasev



(Xiaohui Zhan et al.)





# Basics: choice of FF

- Two common choices of FF:
  - Helicity conserving $F_1$ Dirac and helicity non-conserving $F_2$ Pauli FF provide a simpler current for theorists
  - Sachs electric $G_E$ and magnetic $G_M$ FF provide simpler cross section expressions, and a misleading interpretation, for experimentalists

$$J_p^\mu = \bar{u}(p)[F_1(Q^2)\gamma^\mu + i\frac{\kappa}{2M}F_2(Q^2)\sigma^{\mu\nu}q_\nu]u(p)$$

$$G_E = F_1 - \tau\kappa F_2 \qquad G_M = F_1 + \kappa F_2$$

$$F_1 = \frac{G_E + \tau G_M}{1+\tau} \qquad F_2 = \frac{G_M - G_E}{\kappa(1+\tau)}$$

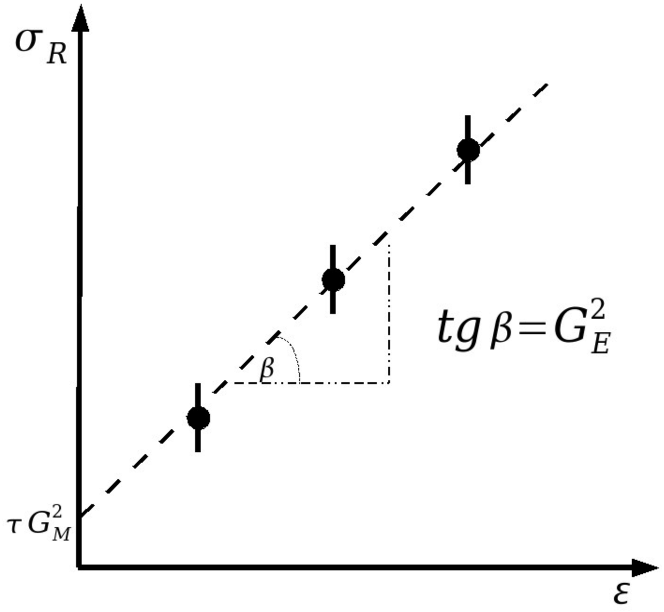
$$\sigma_R \equiv \epsilon(1+\tau)\frac{\frac{d\sigma}{d\Omega}}{\frac{d\sigma_{Mott}}{d\Omega}} = \epsilon G_{Ep}^2(Q^2) + \tau G_{Mp}^2(Q^2)$$

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

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

# Basics: Extracting FF from cross section

- FF can be determined from cross sections in model dependent or model-independent ways
  - Choose functional form for FF and fit data
  - Use Rosenbluth technique on cross sections: measure different combinations of E, θ that give the same $Q^2$ but different ε



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# Basics: Extracting FF from cross section

- FF can b
  sections
  indepen
  - Choo
    fit d
  - Use
    sect
    combinations of F … at give the
    same $Q^2$ but differ … ε

- Small FF hard to extract:
  - Either if relatively small ($G_E^n$ at small $Q^2$)
  - $G_E$ at large $Q^2$
  - $G_M$ at low $Q^2$, except at 180°

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

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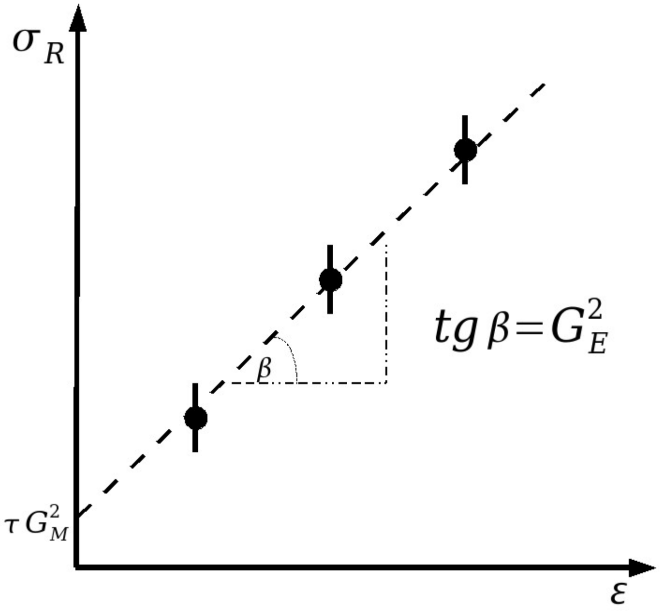


# Basics: Extracting FF from “polarizations”

- Double-polarization observables depend on ratios of the EM FF, allowing a small FF to be determined from polarizations and measured cross sections
  - Polarized beam + recoil proton polarization determined by polarimeter (FPP)
    - High luminosity, but FPP eA^2 ~ 0.01
  - Polarized beam + polarized target asymmetry
    - Low luminosity, dilution factors
- Proposed by Akhiezer et al., 1950s and 1960s, repopularized by Arnold, Carlson, and Gross in 1980s
- First double-polarization FF experiments at Bates and Mainz ~ 1990

# Polarization Transfer

$$I_0 P_x = -2\sqrt{\tau(1+\tau)}\tan\left(\frac{\theta_e}{2}\right) G_E^p G_M^p$$

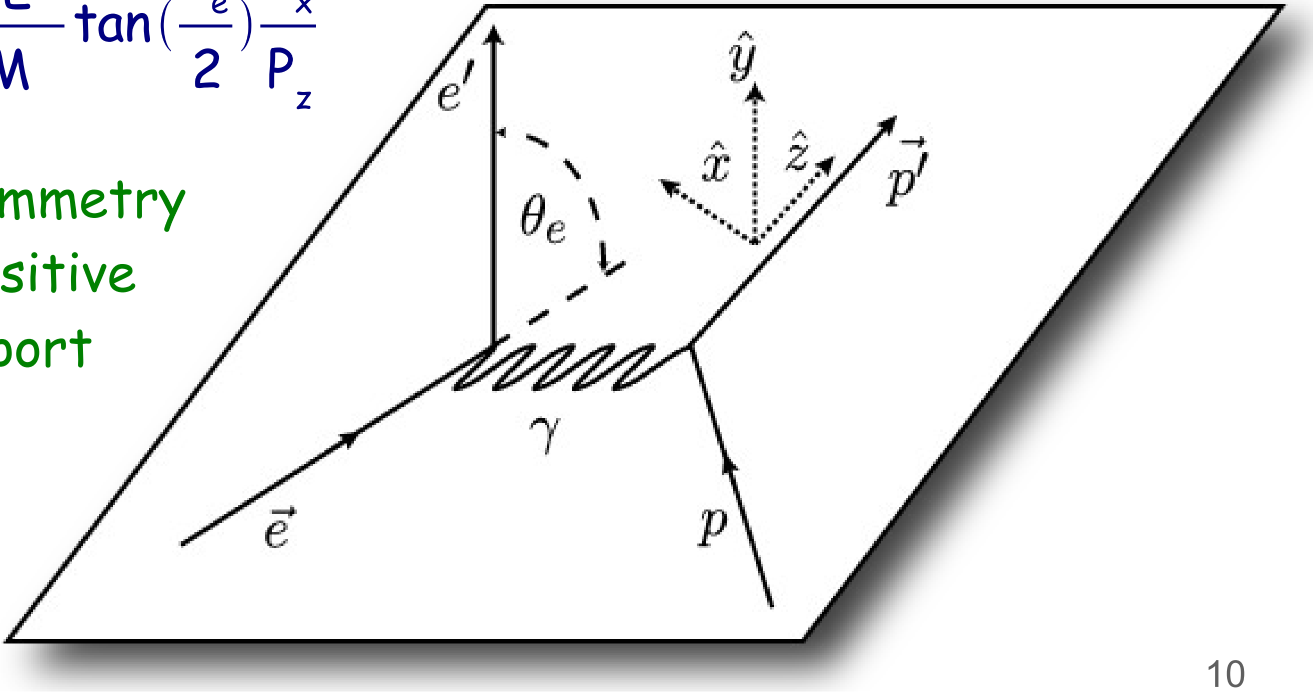
$$I_0 P_z = \frac{E+E'}{M}\sqrt{\tau(1+\tau)}\tan^2\left(\frac{\theta_e}{2}\right) G_{Mp}^2$$

$$I_0 = G_E^2 + \frac{\tau}{\epsilon} G_M^2$$

Py: induced from (imaginary part of) 2γ exchange, small and hard to measure

$$R = \mu_p \frac{G_{Ep}}{G_{Mp}} = -\mu_p \frac{E+E'}{2M}\tan\left(\frac{\theta_e}{2}\right)\frac{P_x}{P_z}$$

FPP azimuthal asymmetry determines R, sensitive only to spin transport



# Polarization Transfer

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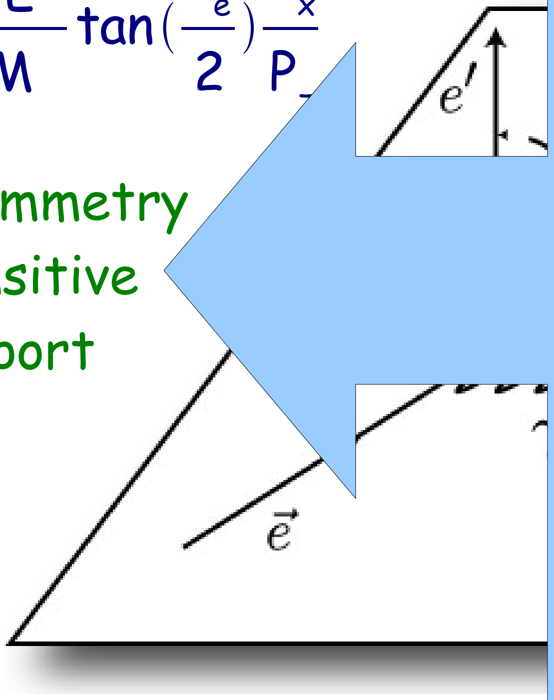

Insensitive to: spectrometer solid angle, target density, trigger and detector efficiencies, beam charge, charge asymmetry, normal radiative corrections, false asymmetries in FPP.

These might affect statistics and size of uncertainty, but not value of data point.

# Polarization Transfer

$$I_0 P_x = -2\sqrt{\tau(1+\tau)}\tan\left(\frac{\theta_e}{2}\right) G_E^p G_M^p$$

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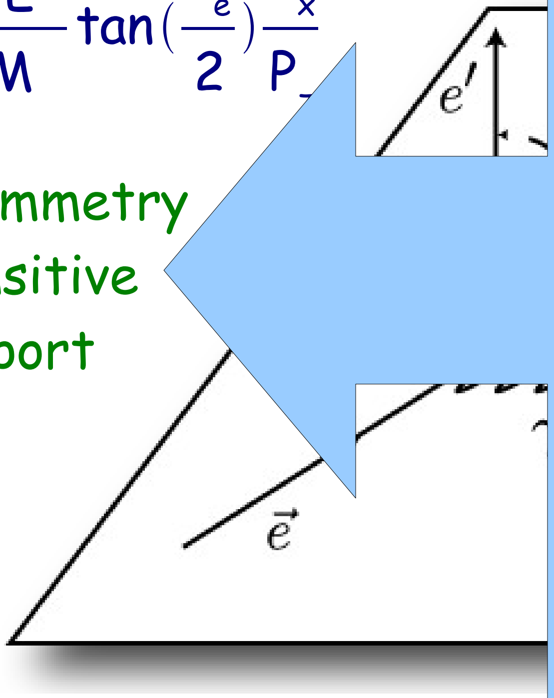
Py: induced from (imaginary part of) 2γ exchange, small

Minimal sensitivity to helicity-correlated asymmetries (beam energy, position, angle) and box/cross 2γ radiative corrections.

We measure "%" asymmetries, not ppm.

