MEASUREMENT OF THE NEUTRON ELECTRIC FORM FACTOR G_{E_N} AT HIGH Q^2

KATHY MCCORMICK

Rutgers, The State University of New Jersey
Piscataway, NJ 08855, USA
E-mail: mccormic@jlab.org

FOR THE JLAB HALL A COLLABORATION

Experiment E02-013 [1] at Thomas Jefferson National Accelerator Facility (Jefferson Lab) will measure the neutron electric form factor G_E^n at the high four–momentum transfer values of $Q^2 \approx 1.3$, 2.4 and 3.4 (GeV/c)^2 via a measurement of the cross section asymmetry A_T in the reaction $^3\vec{H}e(\vec{e}, e'n)pp$. This measurement was approved for 32 days of running by Jefferson Lab PAC 21 [2] in January 2002.

1. Introduction

Knowledge of the neutron electric form factor G_E^n is essential for an understanding of nucleon structure. Furthermore it is an ingredient in the analysis of processes involving electromagnetic interactions with complex nuclei. The neutron electric form factor is related to the charge distribution of the valence and sea quarks inside the neutron. In the Breit–frame, where the squared three momentum transfer $\vec{q}^{\,2}$ equals the square of the four momentum transfer Q^2, G_E^n is the Fourier transform of the charge distribution. Such a Fourier transformation using the world data on the Sachs form factors has been done recently [3].

Our knowledge of G_E^n at high Q^2 is rather poor compared to the data available on the Sachs form factors of the proton, G_E^p and G_M^p, as well as on the neutron magnetic form factor G_M^n. The reason is twofold. Because the net charge of the neutron is zero, G_E^n is a very small quantity at low Q^2. Secondly, there are no free neutron targets on which to perform experiments.

Measuring G_E^n in inclusive unpolarized electron scattering is limited in the accuracy of the information it can provide. Several factors make the standard method of the Rosenbluth separation very demanding. Because

$\tau G_M^n \gg G_E^n$ the magnetic form factor dominates the cross section. Additionally, these experiments have to be performed on light nuclei, mostly ^{2}H, so the contribution from the proton to the cross section has to be subtracted. Furthermore to extract the neutron information, the wave functions have to be known, and FSI, MEC, IC, and relativistic effects have to be taken into account. Results for G_E^n determined in quasi elastic $e-d$ scattering [6] are shown in Figure 1. The uncertainties are rather large, and the result is compatible with $G_E^n = 0$, as well as with the Galster "parameterization", an empirical fit to data on G_E^n obtained at lower values of Q^2 [7]: $G_E^n = -\mu_n \tau/(1 + 5.6 * \tau) \cdot G_D$, where G_D is the dipole form factor and $\tau = Q^2/4m_N^2$.

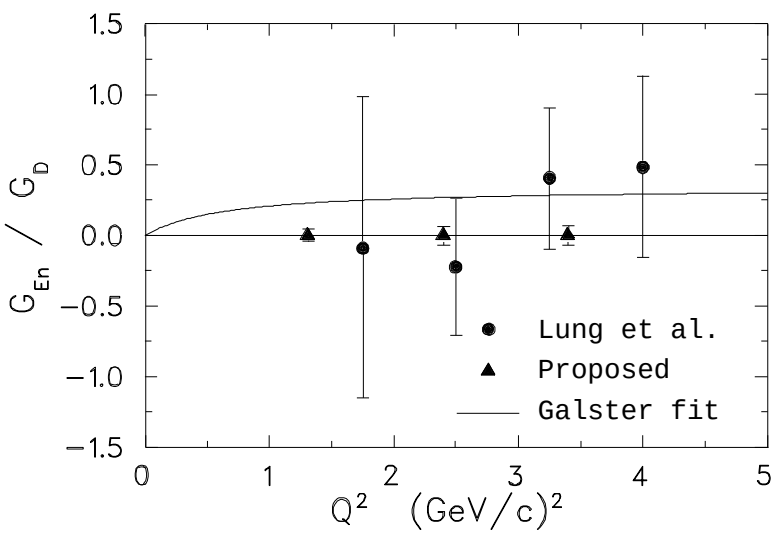

Figure 1. The ratio of the electric form factor of the neutron and the dipole form factor as function of Q^2 determined in quasi elastic $e-d$ scattering [6]. The solid line represents the prediction for G_E^n according to the Galster approximation [7], a phenomenological fit to low Q^2 data. The triangles show the projected data points of this proposal.

