Measuring G_E^n at High Momentum Transfers

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Abstract. Experiment E02-013 at Thomas Jefferson National Accelerator Facility will extend the measured range of the neutron electric form factor G_E^n to Q^2=3.4 (GeV/c)^2 through a measurement of the cross section asymmetry in the reaction $^3\vec{H}e(\vec{e},e'n)$. Recent theoretical investigations, motivated by the results on the ratio of the proton electric and magnetic form factor, predict higher values of G_E^n compared to older predictions. The experiment utilizes a polarized ^{3}He target and the polarized CEBAF electron beam. Scattered electrons will be detected in the BigBite spectrometer, recoiling neutrons in an array of scintillators. The experimental and theoretical developments needed to perform the measurement and to extract G_E^n from ^3He will be described. Concepts of extending the measurement of G_E^n to even higher momentum transfers will be discussed.

INTRODUCTION

Elastic electron scattering off the nucleon provides important ingredients to our knowledge of nucleon structure. In the one-photon approximation the interaction is fully characterized by only two independent form factors. There are well founded predictions for the Q^2 dependence of the form factors and their ratio in the limit of high momentum transfers in pQCD [1], indicating that the ratio becomes constant. However recent results [2, 3] on the electric form factor of the proton G_E^p show that the ratio G_E^p / G_M^p declines as Q^2 increases, and therefore pQCD is not applicable up to 10 (GeV/c)^2. According to these measurements, G_M^p and G_E^p behave differently, starting at Q^2 = 1 (GeV/c)^2. The same mechanism causing this deviation should also be present in the neutron, and therefore it is an important question, how G_E^n develops in the Q^2 regime of several (GeV/c)^2.

DATA ON G_E^N

Although experiments to measure G_E^n have been performed at all electromagnetic labs for the last two decades, our knowledge of this quantity at higher momentum transfers is still rather poor compared to the data available on G_E^p, G_M^p, and G_M^n. The reason is manyfold. First of all, there are no targets of free neutrons with sufficient density to perform electron scattering experiments on. Therefore experiments have to be performed on light nuclei, and the contribution from the proton has to be taken into account. Secondly due to the zero charge of the neutron, G_E^n is small at low momentum transfers, whereas at higher momentum transfers, the cross section is dominated by the magnetic form factor. All these factors make the standard method of the Rosenbluth separation very

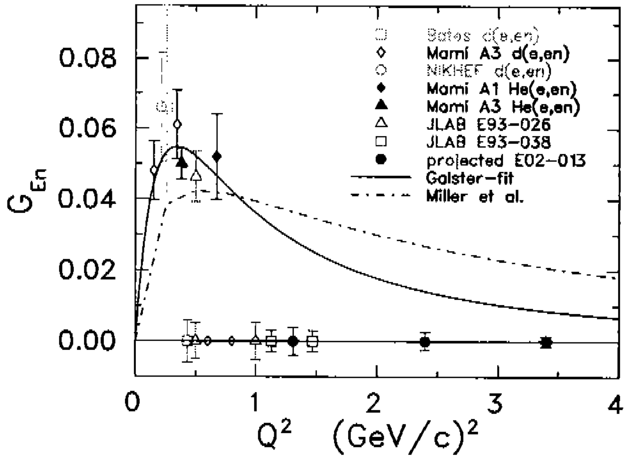

FIGURE 1. Data on G_E^n from double polarization experiments. For experiments which have not published their results yet, only the expected uncertainty is plotted. Also shown are the projected error bars of E02-013. The solid line represents the predictions from [5], the dashed dotted line the ones from [16]

demanding. At SLAC G_E^n was extracted up to $Q^2 = 4$ (GeV/c)^2 from quasi elastic e – d scattering data [4], however 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 [5].

Double polarization experiments are another tool to study G_E^n. By investigating spin observables, the sensitivity of these reactions is enhanced due to the interference between G_E^n and G_M^n. Figure 1 shows the published results on G_E^n obtained with this method [6] – [12] together with the projected error bars for experiments which have already collected data, but not yet published [13, 14]. Also the projected error bars for the future Jlab Hall A experiment E02-013 are shown [15]. These experimental data are compared to the Galster approximation and to the calculations from [16]. The latter theoretical calculations are also able to reproduce the data on G_E^p from [2, 3].

The double polarization technique was already introduced 20 years ago [17] – [19]. In all of them a polarized electron beam was utilized, together with either a polarized ND_3 or polarized ^{3}He target, or with an unpolarized deuterium target (and a neutron polarimeter).

EXPERIMENT E02–013

The previously described experiments provide an accurate determination of G_E^n up to 1.47 (GeV/c)^2. For an further increase in Q^2 an experimental approach with a much higher figure-of-merit (FOM) is required. Compared to the previous experiments the following items have been optimized for Jlab Hall A Experiment E02-013:

- the solid angle of the electron detector,
- the neutron detector efficiency,
- the type of the (polarized) target.

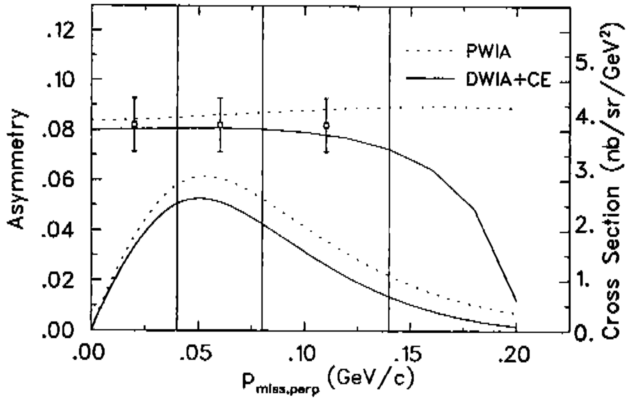

FIGURE 2. The GEA predictions for the cross section and the asymmetry in E02-013. For each Q^2 the asymmetry will be measured in three bins in $p_{m,\perp}$. The error bars show the projected statistical accuracy.