FPP azimuthal asymmetry determines R, sensitive only to spin transport



# Polarization Transfer: naïve analysis

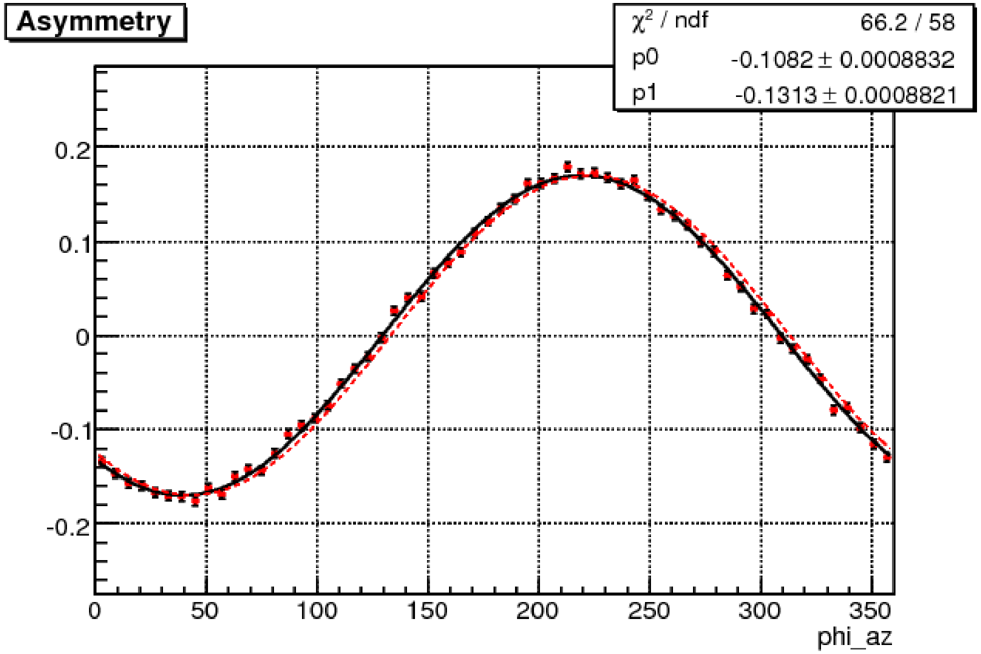
FPP azimuthal asymmetry phase shift determines R, magnitude determines product $P_e A_c$

$$A_{FPP} = \frac{A_c}{\pi} \sqrt{P^2_{x\,FP} + P^2_{y\,FP}}$$

$$\tan\delta = \frac{P_{y\,FP}}{P_{x\,FP}}$$

$$\begin{pmatrix} P_{x\,FP} \\ P_{y\,FP} \end{pmatrix} = \begin{pmatrix} S_{xy} & S_{xz} \\ S_{yy} & S_{yz} \end{pmatrix} \begin{pmatrix} P_{y\,TG} \\ P_{z\,TG} \end{pmatrix}$$

(transport coordinates)



(Xiaohui Zhan et al.)

In practice, use COSY for optics, generate matrix elements for each event, maximum likelihood analysis determines target polarizations

# Polarization Transfer: neutrons

Nucleon polarimeters measure transverse, not longitudinal, spin components through the σ •L spin-orbit force

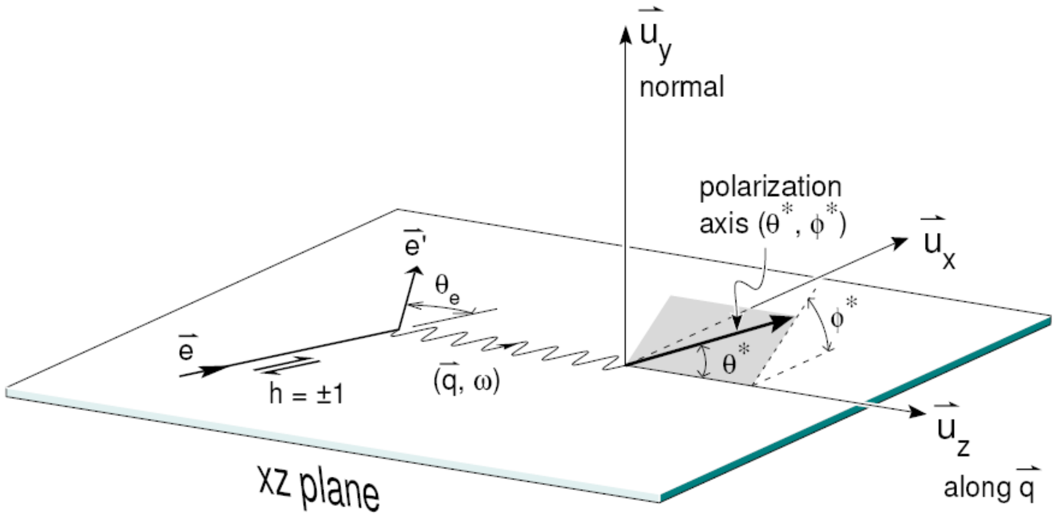
For protons, being bent in the spectrometer magnetic field leads to spin precession, mixing the spin components and allowing both to be measured at the same time – for planar trajectories:

$$\chi_{\text{precess}} = \frac{g-2}{2} \gamma \theta_{\text{bend}}$$

The neutron spin can be precessed in a magnetic field so that the longitudinal spin rotates to transverse. Two different precession angles allow the ratio of form factors to be determined.

# Polarized Beam & Target Asymmetry

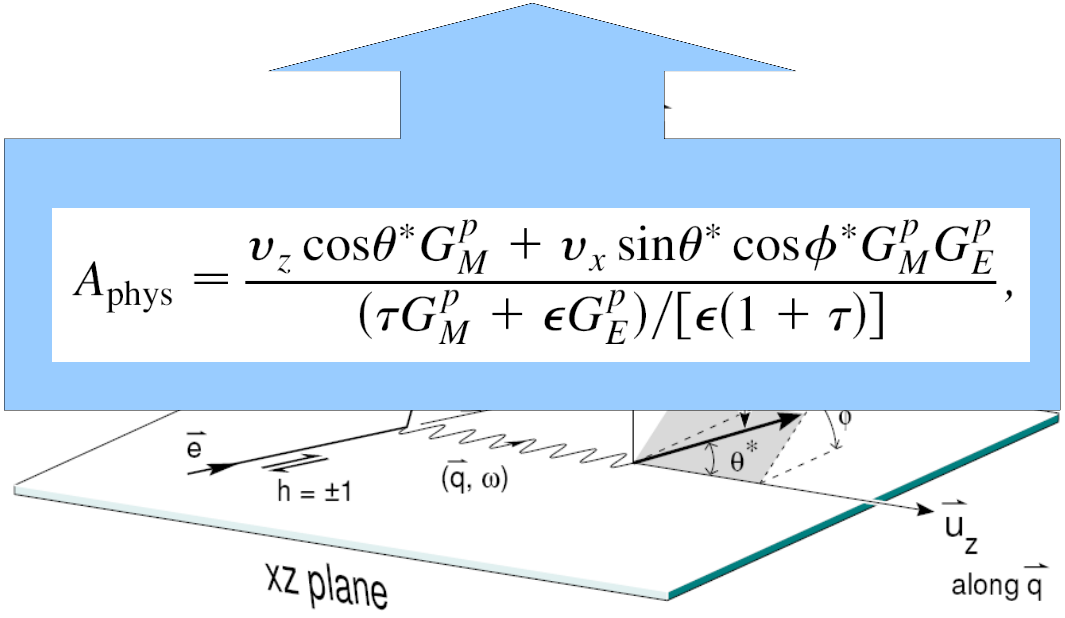
$$A_{phys} = \frac{v_z \cos\theta' G_M^2 + v_x \sin\theta' \cos\phi' G_E G_M}{(\epsilon G_{Ep}^2 + \tau G_{Mp}^2)/[\epsilon(1+\tau)]}$$



- Following notation of Crawford et al, BLAST article, PRL98 – but note typos in their formula (e.g., $G_E$, not $G_E^2$)
- Measuring with two sectors at the same time allowed determination of both $R = \mu_p G_E/G_M$ and of the product $P_{beam} P_{target}$

# Polarized Beam & Target Asymmetry

$$A_{phys} = \frac{v_z \cos\theta' G_M^2 + v_x \sin\theta' \cos\phi' G_E G_M}{(\epsilon G_{Ep}^2 + \tau G_{Mp}^2)/[\epsilon(1+\tau)]}$$



$$A_{\text{phys}} = \frac{v_z \cos\theta^* G_M^p + v_x \sin\theta^* \cos\phi^* G_M^p G_E^p}{(\tau G_M^p + \epsilon G_E^p)/[\epsilon(1+\tau)]},$$

- Following notation of Crawford et al, BLAST article, PRL98 – but note typos in their formula (e.g., $G_E$, not $G_E^2$)
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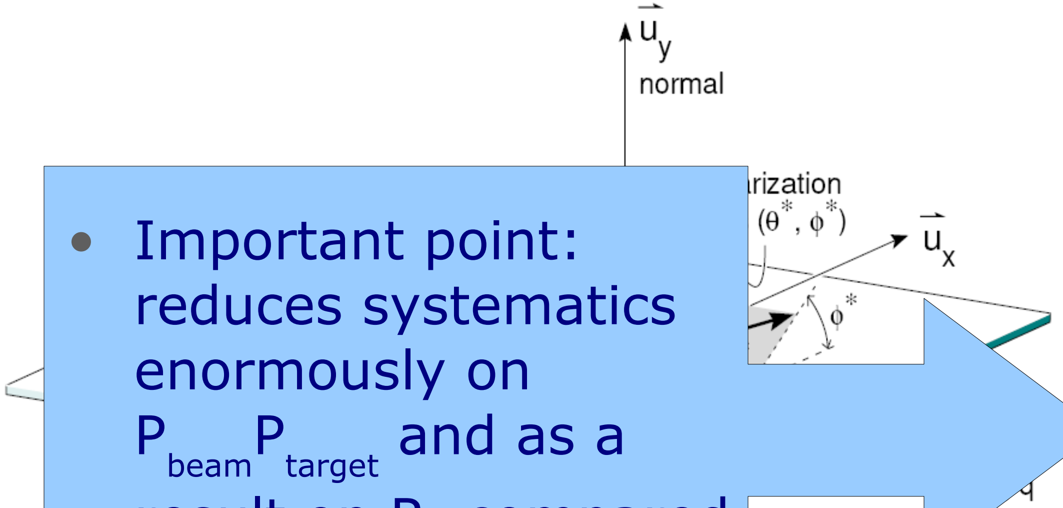


- Important point: reduces systematics enormously on $P_{beam}P_{target}$ and as a result on R, compared with sequential measurements

- Following notation of Crawford et al, BLAST article, PRL98 – but note typos in their formula (e.g., $G_E$, not $G_E{}^2$)
- Measuring with two sectors at the same time allowed determination of both $R = \mu_p G_E/G_M$ and of the product $P_{beam}P_{target}$

# Data – recent and future improvements

- Proton:
  - High precision ep cross sections (Mainz, JLab)
  - Multianalyzer FPP systems to improve FOM
- Neutron:
  - High precision en cross sections from precise neutron detector calibrations from, e.g., in situ ratio techniques
  - Improved polarized $^3$He targets:
    - Polarization up from ~40% to 75% in Hall A “today” from narrow bandwidth COMET lasers
    - Improved polarization rate through two-tube flow-through, vs one-tube diffusion, geometry
    - Two orders of magnitude improvement of a few years ago!

