# Measurements of the Electric Form Factor of the Neutron at High Momentum Transfer

Seamus Riordan

*University of Virginia*
*CEBAF Center F206, Jefferson Laboratory*
*12000 Jefferson Ave., Newport News, VA 23606*

**Abstract.** The electric and magnetic form factors of the nucleon provide experimental access to the underlying charge and magnetic moment distributions of quarks. We have measured the electric form factor of the neutron at four kinematic points between 1.2 and 3.5 GeV$^2$ in Hall A at Jefferson Lab. This more than doubles the momentum transfer region for which this quantity has previously been measured, providing new information on the structure of the neutron. Preliminary results for $G_E^n$ at $Q^2$ = 1.7, 2.5, and 3.5 GeV$^2$ were presented and were compared with QCD-based models and phenomenological approaches.

**Keywords:** neutron, form factors, electric form factor, sachs
**PACS:** 13.40.Gp

## INTRODUCTION

The electromagnetic current of a spin 1/2 target with structure interacting with a single virtual photon can we described using two form factors, the Sachs electric and magnetic form factors, $G_E$ and $G_M$,

$$J^\mu = e\bar{u}(p')\left[\gamma^\mu \frac{G_E(Q^2)+\tau G_M(Q^2)}{1+\tau} + \frac{i\sigma^{\mu\nu}}{2M}q_\nu \frac{G_M(Q^2)-G_E(Q^2)}{1+\tau}\right]u(p)$$

where $p$ and $p'$ are the final and initial momenta of the nucleon, respectively, $q^\mu$ is the four momentum of the virtual photon, $Q^2$ is the four-momentum transfer, $\tau$ is $Q^2/4M^2$, and $M$ is the mass of the target. These form factors carry the physical interpretation of being related to the Fourier transforms of the electric charge distribution, for $G_E$, and magnetic moment distribution, for $G_M$ distributions in the Briet frame.

Form factors are important to our understanding of QCD because they provide experimental access to the underlying structure of the valence and sea quarks in the nucleon. Measurements of these form factors provide important testing grounds for QCD and QCD-inspired models and can provide insight into the dominant mechanisms of nucleon structure. In 1989, measurements of the electric form factor of the proton using techniques involving spin-observables yielded surprising results that were in severe disagreement with previous Rosenbluth separation techniques. Standard Rosenbluth separation had measured $G_E^p$ to be consistent with the so-called "dipole parameterization", but polarization observables showed a reduction in $G_E^p$ as one went to higher $Q^2$ [1]. One of the mechanisms for this reduction was suggested to be due to quark orbital angular momentum in the nucleon [2].

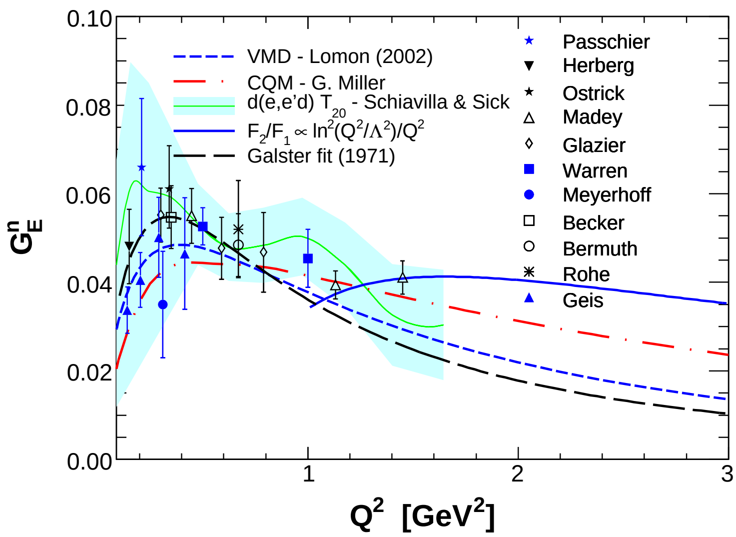


**FIGURE 1.** Previous measurements of $G_E^n$.

While the Sachs form factors of the proton have presently been relatively well measured up to and beyond $Q^2 = 10$ GeV$^2$, precise data on the form factors of the neutron only range up to $2 \sim 4$ GeV$^2$. In particular, the electric form factor, $G_E^n$ has the smallest $Q^2$ coverage of all the form factors, Fig. 1. This is due to two reasons: first, the neutron is an overall neutral particle, making the value of $G_E^n$ small compared to $G_M^n$. This is a hindrance when attempting to employ techniques such as Rosenbluth separation, where the cross section is dominated by $G_M^n$ at high $Q^2$. Second, there are no sufficient free-neutron targets, requiring the neutron to be bound in a nucleus when studied, typically $^2$H or $^3$He.

