PROSPECT FOR MEASURING G_E^N AT HIGH MOMENTUM TRANSFERS

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Experiment E02-013, approved by PAC21, will measure the neutron electric form factor at Q^2 up to 3.4 $(GeV/c)^2$, which is twice that achieved to date. The main features of the new experiment will be the use of the electron spectrometer BigBite, a large array of neutron detectors, and a polarized $^3\vec{He}$ target. We present the parameters and optimization of the experimental setup. A concept of an experiment for G_E^n where precision G_E^p data is used for calibration of the systematics of a Rosenbluth type measurement is also discussed.

1. Introduction

Elastic electron scattering, which in the one-photon approximation is characterized by two form factors, is the simplest exclusive reaction on the nucleon. It provides important ingredients to our knowledge of nucleon structure. There are well-founded predictions of pQCD for the Q^2 dependence of the form factors and their ratio in the limit of large momentum transfer [1]. Predictions of a fundamental theory always attract substantial attention from experimentalists. Recent surprising results on G_E^p show that the ratio G_E^p/G_M^p declines sharply as Q^2 increases, and therefore pQCD is not applicable up to 10 $(GeV/c)^2$. According to [2,3] the electric and magnetic form factors behave differently, starting at $Q^2 \approx 1$ $(GeV/c)^2$. The same mechanisms causing this deviation should also be present in the neutron. It is an intriguing question, how the ratio G_E^n/G_M^n develops in this Q^2 regime, where confinement plays an important role.

2. World data on G_E^n

The study of G_E^n has been a priority in electromagnetic labs for the last 15 years. Figure 1 presents recent data [4,5,6,7,8,9] along with points representing the accuracy of JLab experiments [10,11] which have already collected data, and the expected statistical accuracy of experiment E02-013. Presently

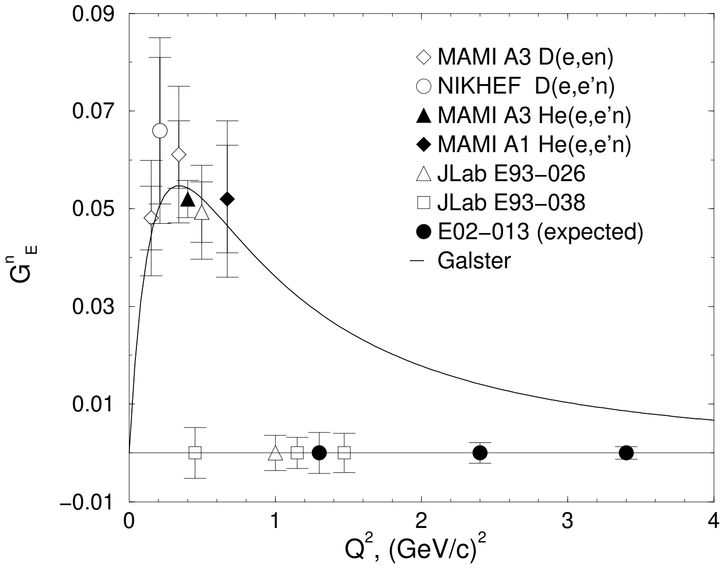

Figure 1. Recent data on G_E^n from double polarization experiments, the obtained accuracy and Q^2 of JLab experiments, and the expected accuracy of E02-013.

published results can be fitted by the Galster approximation [12]. The double polarization technique used in these experiments was introduced more than 20 years ago [14,15,16]. The experiments used a polarized electron beam and three different targets: unpolarized deuterium (together with a neutron polarimeter), polarized ND_3, and polarized ^{3}He.

3. Experiment E02-013

The steady progress of the E93-028 [10] and the E93-026 [11] experiments has made possible the accurate determination of G_E^n up to 1.47 (GeV/c)^2. The next step in Q^2 requires an experimental approach with much higher Figure-of-Merit (FOM).

In E02-013 [13] we optimized the setup in several respects:

- the solid angle of the electron spectrometer,
- the neutron detector efficiency and the trigger logic,
- the type of polarized target.