# Data – John Arrington's ep Database

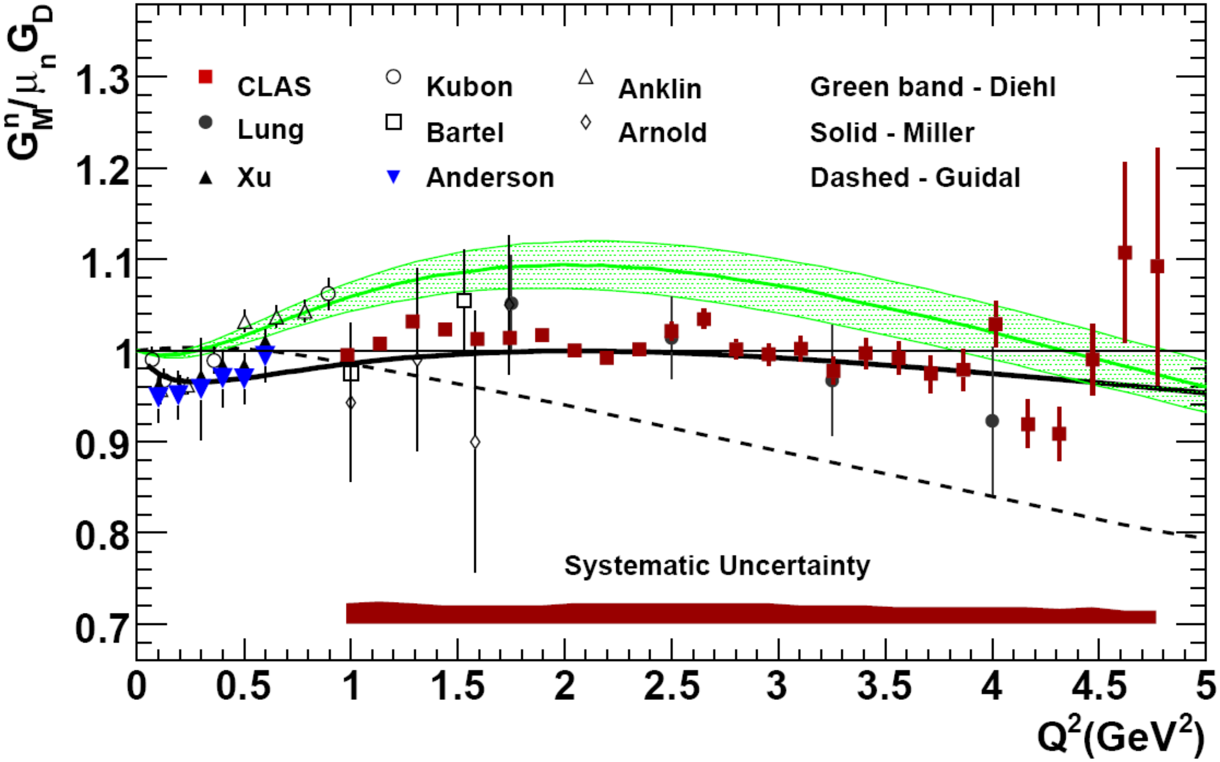
- http://www.jlab.org/resdata/
  - elastic e-p cross sections, used in the global fit of Phys.Rev.C68:034325(2003) [arXiv:nucl-ex/0305009]
  - elastic e-p cross sections, used in the global fit of Phys.Rev.C69:022201(R)(2003) [arXiv:nucl-ex/0309011]

# Current / Recent and Expected Data

- $G_M^n$:
  - Quasifree ed – ep folded with QF
  - Quasifree (e,e') with pol. beam – pol. target (low $Q^2$)
  - Quasifree (e,e'n) (all $Q^2$)
- $G_E^n$:
  - Quasifree $^3$He(e,e'n) pol. Beam – pol. target + cross section
  - Quasifree d(e,e'n) pol. transfer + cross section
- $G_M^p$: ep cross section
- $G_E^p$: ep polarization transfer + cross section

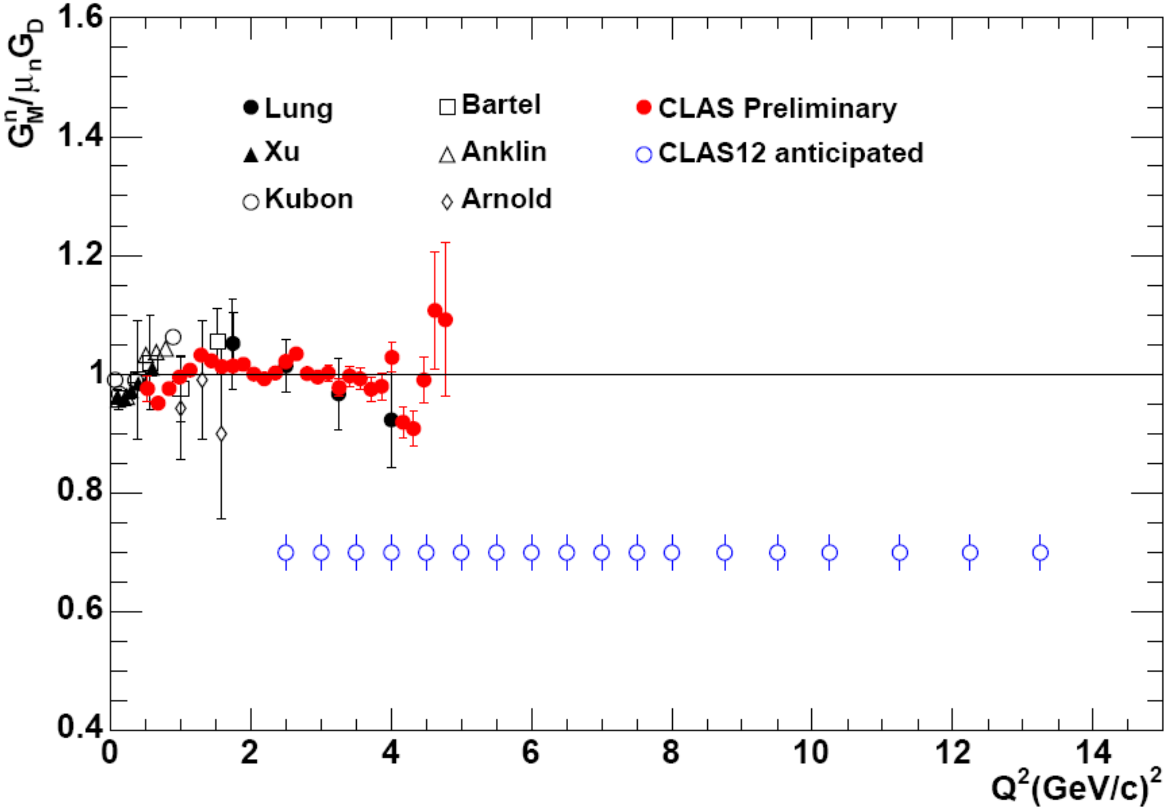
# $G_M^n$: CLAS E94-017

- J. Lachniet et al., submitted to PRL, arxiv/nucl-ex/0811.1716
- Data reported for $Q^2$ = 1 - 4.8 $GeV^2$
- Dual $^{1,2}$H targets for neutron efficiency calibration and ratio
- Data agree well with Miller LF quark model, but with either Diehl or Guidal GPD models fit to existing data



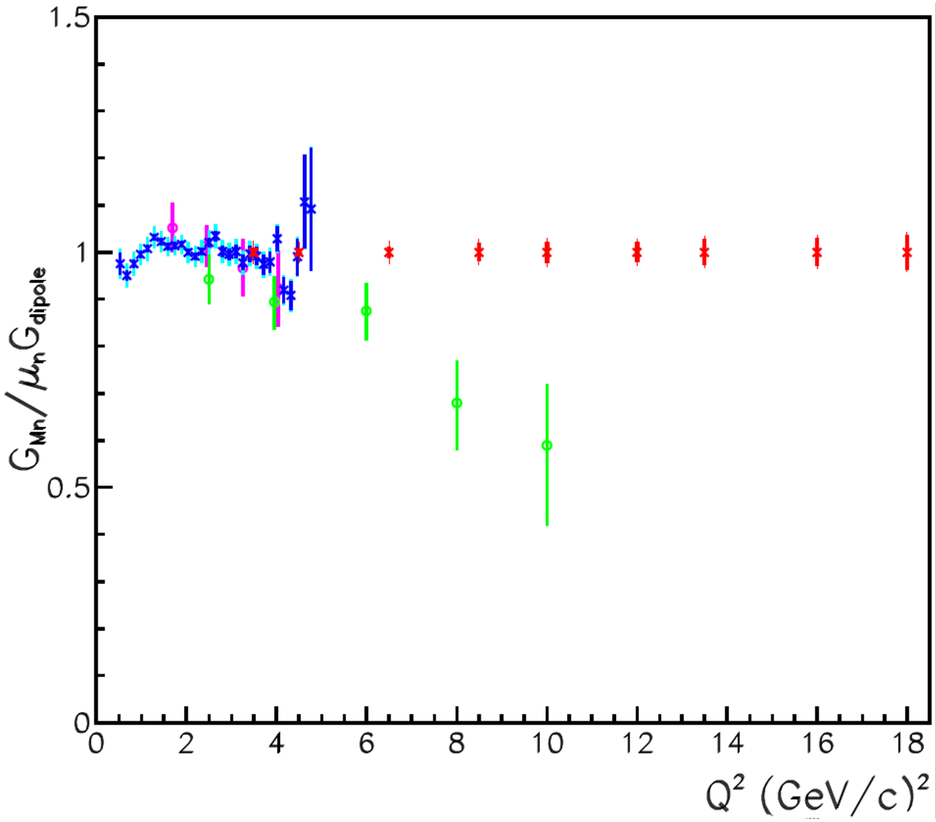
# $G_M^n$: CLAS E12-07-104

- G. Gilfoyle et al.
- Same technique as E94-017, enhanced by CLAS 12 GeV upgrade



# $G_M^n$: Hall A PAC34 PR12-09-0xx

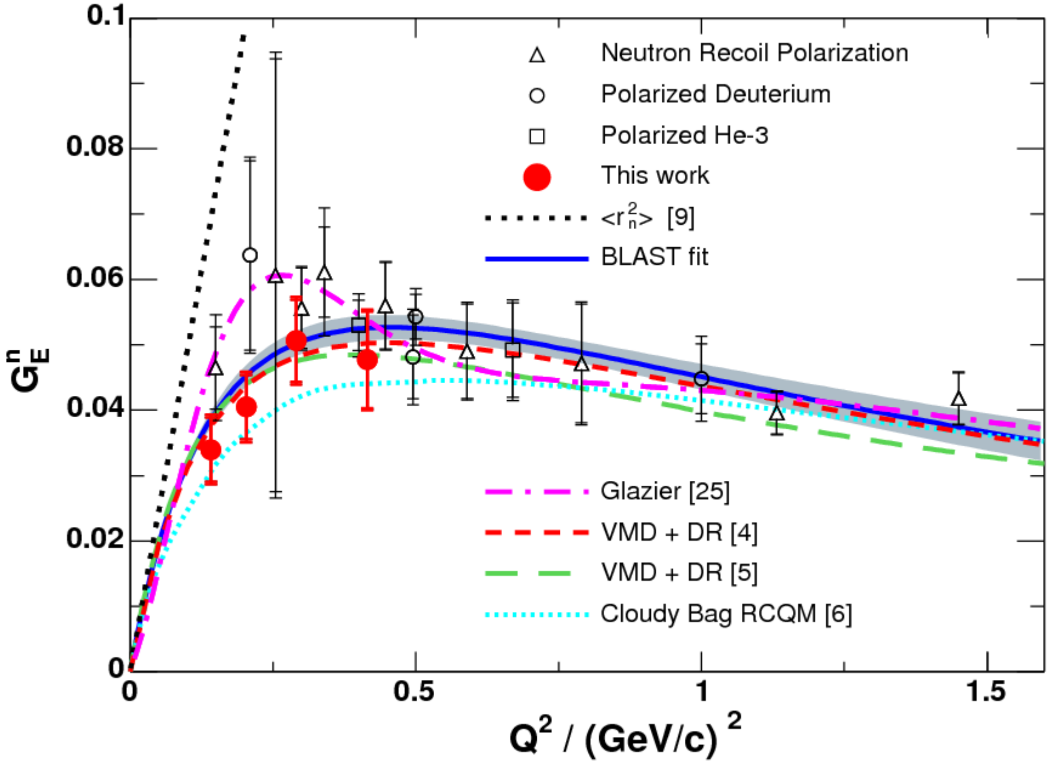
- B. Quinn et al., new proposal to upcoming PAC 34
- New proposal using neutron detector + Super Bigbite Spectrometer
- Pushes $Q^2$ up to 18 $GeV^2$, vs ~13 $GeV^2$ of approved CLAS E12-07-104



# $G_E^n$: existing data

- Latest results from MIT Bates BLAST, E Geis et al., PRL 101, 042501 (2008)