Double polarization experiments provide another tool to study G_E^n. By investigating spin observables, the interference between G_E^n and G_M^n enhances the sensitivity of these reactions to G_E^n. In 1984 Woloshyn proposed the use of a polarized ^{3}He target to measure G_E^n [11], and there have been several proposals at JLab making use of this idea [12,13,14]. In the last ten years, a variety of double polarization experiments to measure G_E^n have been performed at different facilities: MIT-Bates, NIKHEF, MAMI, and

JLAB Hall C. Figure 2 shows the published results on G_E^n obtained from these types of experiments [15,16,17,18,19,20,21,22,23,24,25]. Not shown are projected data points or preliminary results from JLab experiments E93-026 and E93-038 [26,27]. Both experiments have already been run in Hall C, but the final results are not yet published. Both Hall C experiments, as well as the experiments at other facilities, are focused on lower momentum transfers, as compared to the proposed measurements of this proposal: the maximum momentum transfer of E93-038 is $Q^2 = 1.47$ (GeV/c)^2, while E93-026 will stop at $Q^2 = 1.0$ (GeV/c)^2.

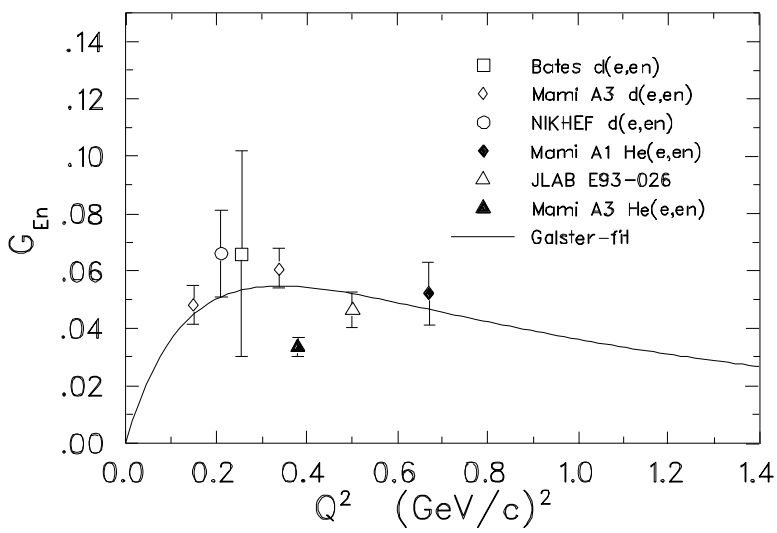

Figure 2. The published world data on G_E^n obtained from double polarization electron scattering experiments [15,16,17,18,19,20,21,22,23,24,25]. Further data from currently running Hall C experiments 93-026 and 93-038 [26,27], which will cover Q^2 values of 0.43, 0.5, 1.0, 1.13, and 1.47 (GeV/c)^2, are not included.

In Fig. 1 the projected data points from our proposed measurements are shown, compared to the results from [6] and the empirical fit from [7]. We plan to measure G_E^n at $Q^2 = 1.3$, 2.4, and 3.4 (GeV/c)^2, where the point at Q^2=1.3 (GeV/c)^2 will allow us to study model dependencies originating from the use of a polarized ^{3}He target and to facilitate the comparison with experimental data obtained by other double polarization experiments. We expect to achieve a statistical uncertainty in $\Delta G_E^n / G_E^n$ of 0.14 in each of the three data points. This accuracy is comparable to the precision of the data on the proton, so a direct comparison of G_E^n and G_E^p will be possible.

The measurement at these momentum transfers is possible because of several factors: firstly, the large acceptance BigBite spectrometer and a neutron detector with an angular acceptance matched to the electron arm results in a large solid angle which cannot be achieved with any of the other standard detectors in Hall A or Hall C; second is the large degree of neutron polarization in the Hall A polarized ^{3}He target, which has a luminosity capability which exceeds that of other polarized targets. The use of the polarized ^{3}He target together with the polarized electron beam allows us to perform a double polarization experiment without the need to use a polarimeter to measure the polarization of the recoiling neutron. Additionally, due to the high momentum of the recoiling neutron, the neutron detector can be built with a very high neutron detection efficiency.

In the following sections, an overview of the experimental apparatus necessary to perform this experiment will be presented, as well as a brief discussion of the theory input necessary to extract G_E^n from the measured asymmetry.

2. Experimental Setup

As illustrated in Fig. 3, this experiment will study the scattering of polarized electrons from a polarized ^{3}He target. The scattered electron will be detected in the BigBite spectrometer, while a new, large solid angle scintillator array, matched to the BigBite acceptance, will be used to detect the recoiling neutron.