A recent addition in Hall A at JLab, the BigBite spectrometer developed by NIKHEF [17], has a 76 msr solid angle for a 40 cm long target. We found that for the identification of quasi-elastic scattering, the momentum

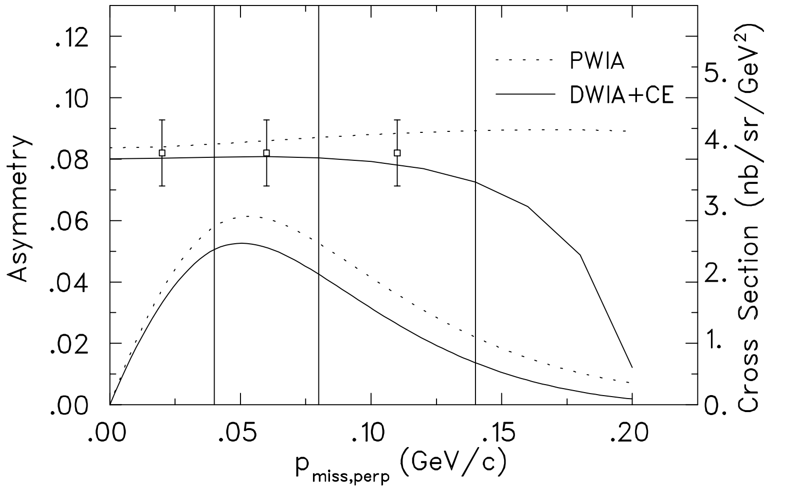

Figure 2. The GEA predictions for cross section and asymmetry in E02-013. The error bars show the expected accuracy. For each Q^2 the asymmetry will be measured for three values of $p_{miss,perp}$.

resolution of BigBite ($\approx$ 1%) is sufficient for electron momenta up to 1.5 GeV/c. The luminosity available with the $^3\vec{H}e$ target is about 10^{36} Hz/cm^2. According to our calculations it can be used with BigBite in spite of the direct view of the target by the detectors. Neutrons with kinetic energy above 1 GeV with which we have to deal at the proposed momentum transfers, can be efficiently detected with a relatively high detector threshold, which allows to suppress background and is crucial for the operation at the expected luminosity, which is about a factor of 10 higher than used in a recent JLab experiment [10] with a polarized ND_3 target.

In the last several years the theoretical development of the Generalized Eikonal Approximation (GEA) [18] has provided a framework for taking into account nuclear effects in the extraction of G_E^n from the experimental asymmetry. The GEA prediction for the asymmetry as a function of the missing transverse momenta $p_{miss,perp}$ is shown in Fig. 2. The GEA calculations and experimental data from JLab Hall B for the unpolarized reaction ^{3}He(e,e'p) have demonstrated the dominance of quasi-elastic scattering at $p_{miss,perp}$ below 0.15 GeV/c, when a modest cut of 0.5 GeV/c is applied on $p_{miss,parallel}$.

Table 1 summarizes the contributions to the error budget for the highest Q^2 point. For each Q^2 the measurement will be done with ~14% statistical accuracy for three intervals of $p_{miss,perp}$. As a result the systematics will be evaluated by comparison of an experimental asymmetry and the GEA prediction vs $p_{miss,perp}$.

Table 1. The contributions to the error budget in G_E^n for the data point at Q^2=3.4 $(GeV/c)^2$.

quantity	expected value	rel. uncertainty
statistical error in raw asymmetry A_{exp}	-0.0233	13.4%
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	0.94	3%
dilution factor V	0.91	4%
correction factor for $A_{parallel}$	0.94	1%
G_M^n	0.057	5%
nuclear correction factor	1.0 – 0.85	5%
statistical error in G_E^n		13.8%
systematic error in G_E^n		10.4%

4. Future considerations

Experiment E02-013 is based on presently achieved parameters of the $^3\vec{He}$ target and the existing electron spectrometer. With additional developments the FOM of the experiment can be increased by a factor of 5 and a measurement of G_E^n will be feasible at Q^2 up to 5 $(GeV/c)^2$.

4.1. *Luminosity with the $^3\vec{He}$ target*

The present configuration of the $^3\vec{He}$ target has the highest FOM at a beam current of 12-15 μA, when the beam-induced depolarization time is on the order of 30 hours. The use of the higher beam current requires a higher rate of polarizing and faster delivery of the polarized gas to the target cell. Advances in solid-state laser technology have made available 100 and even 200 W light power suitable for polarizing Rb atoms. Fig. 3 shows the target cell where the polarized gas flows through two tubes connecting the pumping and target cells. The flow will dramatically reduce the time for exchange of the polarized atoms between the pumping cell and the target cell.

