The Electric Form Factor of the Neutron with Super Bigbite

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for the Super Bigbite and E12-09-016 Collaborations

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Outline

- Form Factor Models and Interpretations
- G_E^n to $Q^2 = 10\ \mathrm{GeV}^2$: E12-09-016

Motivation

- Form factors are a fundamental property of the nucleon
- Provide excellent testing ground for QCD and QCD-inspired models
- Gives constraints on models of nucleon structure
- Are not yet calculable from first principles

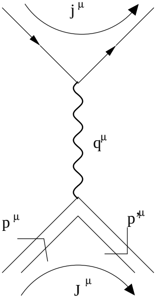
Nucleon Currents

Scattering matrix element, $M \sim \frac{j_\mu J^\mu}{Q^2}$
Generalizing to spin 1/2 with arbitrary structure, one-photon exchange, using parity conservation, current conservation the current parameterized by two form factors

$$J^\mu = e\bar{u}(p')\left[F_1(q^2)\gamma^\nu + i\frac{\kappa}{2M}q_\nu\sigma^{\mu\nu}F_2(q^2)\right]u(p)$$

Form Factors

- Dirac - F_1, chirality non-flip
- Pauli - F_2, chirality flip



Sachs Form Factors

Replace with Sachs Form Factors

$$\begin{aligned} G_E &= F_1 - \kappa\tau F_2 \\ G_M &= F_1 + \kappa F_2 \end{aligned}$$

$\lim_{Q^2 \to 0}$

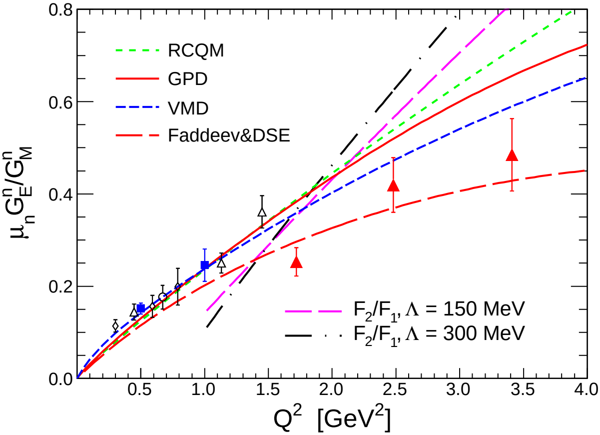
$$\begin{aligned} G_E^p(Q^2=0) &= 1, & G_M^p(Q^2=0) = \mu_p &= \quad 2.79 \\ G_E^n(Q^2=0) &= 0, & G_M^n(Q^2=0) = \mu_n &= \quad -1.91 \end{aligned}$$

Rosenbluth Formula

$$\frac{d\sigma}{d\Omega} = \left.\frac{d\sigma}{d\Omega}\right|_{\mathrm{Mott}} \frac{E'}{E}\left[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2\frac{\theta}{2}\right], \tau = \frac{Q^2}{4M^2}$$

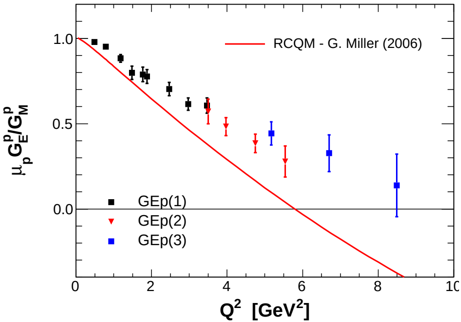
Neutron Form Factors

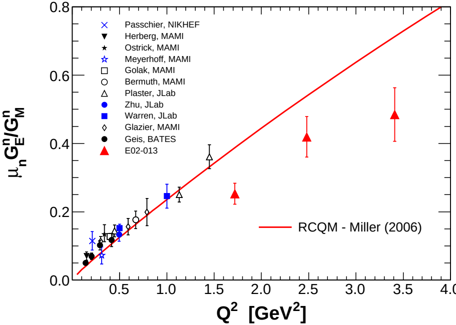
- Typically lag behind proton counterparts
- Neutron studies require nuclear corrections
- G_E^n is small