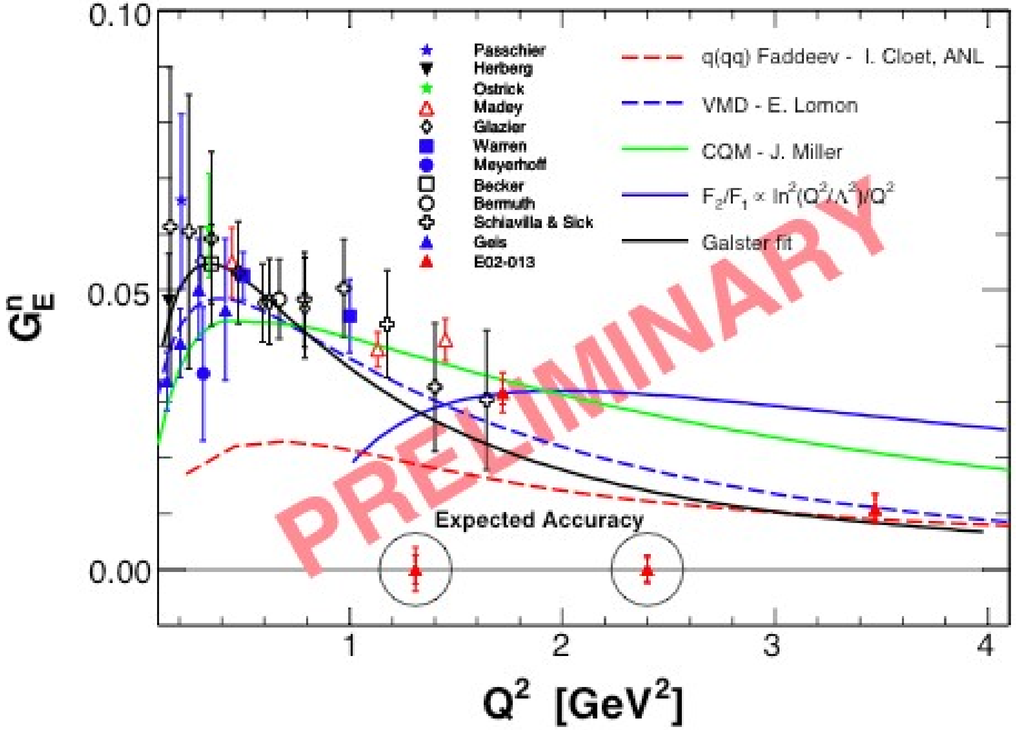
- No need for a bump in low $Q^2$ $G_E^n$
- Lomon VMD better than Miller RCQM at low $Q^2$ or Belushkin VMD at moderate $Q^2$



# $G_E^n$: Hall A E02-013

- Wojtsekhowski, Cates, et al.
- Pol. $^3$He(e,e'n), Bigbite for e' + BigHand for n

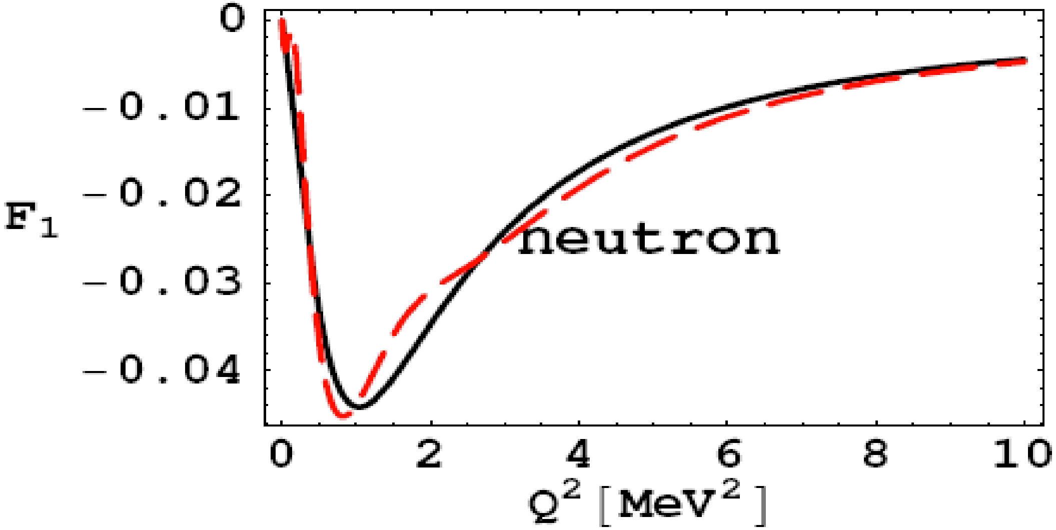
- Highest $Q^2$ $G_E^n$ to date
- With pol $^3$He target improvements, new PAC34 proposal to go to ~ 10 GeV$^2$

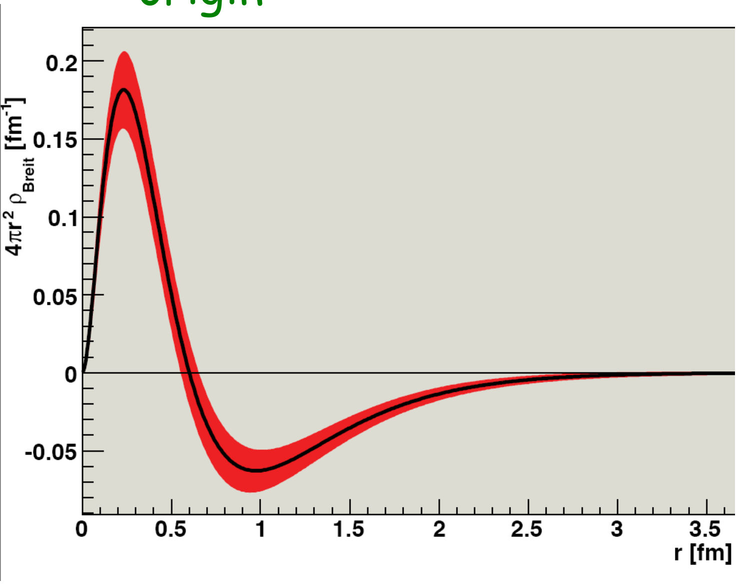


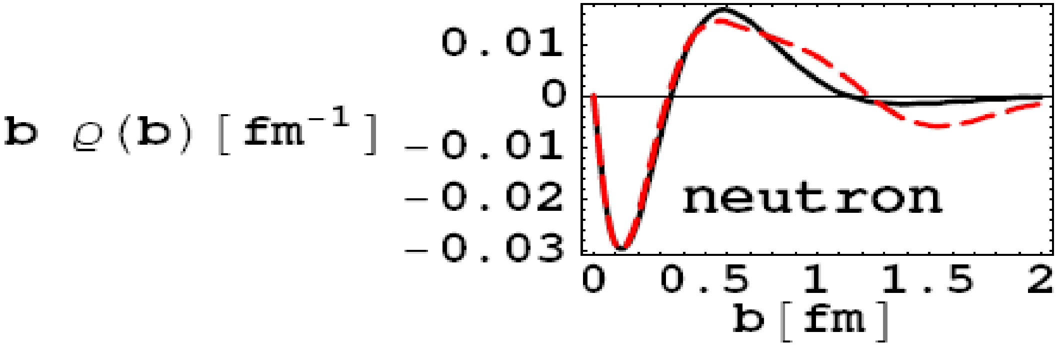
# “Neutron charge distribution”

Miller notes high $Q^2$ data could affect conclusion

- Long Range Plan: conventional 3d Fourier transform
- Miller Trento talk: 2d Fourier transform of $F_1$ gives neutron transverse charge distribution negative at origin



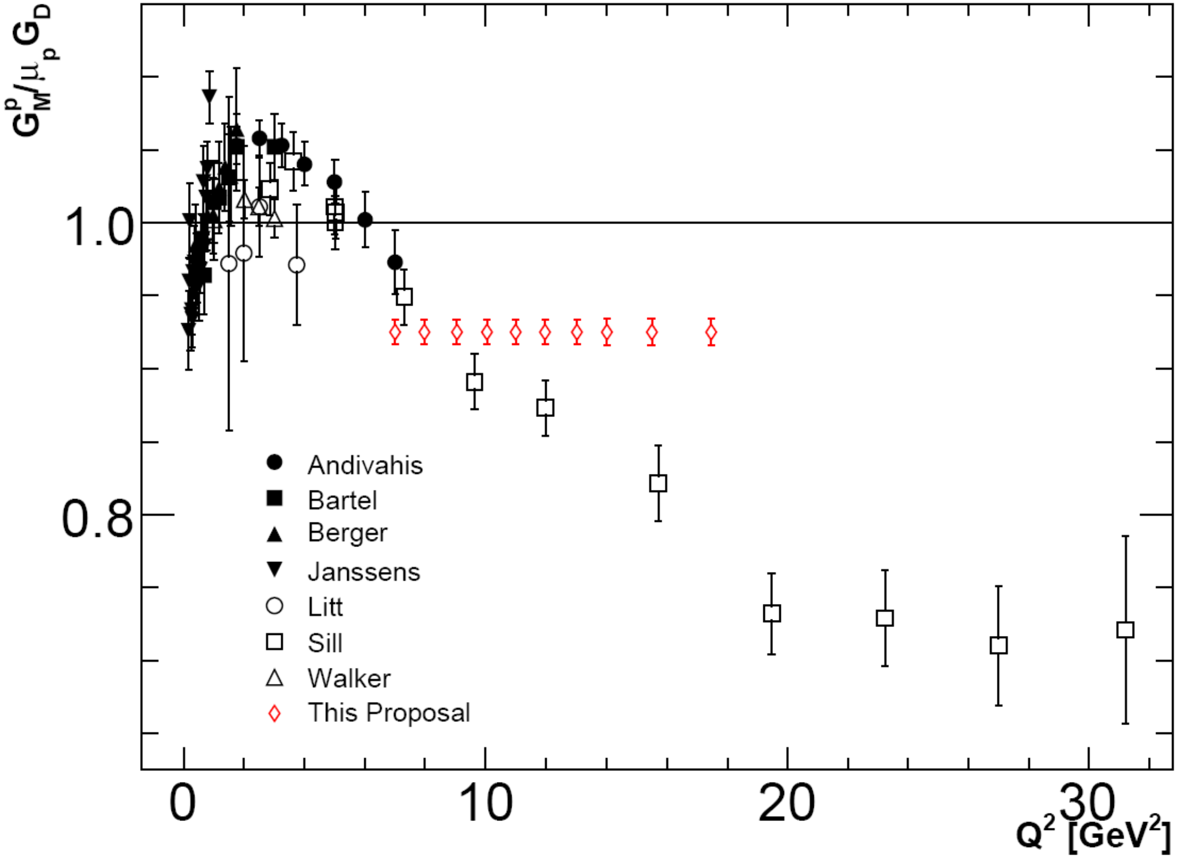




# $G_M^p$: Hall A E12-07-108

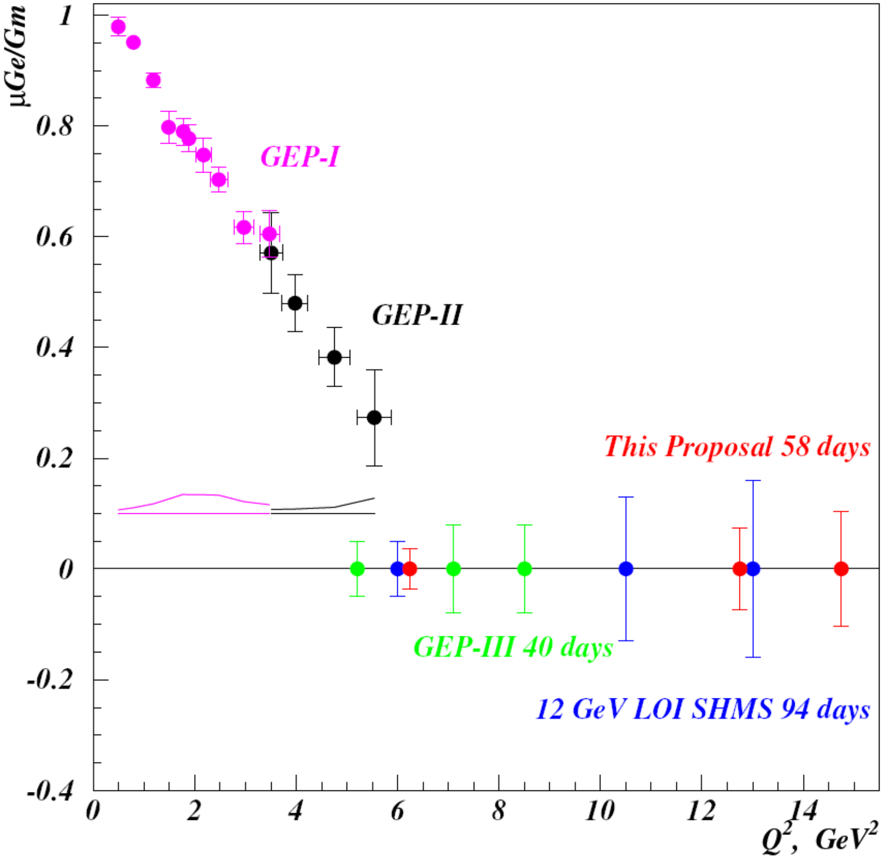
- B. Moffit et al.
- Cross sections for ep elastic scattering