4.2. *High momentum 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 the $E_{i(f)}$ is the initial(final) electron energy. By using a beam energy of 7.8 GeV it is possible to increase the FOM by a

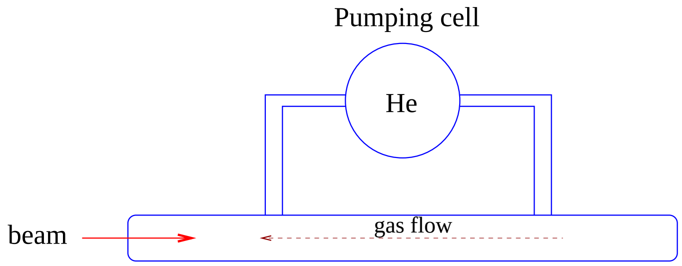

Figure 3. The target cell with two attachments to the pumping cell which allow the gas flow.

factor of 2.7 in comparison to the plan in E02-013 [13] for Q^2=3.4 (GeV/c)^2. It requires a new spectrometer for scattered electrons with a momentum 6 GeV/c and a solid angle of 75 msr. For Q^2= 5 (GeV/c)^2 the gain of FOM is 3.4. The relative momentum resolution should be of 0.5% to keep a W resolution sufficient for identification of the quasi-elastic events. The base component of the spectrometer is a dipole magnet with a 4.5 T·m field integral and a 35 cm open gap. The scheme of a spectrometer based on such a dipole magnet is shown in Fig. 4 [19]. We call it Super BigBite. Its characteristics are similar to BigBite, but with the momentum range extended by a factor of 5-8. As in the case of BigBite, the detector will be open to the target, so it can be used mainly with a polarized target luminosity.

5. Rosenbluth approach

In the Rosenbluth method the form factors ratio $g = G_E/G_M$ is obtained from two (or more) measurements at different beam energies at a fixed value of Q^2. The following equation is used to find g:

$$g^2 = \tau \cdot \frac{F^2_{\epsilon_1}\epsilon_2^{-1} - F^2_{\epsilon_2}\epsilon_1^{-1}}{F^2_{\epsilon_2} - F^2_{\epsilon_1}} \qquad (1)$$

where F is the total form factor measured experimentally, $F^2 = \left(G_E^2 + \frac{\tau}{\epsilon}G_M^2\right)/(1+\tau)$, $\tau = \frac{Q^2}{4M_N^2}$ and ϵ is virtual photon polarization. The uncertainty of g, which is growing with Q^2, can be estimated from the equation

$$\sigma(g^2) \approx \frac{\sigma(F^2_\epsilon)}{F^2_\epsilon}\frac{\sqrt{2}\cdot\tau}{\epsilon_1 - \epsilon_2} \qquad (2)$$

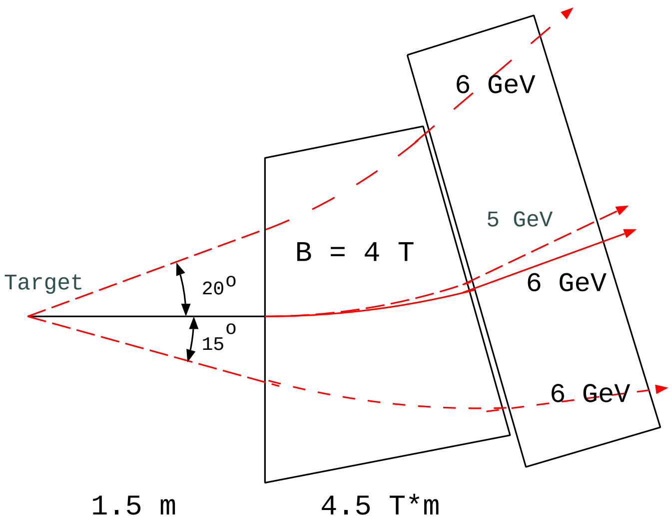

Figure 4. A side view of the Super BigBite.

where we neglect uncertainties in ϵ and τ. The total form factor is calculated from the event rates and other parameters of the experiment as

$$F^2 = N_{events}/[I_{beam} \cdot d_{target} \cdot t_{DAQ} \cdot \sigma_{Mott} \cdot \Omega_e \cdot \eta_e] \tag{3}$$

Each of these experimental parameters - the beam current I_{beam}, the target density d_{target}, the data taking time t_{DAQ}, the Mott cross section σ_{Mott}, the detector solid angle Ω_e, and the detection efficiency η_e - is known with limited accuracy, which contributes to the systematics of the measurement. Some of them cancel in the calculation of the ratio g, because of the good stability of the target and detectors. A sufficiently accurate determination of the beam energy, the detector solid angle, and the scattering angle present a big challenge for the experiment. In the best case the overall systematic error is on the level of a few percent. By detecting the recoiling proton, as was suggested in LOI99-103 [20], the acceptance of the detector can be excluded from the list of problems, because at a given value of the proton momentum the solid angle of the detector is fixed. Experiment E01-001[21], which used such an approach, recently took data in JLab Hall A.