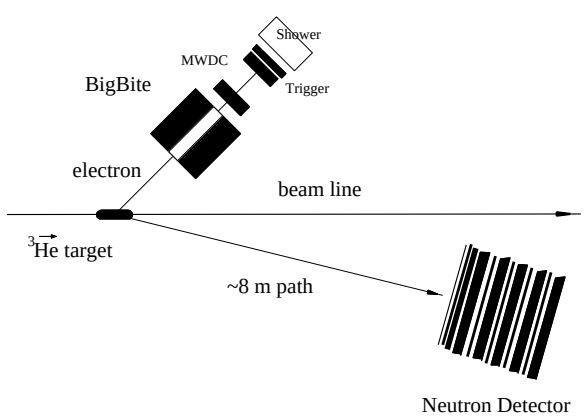

Figure 3. Layout of the experimental setup.

The experiment will utilize the polarized ^3He target that has been constructed and successfully employed for a series of experiments in Hall A. The target is based on the technique of spin-exchange optical pumping, which can be viewed a two step process. In the first step, an alkali-metal vapor such as rubidium (Rb) is polarized by optical pumping using radiation from a laser. In the second step, the polarized Rb atoms collide with ^{3}He atoms, transferring their spin to the ^{3}He nuclei through the hyperfine interaction. Both the Rb atoms and the ^{3}He are contained in sealed glass cells.

The scattered electrons will be detected in the Bigbite spectrometer. BigBite is a non-focusing large momentum and angular acceptance spectrometer that was originally designed and built for use at the internal target facility of the AmPS ring at NIKHEF [29,30]. The spectrometer consists of a single dipole magnet (maximum magnetic field 1.2 Tesla) and a detection system. The detection system will be upgraded to cope with the high rates possible at JLab. The original trigger plane will be replaced by a segmented two-layer array of plastic scintillators, with the first ΔE layer consisting of thin (3 mm) counters and the second E layer consisting of 3 cm thick counters. Each plane will be segmented into 24 elements which will be read out on both sides by fast PMTs. There are also plans to replace the original MWDC with MWPC to improve the rate capability. However, we wish to employ the MWDC for this experiment because of their higher resolution. The momenta of the scattered electrons in this experiment will be between 1200-1500 MeV/c. In order to make their field integral through the BigBite dipole as large as possible, the magnet will be run at its maximum field of 1.2 T. To minimize field gradients at the position of the polarized Helium target, a field clamp will be added to the spectrometer.

This experiment is focused on large momentum transfer, where the recoiling neutrons have kinetic energies of 0.7 GeV, 1.3 GeV, and 1.8 GeV. Such large energies allow a high detection efficiency for neutrons, and at the same time they allow us to apply relatively high thresholds to suppress background from low energy particles. The proposed detector will have five layers, with each layer separated by a 2.75 cm iron converter to increase the probability of a neutron interaction in the detector. Each neutron bar is equipped with two photomultipliers, one on each end. The front of the detector will be covered by a segmented veto detector protected by a 2 cm thick iron plate. Between the veto counters and the front layer of the neutron bars, there will be an additional 3.75 cm thick iron plate to provide additional shielding from low energy particles.

2.1. *Extraction of G_E^n*

The asymmetry of the e-N scattering reaction can be written as

$$A_{exp} = P_e \cdot P_n \cdot D \cdot V \cdot A_{phys}, \tag{1}$$

where P_e is the polarization of the electron beam, P_n is the polarization of the neutron in ^3He and D and V are dilution factors representing the dilution of the asymmetry from background and atoms other than ^{3}He in the target. The physics asymmetry, A_{phys}, is a function of the neutron electromagnetic form factors and the polar (θ^*) and azimuthal (ϕ^*) angles of the target polarization vector relative to the $\vec{q}$ vector:

$$\begin{aligned} A_{phys} = &- \frac{2\sqrt{\tau(\tau+1)}\tan(\theta/2)G_{En}G_{Mn}\sin\theta^\star\cos\phi^\star}{(G_{En})^2 + (G_{Mn})^2(\tau + 2\tau(1+\tau)\tan^2(\theta/2))} \\ &- \frac{2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2(\theta/2)}\tan(\theta/2)(G_{Mn})^2\cos\theta^\star}{(G_{En})^2 + (G_{Mn})^2(\tau + 2\tau(1+\tau)\tan^2(\theta/2))} \ . \end{aligned} \tag{2}$$

As seen from Eq. 2, G_E^n is nearly proportional to $A_\perp$. However, due to the large acceptance of the Bigbite spectrometer and the neutron detector array, the perpendicular spin alignment can only be made for part of the acceptance, and longitudinal contributions to the asymmetry have to be taken into account.