Constituent Quark Light-Front Cloudy Bag Model

- Predicts G_E^p polarization transfer results

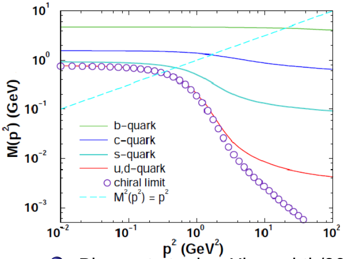


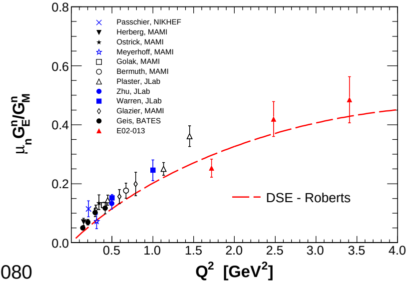


- G_E^p suppression at higher Q^2 due to inclusion of quark orbital angular momentum

Novel DSE/Fadeev q(qq) ANL Calculation

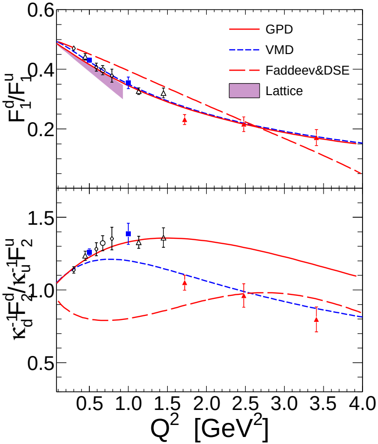
- Poincare covariant model based on QCD’s Dyson-Schwinger equations to describe dressed quark propagator
- Uses model where two of three quarks are in diquark state
- Bethe-Salpeter equation describes diquark boundstate
- Fadeev amplitudes describe quark interchanges
- Few free parameters tuned to nucleon properties such as mass and magnetic moments





- Bhagwat et. al. arXiv:nucl-th/0610080
- Cloët et. al. arXiv:nucl-th/0804.3118

GPDs, Quark Flavor Decomposition



Lattice: Bratt et al., arXiv:1001.3620, $m_\pi = 140$ MeV

- GPD models are constrained by nucleon form factors

$$\begin{aligned} F^p_{1,2} &= \frac{2}{3}F^u_{1,2} - \frac{1}{3}F^d_{1,2} \\ F^n_{1,2} &= -\frac{1}{3}F^u_{1,2} + \frac{2}{3}F^d_{1,2} \end{aligned}$$

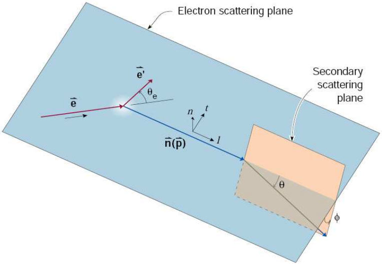
- High Q^2 for G_E^n data allows for quark decomposition
- Lattice is better suited for isovector FF

Extending G_E^n to $Q^2 = 10\ \mathrm{GeV}^2$ - Spin Observables

- Akhiezer and Rekalo (1968) - Polarization experiments offer a better way to obtain G_E than Rosenbluth separation
- Polarization observable measurements generally have fewer systematic contributions from nuclear structure and radiative effects

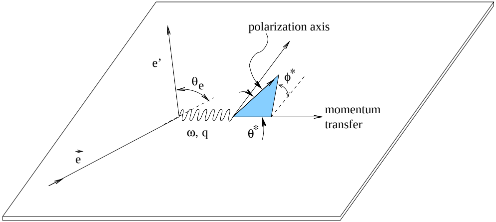
Polarization Transfer

$$\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{(E_e + E_{e'})\tan\theta_e/2}{2M}$$



Polarized Target Measurements

Long. polarized beam/polarized target transverse to $\vec{q}$ in scattering plane



Helicity-dependent asymmetry roughly proportional to G_E/G_M

$$\frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx A_\perp = -\frac{2\sqrt{\tau(\tau+1)}\tan(\theta/2) G_E/G_M}{(G_E/G_M)^2 + (\tau + 2\tau(1+\tau)\tan^2(\theta/2))}$$