## JLAB HALL A EXPERIMENT E02-013

In spring 2006, we measured the electric form factor of the neutron, $G_E^n$, at $Q^2 = 1.4, 1.7, 2.5$, and $3.5$ GeV$^2$ through the reaction $^3\overrightarrow{\mathrm{He}}(e,e'n)pp$. This experiment more than doubles the previously measured $Q^2$ range. In this reaction we are sensitive to the form factor ratio $G_E^n/G_M^n$, which is related to the helicity-dependent cross section asymmetry

$$\begin{aligned} A_{\mathrm{phys}} &= \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \\ &= -\frac{2\sqrt{\tau(\tau+1)}\tan(\theta_e/2) G_E/G_M \sin\theta^* \cos\phi^*}{(G_E/G_M)^2 + (\tau + 2\tau(1+\tau)\tan^2(\theta_e/2))} \\ &\quad -\frac{2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2(\theta_e/2)}\tan(\theta_e/2)\cos\theta^*}{(G_E/G_M)^2 + (\tau+2\tau(1+\tau)\tan^2(\theta_e/2))}, \end{aligned}$$

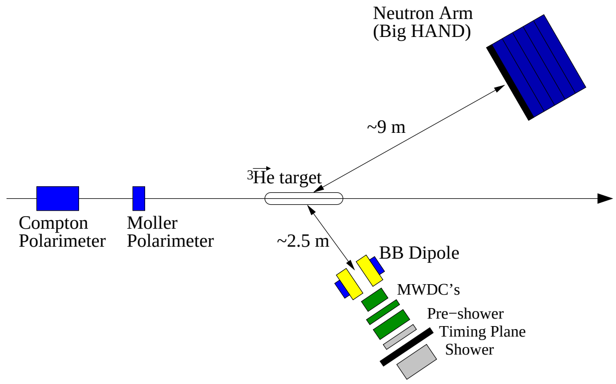


**FIGURE 2.** The detector configuration used in E02-013 (not to scale).

where $\sigma_{+/-}$ is the measured cross section for two electron beam helicities, $\theta_e$ is the scattering angle of the electron, and $\theta^*$ and $\phi*$ are the polar and azimuthal angles of the momentum transfer with respect to the target polarization and electron scattering plane.

A diagram of our experimental setup can be found in Fig. 2. A polarized $^3$He target acts as our effective polarized neutron target. This target was polarized using a hybrid spin-exchange optical pumping technique, where both Rb and K vapors are used to efficiently transfer angular momentum from circularly polarized photons to the $^3$He nucleus. From this target we were able to achieve just below 50% nucleus polarization during a majority of data taking.

To detect the scattered electron, we used the BigBite spectrometer, a large angular and momentum acceptance spectrometer consisting of a large dipole magnet of field integral approximately 1 T m with a newly constructed detector stack. A set of multiple wire drift chambers were used to perform high resolution hit based tracking. This spectrometer provided an overall momentum resolution of approximately $\sigma_{(\delta p/p)} = 1.0\%$ while operating in a high rate environment of luminosity $5 \times 10^{36}$ Hz/cm$^2$.

The recoiling nucleon was detected by a large array of scintillators that formed the neutron arm. It consists of seven layers, each containing $40 \sim 50$ scintillator bars. Sandwiched between these layers are large plates of iron and lead to enhance the nucleon interaction probability. In front of these layers are two additional layers of scintillator called the veto layers which are used to provide basic nucleon charge identification. The nucleon three-momentum was reconstructed through hit position and time of flight.

## Analysis

Analysis of the data is underway. Quasielastic events are extracted from the data by selecting events with small missing parallel and perpendicular momentum and with invariant mass near the nucleon mass. This selection significantly eliminates accidental and inelastic background events as well as suppresses final state interactions.

The asymmetry is corrected for the degree of polarization of the target and polarization of the beam, both periodically measured during the experiment, as well as dilutions due to various background contributions, which are evaluated from the data. By choosing our cuts conservatively, corrections due to inelastic contributions are unnecessary, as supported by Monte Carlo simulations.

## PRELIMINARY RESULTS DISCUSSION

Currently, we have performed a preliminary analysis on $Q^2$ points 1.7, 2.5, and 3.5 GeV$^2$. The remaining analysis requires the development of a complete Monte Carlo simulation of the experiment for confirmation of the interpretation of detector responses, primarily in the neutron arm. Also remaining are final calculations of final state interaction contributions, which are currently underway.

Our present results are consistent with the Galster parameterization [3], proposed in 1971. They do not show scaling from logarithmic pQCD predictions [4] which was shown to have set in for the proton at surprisingly low $Q^2$. Our results are also consistent with a calculation performed at Argonne [5, 6].

Finally, our results can be used in the direct interpretations of the transverse charge distributions for an unpolarized and transversely polarized nucleon in the infinite momentum frame using an impact parameter representation [7], [8].

## REFERENCES


1. O. Gayou *et al.*, Phys. Rev. Lett. **88**, 092301 (2002).
2. G. Miller, Phys. Rev. C **66**, 032201 (2002).
3. S. Galster *et al.*, Nucl. Phys. B **32**, 221 - 237 (1971).
4. A. V. Belitsky, X. Ji, and F. Yuan, Phys. Rev. Lett. **91**, 092003 (2003).
5. M. S. Bhagwat *et al.*, arXiv:nucl-th/0610080
6. I. Cloet *et al.*, arXiv:nucl-th/0804.3118
7. G. Miller, Phys. Rev. C **78**, 032201 (2008).
8. C. Carlson and M. Vanderhaeghen, Phys. Rev. Lett. **100**, 032004 (2008).