Quasi-elastic electron scattering from the deuteron $D(e, e'n)p$, with the ratio method suggested by Durand [22], has been used for determination of the neutron magnetic form factor in recent experiments at Bonn [23], Mainz [24], and JLab [25]. The same reaction can be used for measurement of the ratio G_E^n/G_M^n even with less stringent requirements on the knowledge of the absolute neutron detection efficiency. The small value of G_E^n made such measurement quite difficult; however, as we are proposing here, the problem can be solved by using the complementary $D(e, e'p)n$ reaction for calibration of the experiment. We will use the fact that in the Q^2 region of 5 $(\mathrm{GeV/c})^2$ the ratio of the proton form factors G_E^p/G_M^p is already well known from JLab experiments [2,3]. In a dedicated experiment the accuracy of g_p can be improved to the level of 2-3%.

The proposed scheme will use the magnetic spectrometer as an electron arm and a non-magnetic detector as a hadron arm. The last one will consist of a large array of plastic scintillators and veto detectors. At a few $(\mathrm{GeV/c})^2$ momentum transfer the kinetic energy of the recoiling nucleon is above 1 GeV and proton and neutron interactions with the detector are similar (nuclear interaction dominates). The neutron detection efficiency of different measurements will be similar to each other because of equal kinetic energy of the neutron in both measurements. Most of the remaining variations of the detector efficiency and solid angle will affect in the same way the complementary reaction $D(e, e'p)n$.

The ratio $F^2_{\epsilon_2}/F^2_{\epsilon_1}$, which defines as the value of g_n, can be expressed in the proposed experiment as

$$\left(\frac{F^n_{\epsilon_2}}{F^n_{\epsilon_1}}\right)^2 = \left(\frac{F^p_{\epsilon_2}}{F^p_{\epsilon_1}}\right)^2 \cdot \frac{N_2^{e,e'n}}{N_1^{e,e'n}} \cdot \frac{N_1^{e,e'p}}{N_2^{e,e'p}} \cdot \frac{\Omega^n_{\epsilon_2}}{\Omega^n_{\epsilon_1}} \cdot \frac{\Omega^p_{\epsilon_1}}{\Omega^p_{\epsilon_2}} \cdot \frac{\eta^n_{\epsilon_2}}{\eta^n_{\epsilon_1}} \cdot \frac{\eta^p_{\epsilon_1}}{\eta^p_{\epsilon_2}} \quad (4)$$

Several parameters such as the beam current, the electron-arm solid angle and efficiency, the Mott cross section, the data taking time, and the target parameters all cancel out from the final ratio of the form factors at two different values of ϵ. The remaining parameters are the neutron/proton detector solid angle Ω and efficiency η, whose variations for different ϵ need to be controlled.

For the proposed non-magnetic detector at large nucleon energy the neutron and proton detector efficiency will be almost equally affected by any change of rates and drifts of detector parameters, so it will be compensated. The detector solid angle is defined by the detector size. It can be well controlled and small changes will be the same for both proton and neutron channels.

The prospect of the Rosenbluth approach for a measurement of G_E^n depends on the high rate capability of the neutron detector. The potential FOM is higher than that possible in the double polarization approach by a factor 10-20, when it operates at a luminosity of 10^{38} Hz/cm^2. Experiment E93-038[11], which was done at a similar luminosity, developed the appropriate techniques for background reduction.

Conclusion

The experimental field of neutron electromagnetic form factors made very good progress in recent years. The present frontier for G_E^n is Q^2 above 2 $(\mathrm{GeV/c})^2$. JLab experiment E02-013 will do the measurement of G_E^n up to $Q^2 = 3.4$ $(\mathrm{GeV/c})^2$. There are possibilities of the further enhancements of the luminosity and polarization of the polarized $^3\vec{He}$ target. The Rosenbluth approach may also be revived by using calibration on the proton G_E^p/G_M^p ratio.

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