- Old SLAC data from forward-angle cross sections, assuming form factor scaling



# $G_E^p$: Hall C E04-108 + Hall A E12-07-109

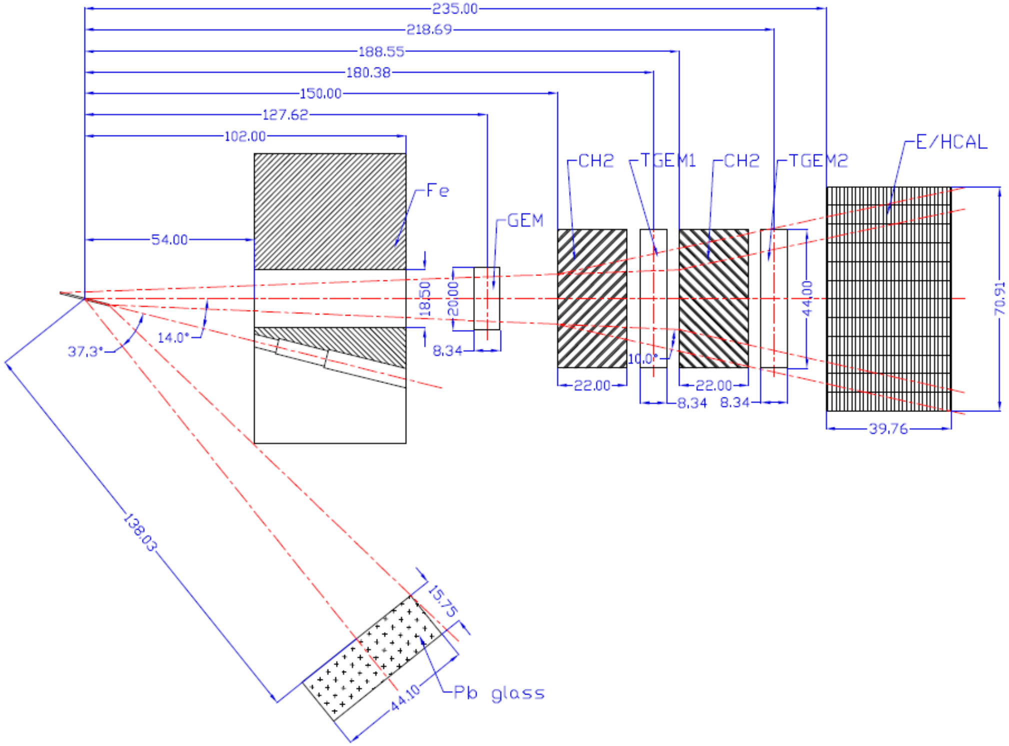
- $G_E^p$-III+2γ took data in late 2007/early 2008
- Working on analysis code, so results too preliminary to show
- E12-07-109 approved to go out to 15 GeV2 using calorimeter for electrons + SuperBigbite for protons



# $G_E^p$: Hall A E12-07-109

- $G_e^p$-I (run 1998) went to 3 GeV$^2$ using 2 HRS spectrometers
- How does $G_e^p$-V get to 15 GeV$^2$?

- Increased electron solid angle: calo vs HRS
- Increased proton solid angle: SBS vs HRS
- Increased rate capability: GEMs vs VDCs
- Dual vs single analyzer FPP
- Beam energy, current, polarization

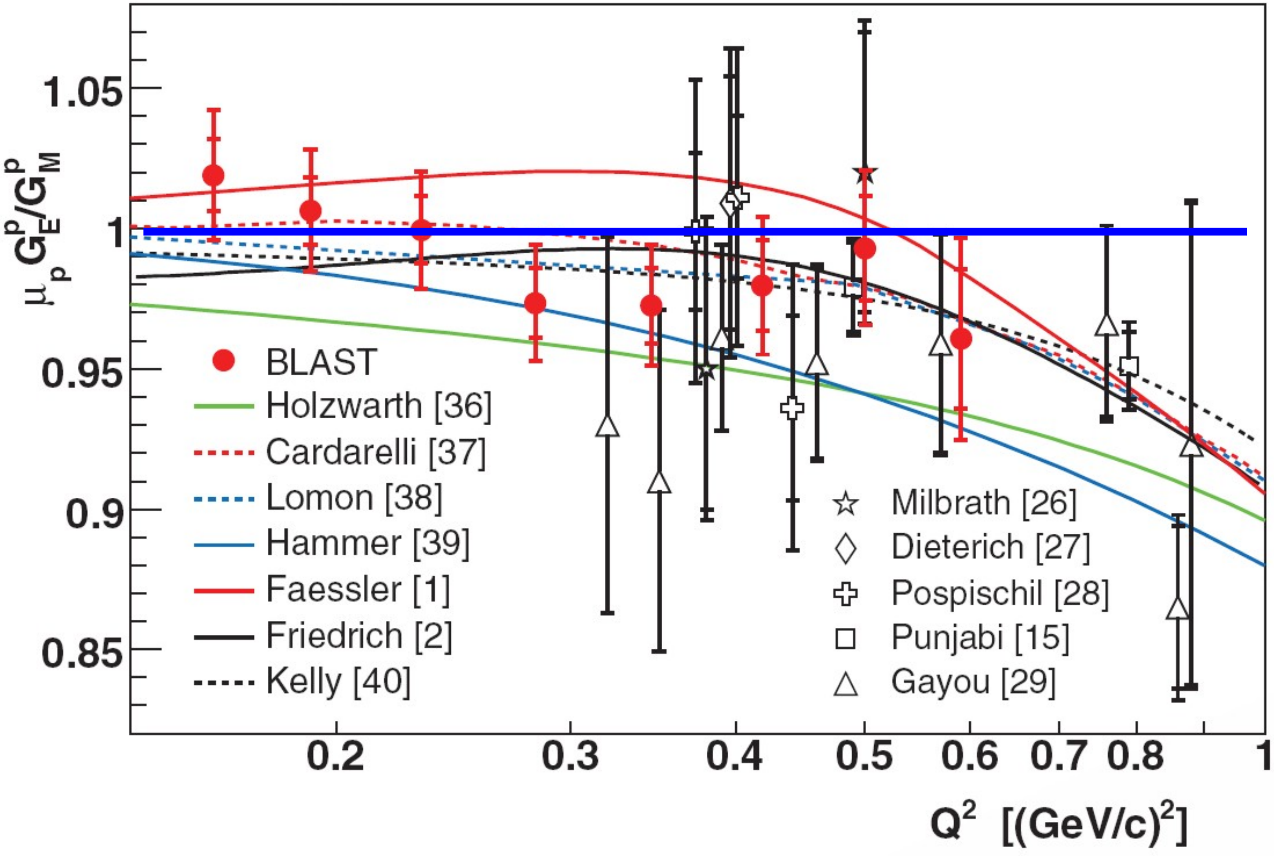


# Low $Q^2$ Proton Ratio Data, early 2007

From Crawford, PRL98, BLAST

R~1 to 0.6 $GeV^2$

Friedrich/Walcher fit reignitied interest in high precision, due to their suggestions of structures and pion clouds

