Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab

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Scientific Motivation - What We Hope to Learn.

- Nucleon elastic electromagnetic form factors (EEFFs) describe the distribution of charge and magnetization in the nucleon.
- They can reveal the internal landscape of the nucleon and nuclei.
- They rigorously test QCD in the non-perturbative regime with different models, constituent quarks, lattice QCD...
- Map the transition from the hadronic picture to QCD.

Some Necessary Background

EEFFs cross section is described with Dirac (F_1) and Pauli (F_2) form factors or Sachs form factors (G_E and G_M).

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott}\left[\left(F_1^2 + \kappa^2\tau F_2^2\right) + 2\tau\left(F_1 + \kappa F_2\right)^2 \tan^2\left(\frac{\theta_e}{2}\right)\right] = \frac{\sigma_{Mott}}{\epsilon(1+\tau)}\left(\epsilon G_E^2 + \tau G_M^2\right)$$

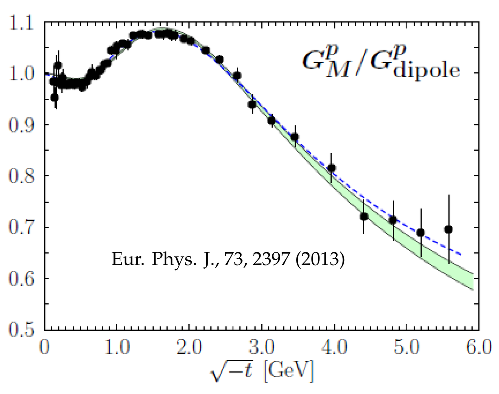
where

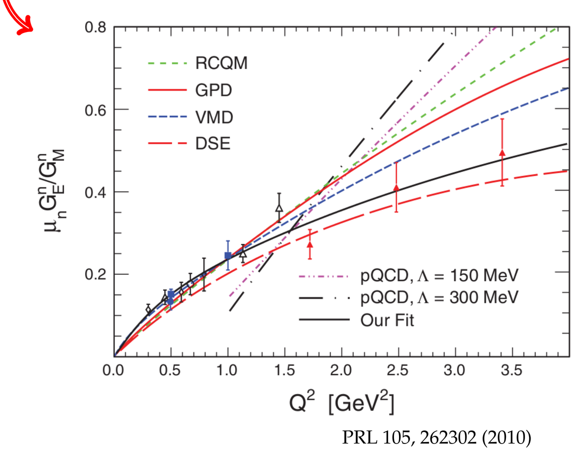
$$\sigma_{Mott} = \frac{\alpha^2 E' \cos^2(\frac{\theta_e}{2})}{4E^3 \sin^4(\frac{\theta_e}{2})} \quad G_E = F_1 - \tau F_2 \quad G_M = F_1 + F_2 \quad \epsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta_e}{2}\right]^{-1}$$

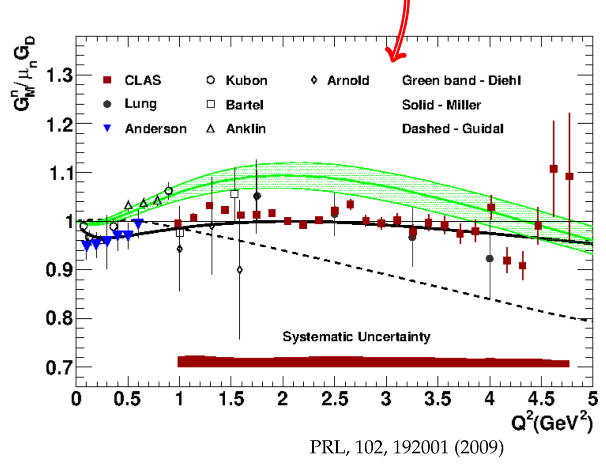
and κ is the anomalous magnetic moment, E (E') is the incoming (outgoing) electron energy, θ is the scattered electron angle and $\tau = Q^2/4M^2$.