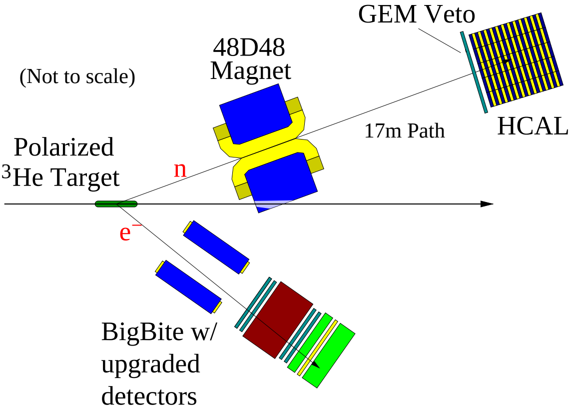
G_E^n Measurements at JLab

- G_E^n least well measured range of Q^2
- More difficult to measure relative to other FFs since
  - G_E^n is intrinsically small compared to G_M^n
  - Neutron is not stable outside nucleus, use targets $^2\mathrm{H}$ and $^3\mathrm{He}$
- Four experiments done at JLab:
  - Hall C - E93-026 - Zhu *et al.*, Warren *et al.* - $\vec{d}(\vec{e},e'n)p$, $Q^2 = 0.5, 1.0\ \mathrm{GeV}^2$
  - Hall C - E93-038 - Madey *et al.* - $d(\vec{e},e'\vec{n})p$, $Q^2 = 0.4 - 1.5\ \mathrm{GeV}^2$
  - Hall A - E02-013 - $^3\overrightarrow{\mathrm{He}}(\vec{e},e'n)pp$, $Q^2 = 1.2 - 3.4\ \mathrm{GeV}^2$
  - Hall A - E05-102 - $^3\overrightarrow{\mathrm{He}}(\vec{e},e'n)pp$, $Q^2 = 0.4 - 1.0\ \mathrm{GeV}^2$

Goals

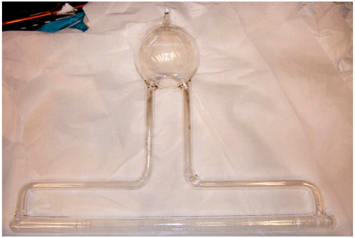
- Bring G_E^n up to similar range as G_E^p
- Challenges:
  - Cross section falls with Q^2
- Strategy:
  - Measure polarized target asymmetry
  - Increase luminosity - upgrade detectors/target
  - Increase target polarization - narrow width laser, hybrid alkalai
  - Improve PID from electron and nucleon arm

High Q^2 G_E^n Experimental Layout

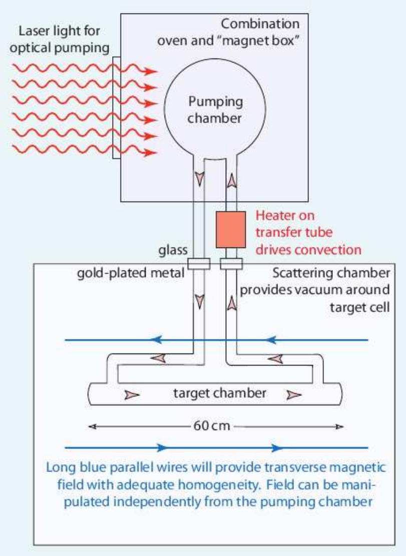


- Upgraded Bigbite detector stack for higher rates, better PID
- Hadron calorimeter at 17 m, additional GEM veto
- Place magnet $B \cdot dl = 1.7\ \mathrm{T} \cdot \mathrm{m}$ in front to deflect protons - reduces background by factor of 5

Upgraded ^{3}He Target



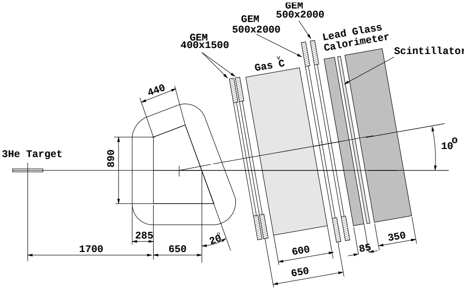
- Simulations show sustainable polarization of 62% with $I = 60\ \mu\text{A}$
- Overall effective luminosity gain of 15