The BigBite spectrometer, which was originally developed and used at NIKHEF [20], is a recent addition to the Jlab Hall A spectrometers. It has a large solid angle of 76 msr for a 40 cm long target. For this experiment the detector package will consist of three drift chambers to obtain the tracking information, a segmented trigger scintillator plane and a lead glass calorimeter for particle identification. The momentum resolution with BigBite for electrons with momenta up to 1.5 GeV/c is 1%, and therefore sufficient to identify quasi elastic scattering events and separate them from other reactions. The luminosity available with the polarized ^{3}He target is about 10^{36} Hz/cm^2, about a factor of 10 higher than the one in a recent Jlab experiment utilizing a polarized ND_3 target [13]. According to our simulations BigBite can still be used at this luminosity, despite of the direct view of the target by the detectors.

The recoiling neutrons will have kinetic energies above 1 GeV at the proposed kinematics. Therefore they can be efficiently detected in an array of neutron detectors, and at the same time relatively high detector thresholds can be utilized to suppress background. The detector will have five layers of 10 cm thick plastic scintillators, with each layer separated by iron converters to further increase the neutron detection efficiency. Two layers of thin scintillators in front of the detector will be used to veto charged particles. The neutron detector will be large enough to match the solid angle of BigBite.

To extract G_E^n from the experimentally measured asymmetry, nuclear effects have to be taken into account. The Generalized Eikonal Approximation (GEA) [21] provides the appropriate framework for this extraction in the proposed range of Q^2. The GEA prediction for the asymmetry as a function of the missing transverse momenta $p_{m,\perp}$ is shown in Fig. 2. The GEA calculations as well as experimental data from Jlab Hall B for the unpolarized reaction ^{3}He(e,e′ p) have demonstrated the dominance of quasi-elastic scattering at $p_{m,\perp}$ below 0.15 GeV/c, when a modest cut on $p_{m,\|}$ is applied.

The error budget for the highest Q^2 point is shown in Tab. 1. For each Q^2 we will achieve a statistical accuracy of 14% within each of the three bins in $p_{m,\perp}$. The statistical and systematic uncertainties will contribute equally to the total uncertainty in G_E^n.

TABLE 1. The contributions to the error in G_E^n at $Q^2 = 3.4$ (GeV/c)^2.

quantity	**expected value**	**rel. uncertainty in G_E^n**
raw asymmetry A_{exp}	-0.0233	
⇒ statistical error in G_{En}		14.2%
beam polarization P_e	0.75	3%
target polarization P_{He}	0.40	4%
neutron polarization P_n	$0.86 \cdot P_{He}$	2%
dilution factor D (nitrogen)	0.94	3%
dilution factor V (background)	0.91	4%
correction factor for $A_{\parallel}$ components	0.94	<3%
G_{Mn}	0.057	5%
nuclear correction factor	1.0 – 0.85	5%
⇒ systematic error in G_{En}		10.4%

FUTURE DEVELOPMENTS

The highest Q^2 point at which G_E^n will be extracted in experiment E02-013 is at $Q^2 = 3.4$ (GeV/c)^2. This limit is based on the achievable luminosity and maximum polarization of the polarized ^{3}He target and the parameters of the BigBite spectrometer. However, this Q^2 is still small compared to the available data on G_E^p, G_M^p, and G_M^n. For testing recent theoretical calculations it is desirable to go beyond that limit. Because the cross section as well as the asymmetry is getting smaller, the FOM has to be further increased.

Improvements necessary to measure G_E^n at 5 (GeV/c)^2 are expected in two areas. An increase of luminosity with the polarized ^{3}He target seems feasible. In its present configuration, the target has its highest FOM at a beam current of 12-15 μA, when the beam induced depolarization time is on the order of 30 hours. To further increase the beam current a higher rate of polarization and a faster delivery of the polarized atoms to the target cell becomes mandatory. Because of the steady advances in solid-state laser technology, 100-200 W lasers suitable for polarizing Rb atoms are becoming available. Changes in the cell design, like utilizing schemes with more than one tube between the pumping cell and the target cell, will provide improved flow of the polarized ^{3}He [22]. To withstand higher beam currents modifications of the end windows of the glass cells are considered.

The second limitation is the maximum momentum accepted in the BigBite spectrometer. The FOM of the experiment is approximately proportional to $E_f^2/E_i^2 = (E_i - Q^2/2M)^2/E_i^2$, where E_i (E_f) is the initial (final) energy of the electron. This illustrates, that by using higher beam energies, and using a medium to large acceptance spectrometer capable of detecting electrons at higher momenta than BigBite will further increase the FOM. With the proposed MAD spectrometer for Jlab Hall A together with the proposed energy upgrade to 12 GeV of Jlab experiments to measure G_E^n up to 5 (GeV/c)^2 will become feasible. A specially designed electron spectrometer, with an even larger angular acceptance than MAD, could further boost the FOM and therefore the possibilities to measure G_E^n.

CONCLUSIONS

After the good progress in the experimental determination of the electromagnetic form factors in the recent years, Jlab experiment E02-013 will push the knowledge of G_E^n even further. It will measure G_E^n up to momentum transfers of 3.4 $(\mathrm{GeV/c})^2$. There are possibilities that future experiments can go even beyond that limit, by improving the luminosity and polarization of the polarized ^{3}He target, and utilizing the possibilities of the proposed Jlab energy upgrade together with new spectrometers.

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