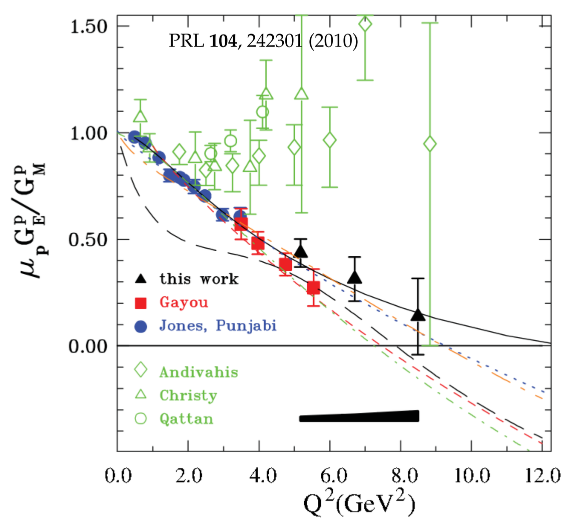
Where Are We Now?

- G_M^p reasonably well known over large Q^2 range.
- The ratio G_E^p/G_M^p from recoil polarization measurements diverged from previous Rosenbluth separations.
  - Two-photon exchange (TPE).
  - Effect of radiative corrections.
- The neutron form factor ratio G_E^n/G_M^n opens up flavor decomposition.
- Neutron magnetic FF G_M^n still follows dipole.

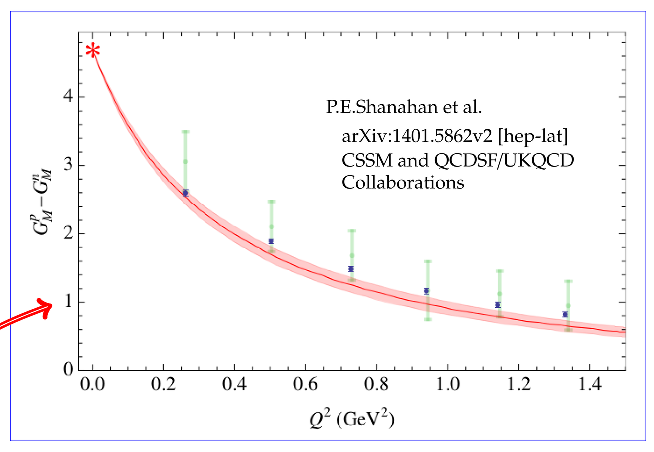








- Theory approaches like Vector Meson Dominance and dispersion analyses fit EEFFs, but use many parameters.
- Constituent Quark Models highlight relativity, but don't capture all of QCD.
- EEFFs are an early test of lattice QCD because isovector form does not have disconnected diagrams.

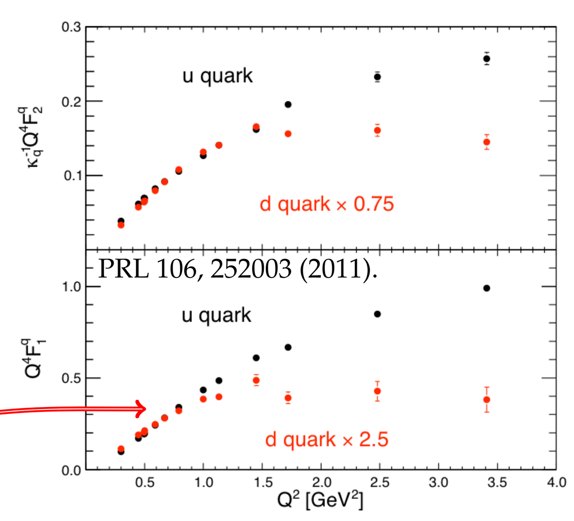


Where Are We Going?