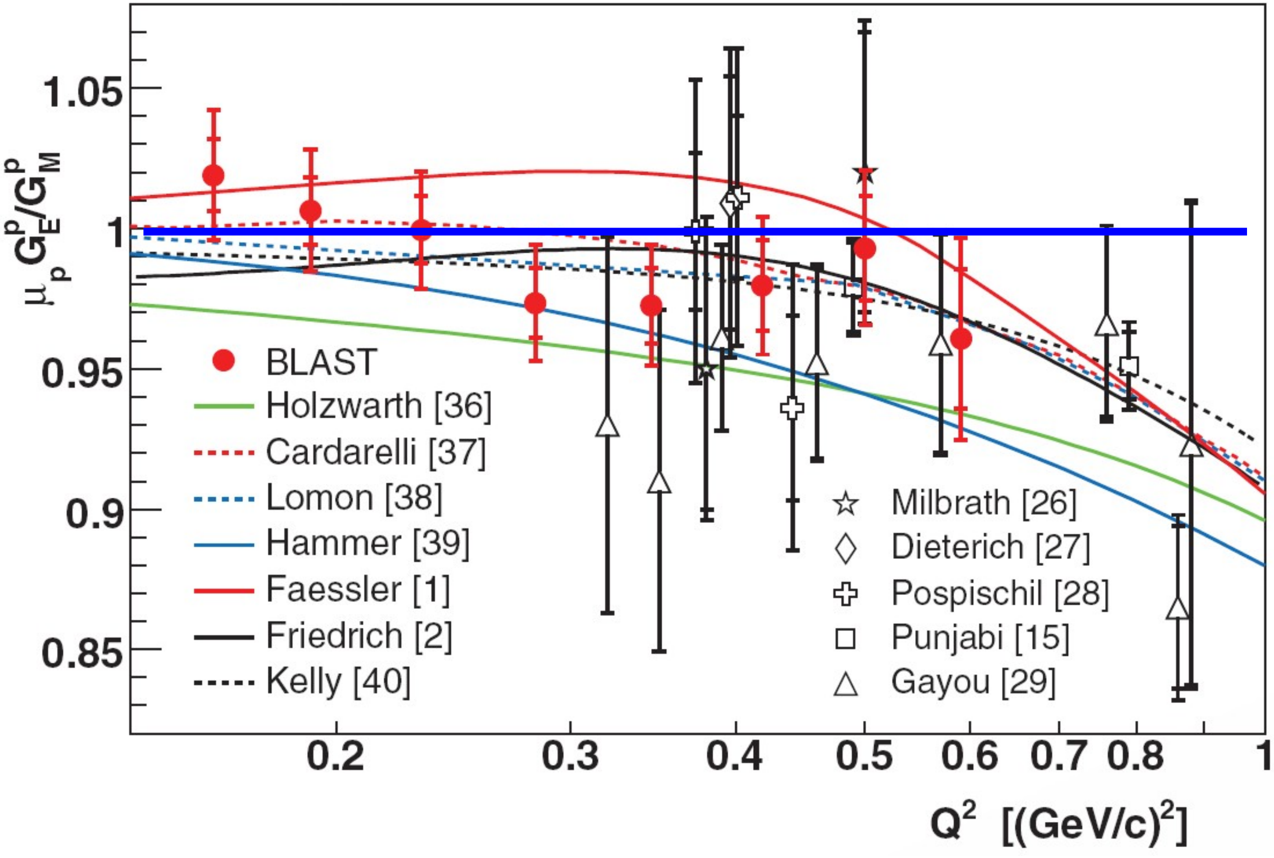


# Low $Q^2$ Proton Ratio Data, early 2007

Structures can be introduced by fit functions

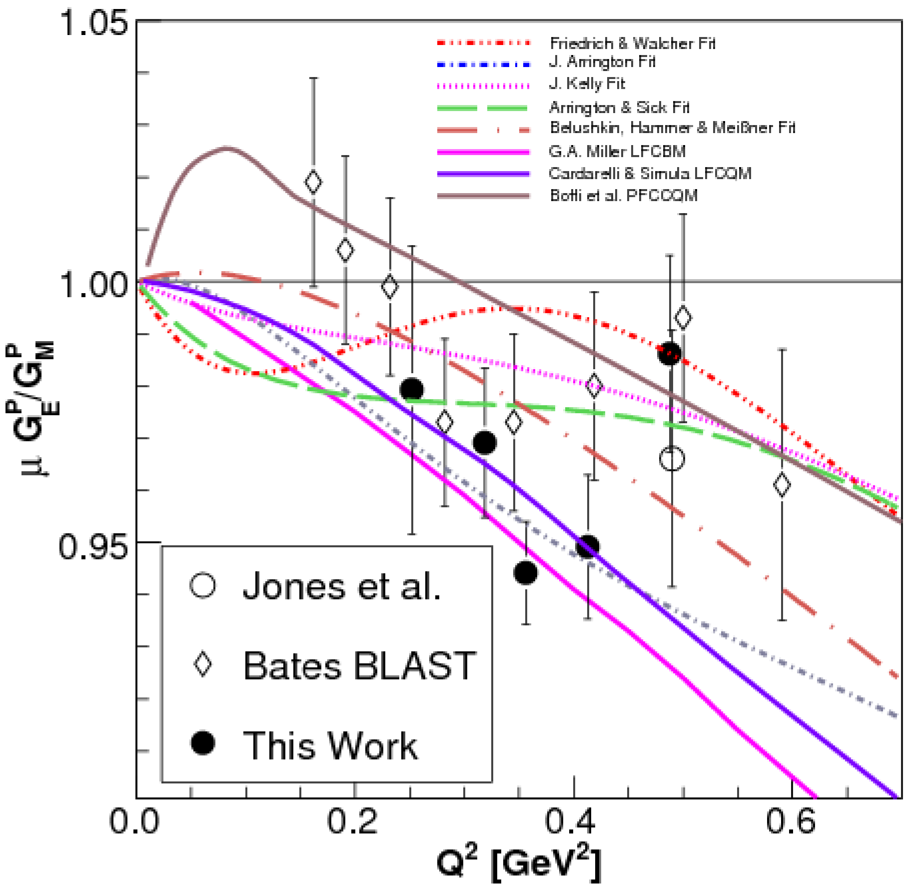
Pion cloud is not localized in $Q^2$

FW analysis led to 1 opportunistic + 2 dedicated experiments: Mainz + E08-007



# Low $Q^2$ Proton Ratio Data, late 2007

E05-103 FPP calibration data (G. Ron et al PRL 98), with higher statistics than previous calibrations (Gayou, Wijesooriya, Jiang et al.) contradict idea of FW structure and clearly show FF ratio < 1



# Direct Implications on Separated F.F.

Combining Berger at al. PLB 35, 1971 dσ/dΩ with new FPP data in G. Ron et al PRL 98, we showed fits tend to get $G_M$ about right, but tend to over predict $G_E$

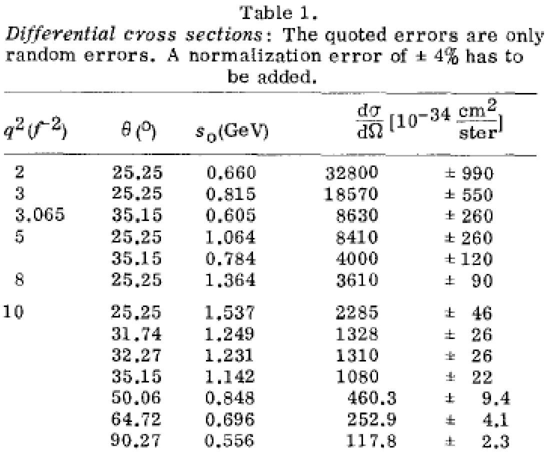
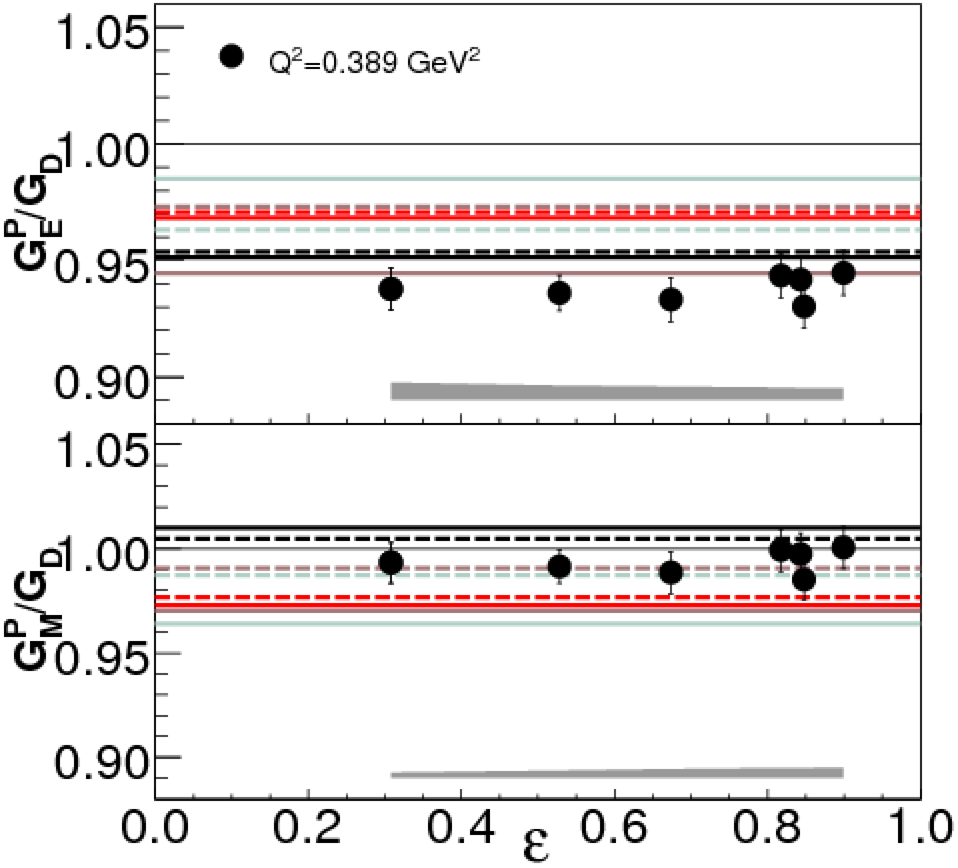


Table 1.

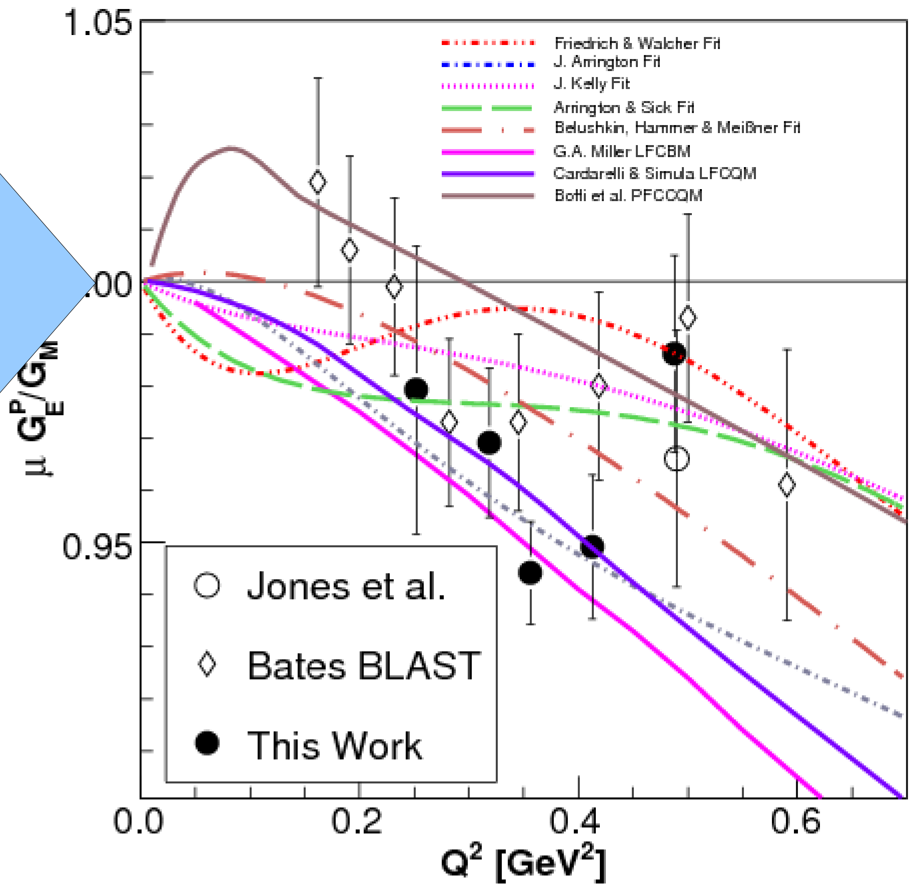
*Differential cross sections*: The quoted errors are only random errors. A normalization error of ± 4% has to be added.

| $q^2 (f^{-2})$ | $\theta$ (°) | $s_0$(GeV) | $\frac{d\sigma}{d\Omega}$ [$10^{-34}$ $\frac{cm^2}{ster}$] | |
|---|---|---|---|---|
| 2 | 25.25 | 0.660 | 32800 | ± 990 |
| 3 | 25.25 | 0.815 | 18570 | ± 550 |
| 3.065 | 35.15 | 0.605 | 8630 | ± 260 |
| 5 | 25.25 | 1.064 | 8410 | ± 260 |
| | 35.15 | 0.784 | 4000 | ± 120 |
| 8 | 25.25 | 1.364 | 3610 | ± 90 |
| 10 | 25.25 | 1.537 | 2285 | ± 46 |
| | 31.74 | 1.249 | 1328 | ± 26 |
| | 32.27 | 1.231 | 1310 | ± 26 |
| | 35.15 | 1.142 | 1080 | ± 22 |
| | 50.06 | 0.848 | 460.3 | ± 9.4 |
| | 64.72 | 0.696 | 252.9 | ± 4.1 |
| | 90.27 | 0.556 | 117.8 | ± 2.3 |



# Low $Q^2$ Proton Ratio Data, late 2007

Belushkin fit and lowest $Q^2$ points suggest a + slope at $Q^2 = 0$, conventionally implying slightly larger magnetic radius



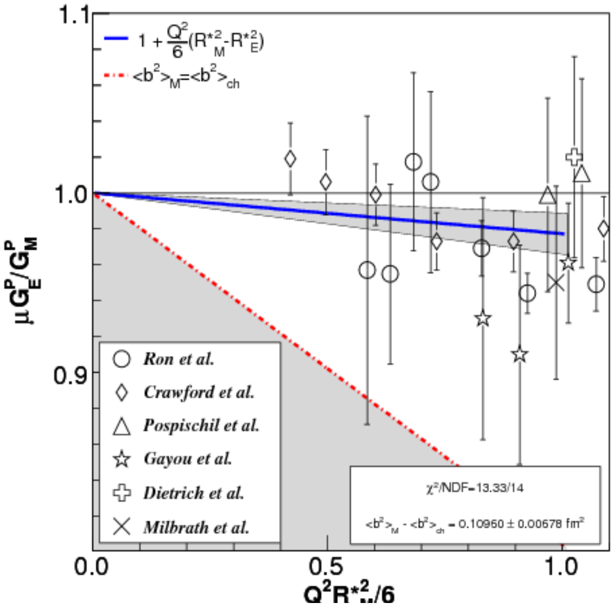
# Radii - Miller et al.