Long blue parallel wires will provide transverse magnetic field with adequate homogeneity. Field can be manipulated independently from the pumping chamber

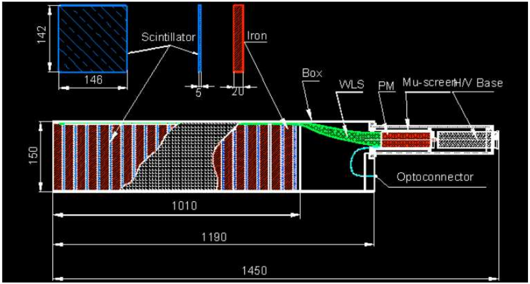
Upgraded BigBite Components

- Estimated rates are 60 $\mathrm{kHz}/\mathrm{cm}^2$ - current drift chambers replaced by GEM chambers
- GEM detectors shown to work up to 2500 $\mathrm{kHz}/\mathrm{cm}^2$ at CERN
- Momentum resolution of $\sigma_p/p \sim 0.5\%$ for e^- of $3-4$ GeV
- BigBite Cerenkov+preshower pushes pion contributions $< 0.1\%$



Hadron Calorimeter, HCAL

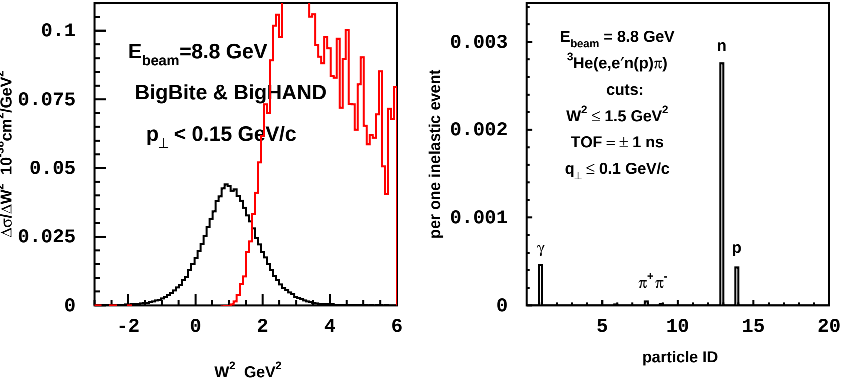
- HCAL based on COMPASS design



- Threshold can be set dramatically higher than original neutron arm, 50 kHz with 50 MeV threshold
- High detection efficiency, $> 95\%$
- Acceptance can be configured to match QE nucleon profile
- Time-of-flight resolution comparable to neutron arm with optimized readout scheme

Quasielastic Selection and Backgrounds

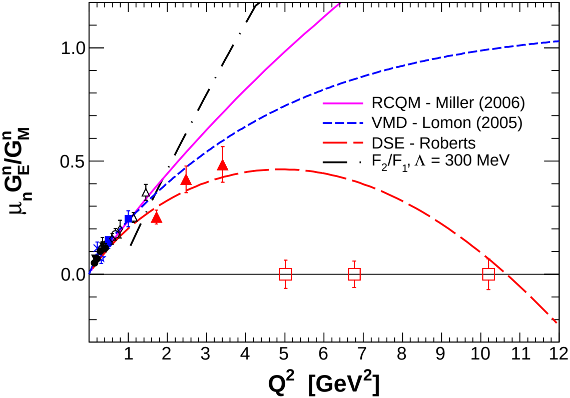
- Cuts on missing momenta, invariant mass allow for suppression of inelastic events
- Inelastics can be corrected using Monte Carlo with MAID or sideband subtraction



- With bending magnet and GEM veto, proton contamination will be negligable

Anticipated Results

Brings G_E^n up to similar level as other form factors in 50 days beamtime



- Strong divergence between different model predictions
- DSE predicts zero crossing

Conclusion

- Measuring the electric form factor of the neutron to high Q^2 helps "complete" our picture of the nucleon
- Super Bigbite allows us to take form factor measurements to very high Q^2 with relative errors comparable to previous measurements
- Will allow for differentiation between several popular form factor models