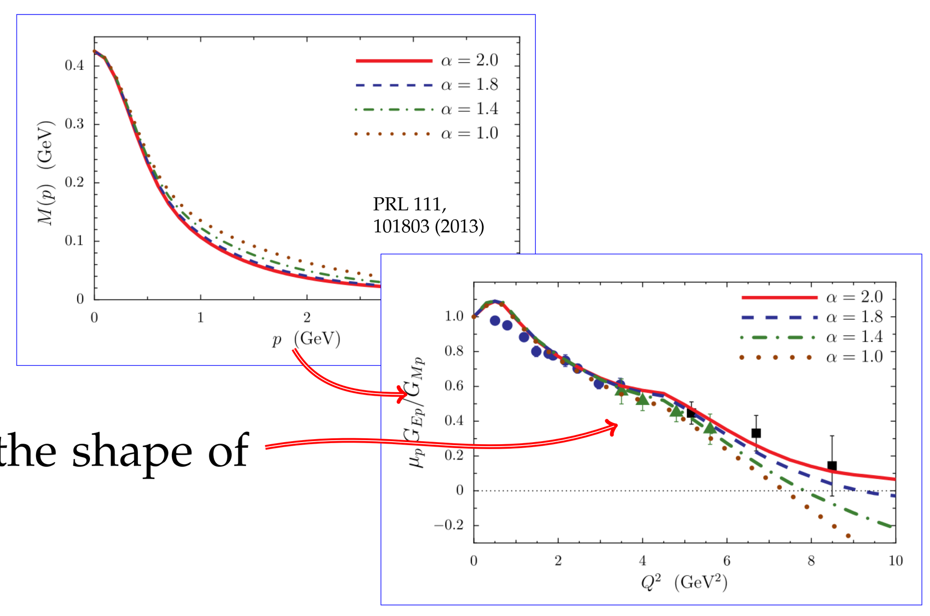
- Flavor Decomposition
  - With all four EEFFs we can unravel the u and d quark structure.
  - Assume charge symmetry, no s quarks and use (Miller *et al.* Phys. Rep. 194, 1 (1990))

$$F_{1(2)}^u = 2F_{1(2)}^p + F_{1(2)}^n \qquad F_{1(2)}^d = 2F_{1(2)}^n + F_{1(2)}^p$$

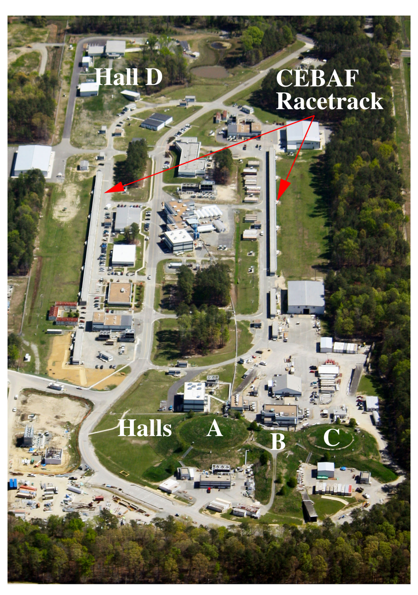
  - The u and d quarks have different, unexplained Q^2 dependence - evidence of di-quarks?



- Dyson-Schwinger Equations
  - Infinite set of coupled integral equations.
  - Inherently relativistic, and nonperturbative.
  - Connected to confinement, dynamical chiral symmetry breaking.
  - Proton form factor ratio sensitive to the shape of the dressed-quark mass function.