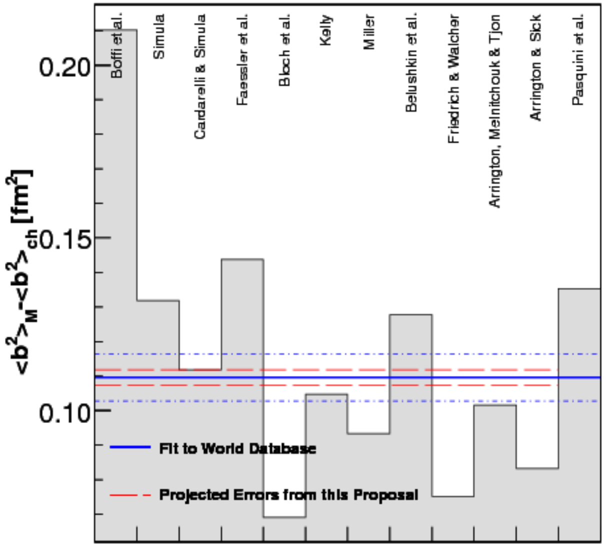
$$\text{As } Q^2 \to \cdot\,,\ R \approx 1 - \frac{Q^2}{6}\left(R_M^2 - R_E^2\right)$$

$$b_M^2 - b_E^2 = \frac{2}{3}\frac{\mu}{\kappa}\left(R_M^2 - R_E^2\right) + \frac{\mu}{M^2}$$

While the sign of $R^2_M - R^2_E$ is basically undetermined – is R really linear out to 0.2 or 0.3 GeV$^2$? - all data and fits indicate $b^2_M - b^2_E > 0$

Fit gives: $R^2_M - R^2_E = -0.014 \pm 0.007$ and $b^2_M - b^2_E = 0.110 \pm 0.007$



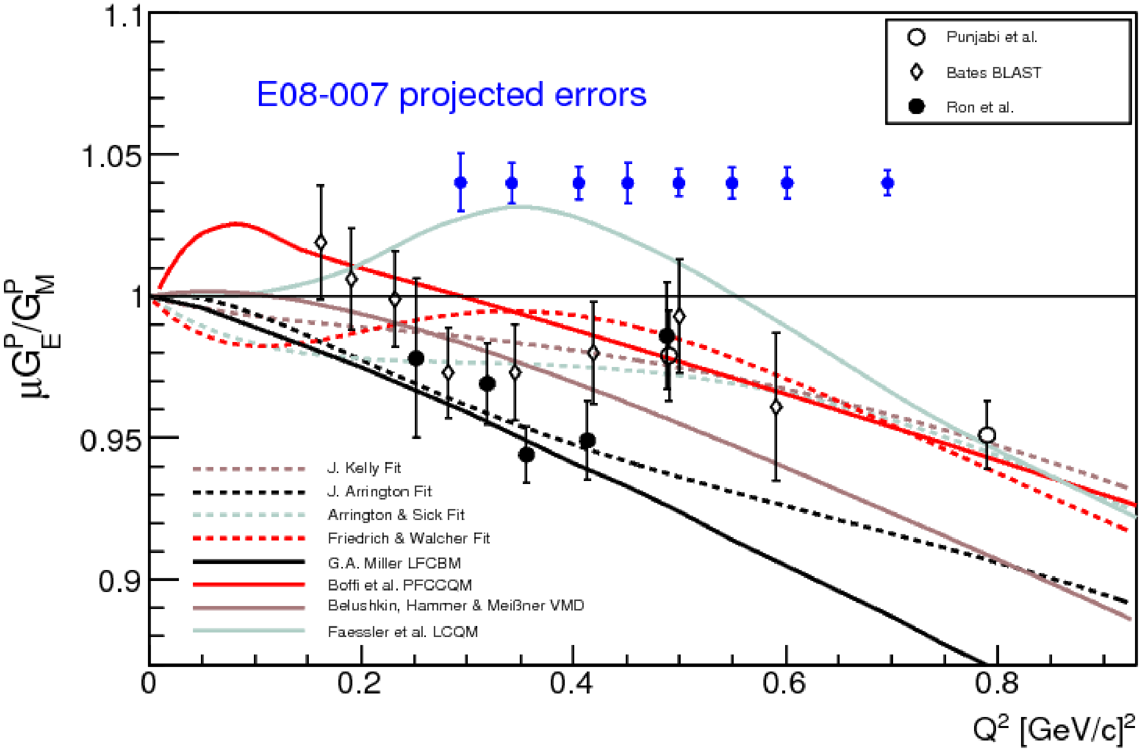


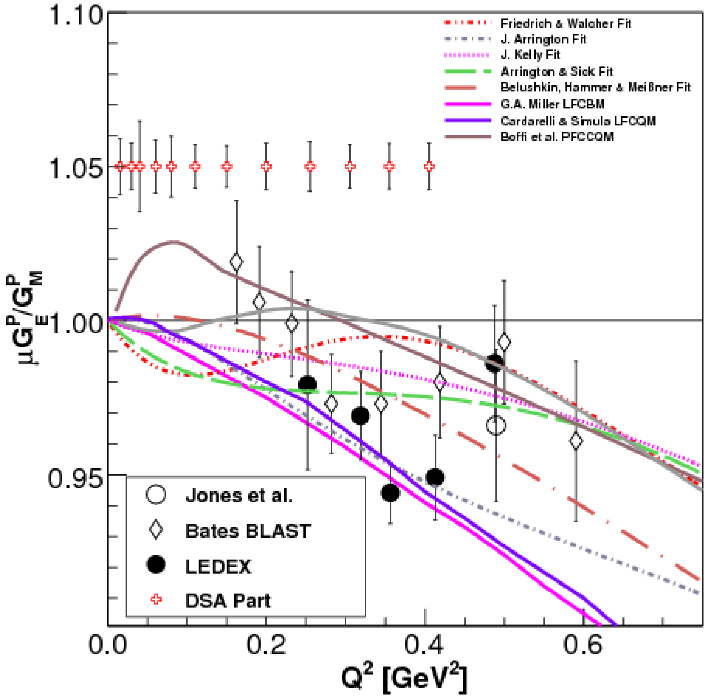
# Mainz, E08-007 Status

- Mainz measured low energy part of their data set, working on achieving 1% cross sections
- E08-007 measured polarization transfer in May/June 2008, and hopes to measure DSA in early 2012

# E08-007 Anticipated DSA/FPP Results

(Xiaohui Zhan et al.)





# Hyperfine Splitting

- $E_{HFS} = (1 + \Delta_{QED} + \Delta^{P}_{R} + \Delta^{p}_{hvp} + \Delta^{P}_{\mu vp} + \Delta^{P}_{weak} + \Delta_{S}) E_{F}^{P} =$ 1420.405 751 766 7(9) MHz
- Structure term $\Delta_S = \Delta_Z + \Delta_{POL}$, $\Delta_Z = -2\alpha m_e r_z (1+d^{rad}_Z)$
- Zemach radius $r_Z = -\frac{4}{\pi}\int_0^\infty \frac{dQ}{Q^2}\left[G_E(Q^2)\frac{G_M(Q^2)}{(1+\kappa_p)} - 1\right]$
- Some recent articles:
  - Friar and Sick, PLB 579 (2004)
  - Brodsky, Carlson, Hiller, and Hwang, PRL 96 (2005)
  - Friar and Payne, PRC 72 (2005)
  - Nazaryan, Carlson, and Griffioen, PRL 96 (2006)
  - Carlson, Nazaryan, and Griffioen, arXiv:0805.2603v1

# Hyperfine Splitting

- Friar and Sick, PLB 579 (2004)
  - Form factors from electron scattering lead to $r_Z$ = 1.086 ± 0.012 fm
    - Continued Fraction Expansion up to 4 $fm^{-1}$, dipole parameterization for higher $Q^2$
  - Need $\Delta_{POL}$ ~ 3.2 ± 0.5 ppm, somewhat inconsistent with estimate of 1.8 ± 0.8 ppm

# Hyperfine Splitting

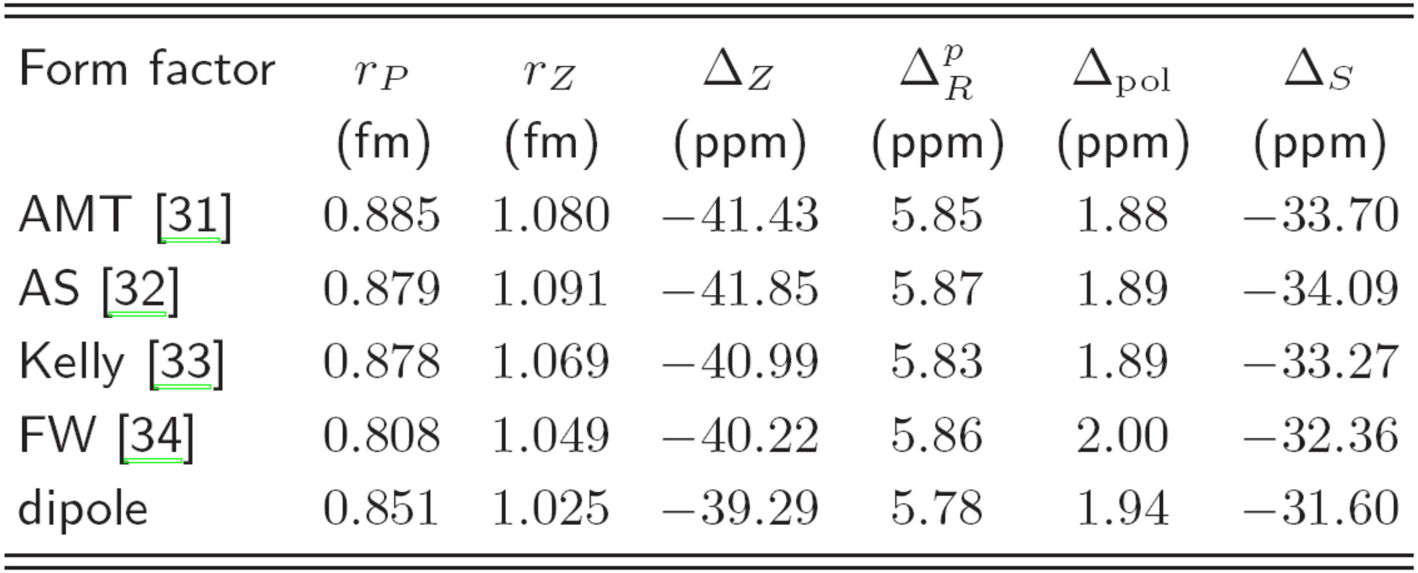
- Brodsky, Carlson, Hiller, and Hwang, PRL 96 (2006)
  - $\Delta_S = \Delta_Z + \Delta_{POL} = -38.62(16)$ ppm
  - Use $\Delta_{POL} \sim 1.4 \pm 0.3$ ppm to obtain $\Delta_Z = -40.0 \pm 0.6$ ppm, and $r_Z = 1.043 \pm 0.016$ fm
  - Fits / parameterizations give $\Delta_Z = -38.8$ -> $-41.7$ ppm, and $r_Z = 1.012$ -> $1.088$ fm
  - Needed Zemach correction between modern fits and the dipole

# Hyperfine Splitting

- Nazaryan, Carlson, and Griffioen, PRL 96 (2006)
  - $\Delta_S = \Delta_Z + \Delta_{POL}$ = -38.58(16) ppm, but $\Delta_Z$ = -39.32 ppm (dipole) or ~ -41->-42 ppm (Kelly,Sick fits) and $\Delta_{POL}$ ~ 1.3 ± 0.3 ppm => perhaps okay to 1 - 2 ppm

# Hyperfine Splitting

- Carlson, Nazaryan, and Griffioen, arxiv:0805.2603 (2008)
  - Use new CLAS EG1b data to determine $g_1$ better at low $Q^2$ and constrain $g_2$
  - $\Delta_{POL}$ ~ 1.88 ± 0.64 ppm
  -

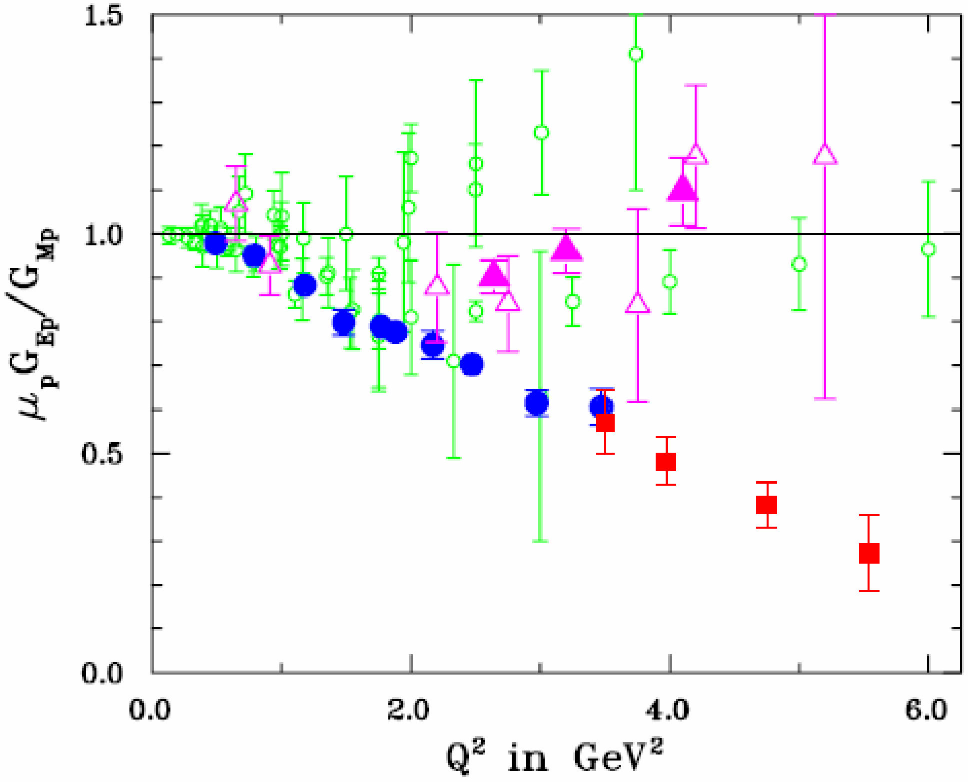


| Form factor | $r_P$<br>(fm) | $r_Z$<br>(fm) | $\Delta_Z$<br>(ppm) | $\Delta_R^p$<br>(ppm) | $\Delta_{\rm pol}$<br>(ppm) | $\Delta_S$<br>(ppm) |
|---|---|---|---|---|---|---|
| AMT [31] | 0.885 | 1.080 | −41.43 | 5.85 | 1.88 | −33.70 |
| AS [32] | 0.879 | 1.091 | −41.85 | 5.87 | 1.89 | −34.09 |
| Kelly [33] | 0.878 | 1.069 | −40.99 | 5.83 | 1.89 | −33.27 |
| FW [34] | 0.808 | 1.049 | −40.22 | 5.86 | 2.00 | −32.36 |
| dipole | 0.851 | 1.025 | −39.29 | 5.78 | 1.94 | −31.60 |