In practice, other effects have to be taken into account, such as relativity, final state interactions and the fact that the neutron is embedded in the nuclear medium. To model these effects, Misak Sargsian has calculated the expected asymmetry A_{phys} in the Generalized Eikonal Approximation [31]. This calculation will be used to extract the neuteron electric form factor by varying the form factor used in the calculation until agreement with the measured asymmetry is observed.

3. Conclusion

We will measure G_E^n at $Q^2 = 1.3$, 2.4 and 3.4 (GeV/c)^2 through a measurement of the cross section asymmetry of the reaction $^3\vec{H}e(\vec{e}, e'n)pp$. This experiment will take place in Hall A, utilizing the BigBite spectrometer to detect electrons scattered off the Hall A polarized ^{3}He target, and an array of scintillators to detect the recoiling neutron. There are no other accurate measurements of G_E^n at these momentum transfers, and the existing data in this kinematical range, extracted from quasielastic $e-d$ scattering, have large uncertainties and are compatible with $G_E^n = 0$ as well as with the Galster approximation.

Knowledge of the neutron electric form factor G_E^n is essential for the understanding of the nucleon structure. Futhermore, it is a needed input in the analysis and interpretation of processes involving the electromagnetic interaction with nuclei. We propose to measure G_E^n to a statistical accuracy of $\Delta G_E^n/G_E^n = 0.14$, which would bring its precision to a level comparable with that of the other Sachs form factors in this kinematical regime.

Acknowledgments

Thanks to Bogdan Wojtsekhowski for valuable comments on the manuscript. The Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility for the United States Department of Energy under contract DE-AC05-84ER40150.

References

1. Jefferson Lab Proposal PR02-013, unpublished.
2. Jefferson Lab PAC 21 report, unpublished.
3. J.J. Kelly, arXiv:nucl-ph/0111251.
4. V. E. Krohn and G. R. Ringo, Phys. Rev. **148**, 1303 (1966).
5. L. Koester, W. Nistler, and W. Waschkowski, Phys. Rev. Lett. **36**, 1021 (1976).
6. A. Lung *et al.*, Phys. Rev. Lett. **70**, 718 (1993).
7. S. Galster *et al.*, Nucl. Phys. **B32**, 221 (1971).
8. N. Dombey, Rev. Mod. Phys. **41**, 236 (1969).
9. A. I. Akhiezer and M. P. Rekalo, Sov. J. Part. Nucl. **3**, 277 (1974).
10. R. Arnold, C. Carlson, and F. Gross, Phys. Rev. **C 23**, 363 (1981).
11. B. Blankleider and R. M. Woloshyn, Phys. Rev. **C 29**, 558 (1984).
12. R. D. McKeown, spokesperson, JLab proposal PR91-020.
13. F. Hersman at T. Smith, spokespeople, JLab proposal PR93-037.
14. W. Korsch and R. McKeown, spokespeople, Jlab proposal PR94-021.
15. T. Eden *et al.*, Phys. Rev. **C 50**, R1749 (1994).
16. M. Meyerhoff *et al.*, Phys. Lett. **B 327**, 201 (1994).
17. H. Schmieden, Poc. of the 12th Int. Symposium on High–Energy Spin Physics, Amsterdam (1996), ed. by C.W. de Jager et al., World Scientific 1997, p.538.
18. F. Klein and H. Schmieden, Nucl. Phys. **A623**, 323c (1997).
19. F. Klein, Proc. of the 14th Int. Conf. on Particles and Nuclei, ed. by C.E. Carlson and J.J. Domingo, World Scientific 1997, p.121.
20. M. Ostrick *et al.*, Phys. Rev. Lett. **83**, 276 (1999).
21. C. Herberg *et al.*, Eur. Phys. J. **A5**, 131 1999).
22. I. Passchier *et al.*, Phys. Rev. Lett. **82**, 4988 (1999).
23. D. Rohe *et al.*, Phys. Rev. Lett. **83**, 4257 (1999).
24. H. Zhu *et al.*, Phys. Rev. Lett. **87**, 081801 (2001).
25. J. Becker *et al.*, submitted to The Eur. Physical Journal **A**.

26. D. Day, spokesperson, JLab proposal E93-026.
27. R. Madey and S. Kowalski, spokespeople, Jlab proposal E93-038.
28. R. Madey and S. Kowalski, spokespeople, JLab proposal PR01-106.
29. D. J. J. de Lange *et al.*, Nucl. Instr. and Meth. **A 406**, 182 (1998).
30. D. J. J. de Lange *et al.*, Nucl. Instr. and Meth. **A 412**, 254 (1998).
31. M. M. Sargsian, arXiv:nucl-th/0110053 and private communication.