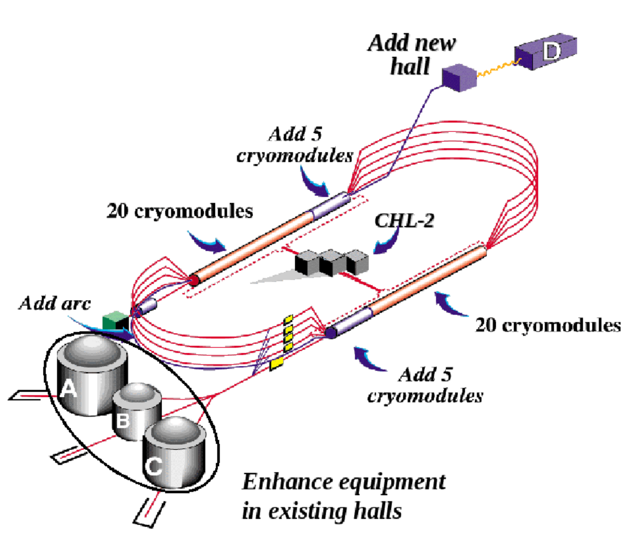


How Are We Getting There? - Upgraded Accelerator

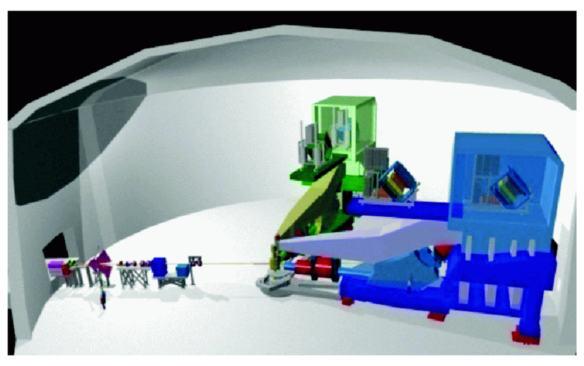


Continuous Electron Beam Accelerator Facility (CEBAF)

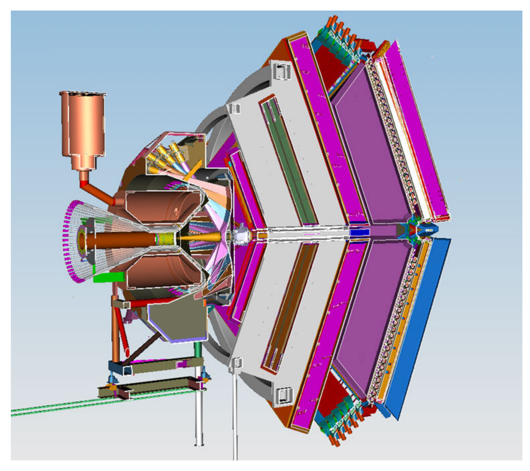
- Superconducting Electron Accelerator (338 cavities)
- 100% duty cycle.
- $E_{max} = 11$ GeV (Halls A, B, and C) and 12 GeV (Hall D)
- $\Delta E/E \approx 2 \times 10^{-4}$
- $I_{summed} \approx 90\ \mu A$, $P_e \geqslant 80\%$.



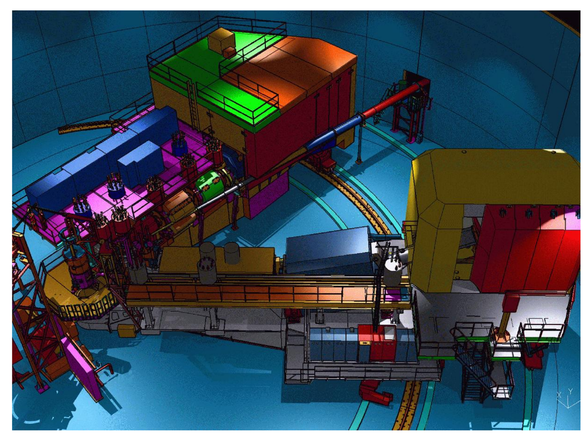
How Are We Getting There? - New Detectors



Hall A - High Resolution Spectrometer (HRS) pair, SuperBigBite (SBS), neutron detector, and others.



Hall B - CLAS12 high luminosity, large acceptance spectrometer with forward and central detectors.

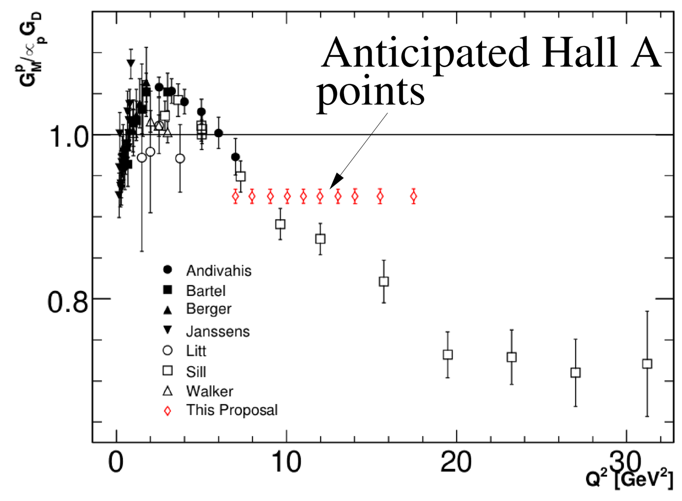


Hall C - Super High Momentum Spectrometer paired with existing High Momentum Spectrometer.