# Some General Comments

- $\Delta_{POL}$ relies on low $Q^2$ estimates of $g_2^p$ in an unmeasured region -> a better data base is needed (Hall A low $Q^2$ $g_2^p$ E08-027, expected 2011)
  - But MAID was okay for $g_{1,2}^n$, so probably okay here
- For $\Delta_Z$, uncertainties (and offsets?) in the fits -> a better data base is needed (Mainz+JLab)
- Our limited result at $Q^2$ = 0.4 GeV$^2$ suggests $G_M$ is about right, but $G_E$ is 2% smaller than fits – if this were true generally, it would reduce the Zemach correction by about 0.5 ppm, moving it in the "right" direction – but this is one point, and high $Q^2$ form factors are largely a guess

# Two-Photon Exchange – The Discrepancy



# Two-Photon Exchange – Hall C data

- **L.Pentchev analysis of JLab E04-019**
- measured R at 3 values of ε for $Q^2$=2.49 GeV$^2$
- no ε-dependence seen at 0.01 level
- Preliminary near on-line analysis; codes still undergoing debugging
- Polarizations apparently robust

- **Several calculations: shown are Chen et al (2003) with GPDs, Blunden et al (2003) in hadronic model**

# Two-Photon Exchange: more experiments!

- **e+/e- comparisons:**
  - **Arrington reanalysis of old $e^+/e^-$ ratio data: slope vs ε = -5.8 +/- 0.8% at 0.4 GeV$^2$**
  - **Novosibirsk VEPP-3 BINP: slope of $e^+/e^-$ ratio vs ε = -10.4 +/- 2.2% at 1.6 GeV$^2$ (Nikolenko)**
  - **CLAS eg5-TPE planned to run in 2012 (Afanasev, Arrington, Brooks, Joo, Raue, Weinstein)**
  - **Olympus [BLAST @ DESY] ~2011 or 2012**
- Induced polarizations:
  - Hall A E05-015 (Averett, Chen, Jiang): QF polarized $^3$He(e,e') SSA
- Rosenbluth separations
  - Hall C E05-017 (Arrington): ran May 2007

# Parity Violation and Strange FF

- The usual relations:

$$G^{p}_{E,M}(Q^2)=\frac{2}{3}G^{u}_{E,M}(Q^2)-\frac{1}{3}G^{d}_{E,M}(Q^2)-\frac{1}{3}G^{s}_{E,M}(Q^2)$$

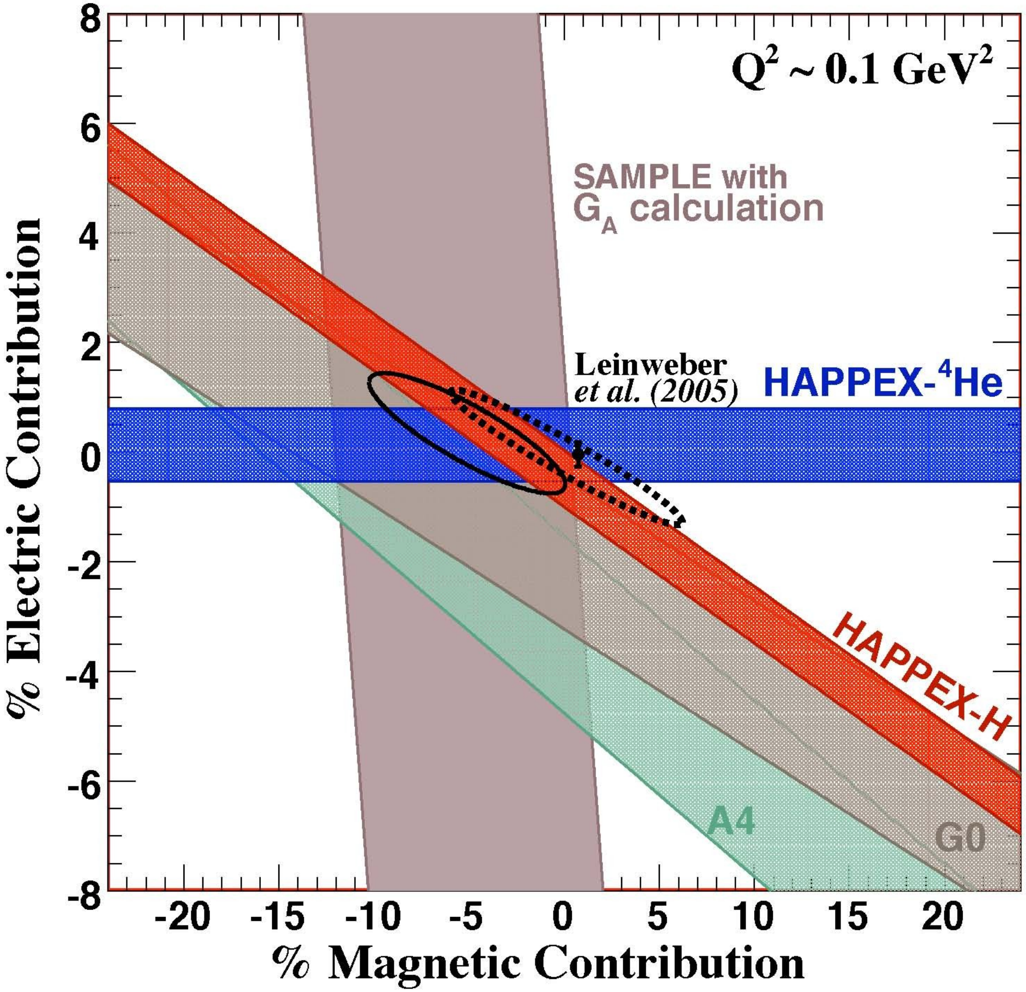
$$A_{\mathrm{th}} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right]\frac{\varepsilon G_E^{p\gamma}G_E^{pZ} + \tau G_M^{p\gamma}G_M^{pZ} - \frac{1}{2}(1 - 4\sin^2\theta_W)\varepsilon' G_M^{p\gamma}G_A^{pZ}}{\varepsilon(G_E^{p\gamma})^2 + \tau(G_M^{p\gamma})^2}$$

$$G^{pZ}_{E,M} = \frac{1}{4}(G^{p\gamma}_{E,M} - G^{n\gamma}_{E,M}) - \sin^2\theta_W G^{p\gamma}_{E,M} - \frac{1}{4}G^{s}_{E,M}$$

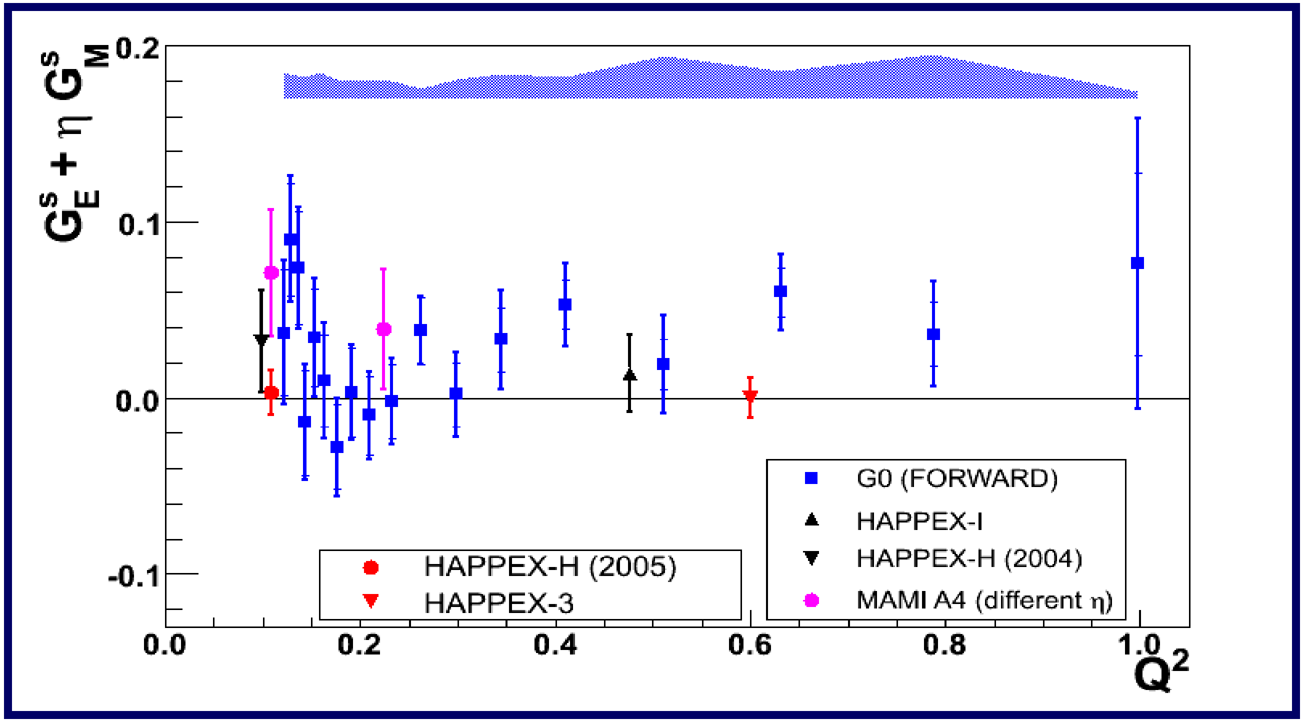
- $A_{PV}$ + $G_{E,M}^{p,n\gamma}$ + $G_A^{pZ}$ (calculated) --> $G_{E,M}^{s}$
- G. Ron et al indicated HAPPEX-I shifted by ~0.5σ towards 0 due to smaller $G_E$
- Similar change in F.F. in HAPPEX-III kinematics would lead to ~1σ shift

# Current PV Experimental Status

- Small contributions of strange quarks at $Q^2$~0.1 $GeV^2$
- R. Young PRL 97: dashed contour
- K. Paschke, unpublished, solid contour
- Or R McKeown, not shown



# Current PV Experimental Status



- G0 expected to unblind analysis and report backward angle measurements for $Q^2$ = 0.2 – 0.6 $GeV^2$ soon
- HAPPEX-3 expected to run late 2009

# Summary

- Lots of new data taken and about to come out
- Many experiments planned for 12 GeV era to extend form factors out to ~10-18 GeV$^2$
- Besides EMFF themselves
  - Radii and densities
  - Hyperfine structure
  - Strange FF
  - Flavor, IS/IV decompositions
  - GPDs, fits, models, calculations

# Thanks to:

- Organizers
- DOE/JLab and NSF Physics
- J Arrington, F Benmokhtar, J Gilfoyle, D Higinbotham, L Pentchev, C Perdrisat, E Piasetzky, B Quinn, G Ron, B Wojtsekhowski, X Zhan...