Hall D - New GlueX detector will search for exotic states, but not for EEFFs.

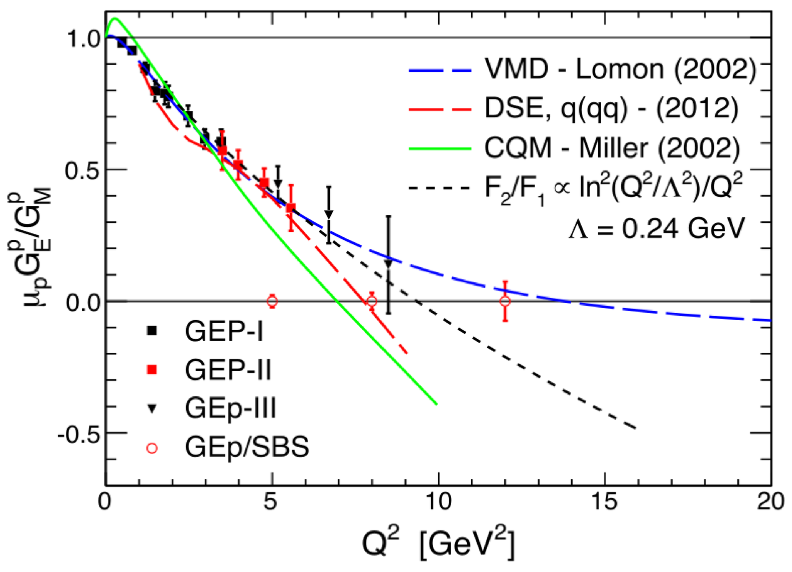
The Measurements and Anticipated Results

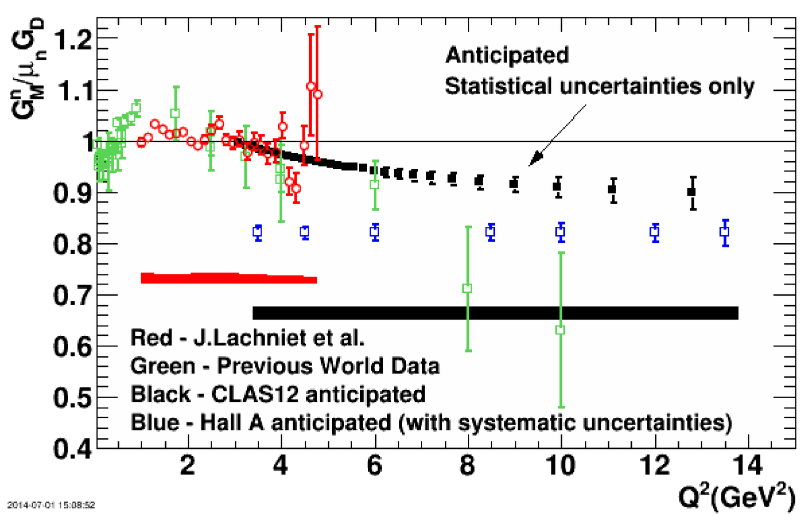
JLab Program Advisory Committee (PAC) has approved six experiments to measure all four EEFFs (some twice) with 224 days of running.



Experiment E12-07-108 in Hall A (Arrington, Christy, Gilad, Silkovsky, Wojtsekhowski) will make a precise measurement of the ep elastic cross section and extract G_M^p.

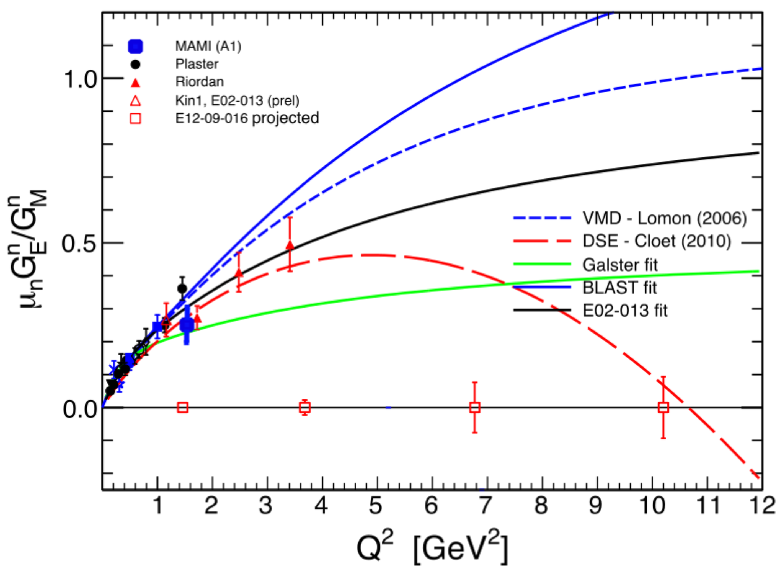
Experiment E12-07-109 (GEp) in Hall A (Cisbani et al.) will use the polarization transfer method on $H(\vec{e},e'\vec{p})$ to measure the form factor ratio $\frac{G_E^p}{G_M^p} = -\frac{P_t}{P_l}\frac{E+E'}{2M}\tan\left(\frac{\theta_e}{2}\right)$.



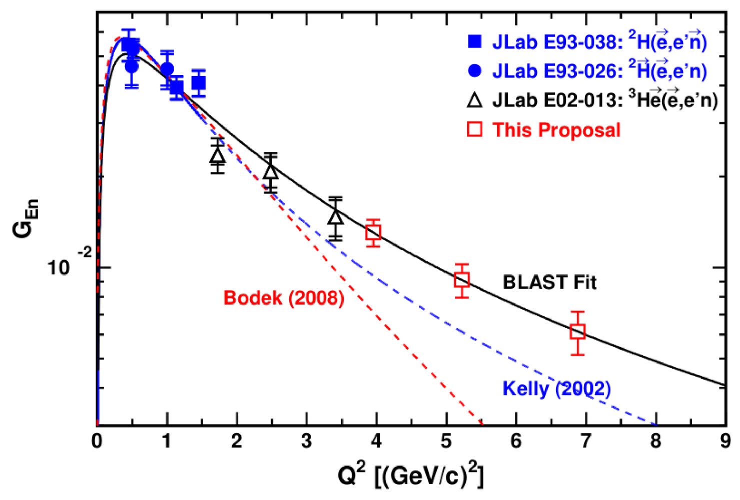


Two experiments E12-07-104 (Gilfoyle, Hafidi, and Brooks) in Hall B and E12-09-019 (Annand, Gilman, Quinn, Wojtsekhowski) in Hall A will use the quasielastic $e-n/e-p$ ratio to extract a precision measurement of G_M^n.

Experiment E12-09-016 in Hall A (Cates, Wojtsekhowski, Riordan) will use the double Polarization Asymmetry A_{en}^V from $^3\vec{He}(\vec{e},e'n)pp$ to extract G_E^n/G_M^n.



Experiment E12-11-009 in Hall C (Arrington, Kohl, Sawadsky, Semenov) will use polarization transfer off $^2H(\vec{e},e'\vec{n})p$ to measure G_E^n/G_M^n complementary to the other G_E^n/G_M^n experiment in Hall A.



Schedule and Conclusions

- The proton cross section measurement (G_M^p) will run in spring, 2016 and the form factor ratio (G_E^p/G_M^p) in 2018.
- Remaining elastic form factor measurements will be done in 2018 or later.
- Large recent gains in understanding of the EEFFs.
- Major changes in our understanding of nucleon structure.
- Jefferson Lab will mount a broad campaign on the EEFFs and will significantly expand our physics reach.
- Discovery potential in mapping out nucleon structure and understanding QCD.