A precise measurement of the neutron magnetic form factor G_M^n in the few-GeV^2 region

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The neutron elastic magnetic form factor G_M^n has been extracted from quasielastic scattering from deuterium in the CEBAF Large Acceptance Spectrometer (CLAS) at Jefferson Lab. The kinematic coverage of the measurement is continuous over a broad range, extending from below 1 (GeV/c)^2 to nearly 5 (GeV/c)^2 in four-momentum transfer squared. High precision was achieved by employing a ratio technique in which many uncertainties cancel, and by a simultaneous in-situ calibration of the neutron detection efficiency, the largest correction to the data. Neutrons were detected using electromagnetic calorimeters and time-of-flight scintillators. Data were taken at two different electron beam energies, allowing up to four semi-independent measurements of G_M^n to be made. The dipole parameterization is found to provide a good description of the data for $Q^2 > 1$ $(GeV/c)^2$.

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1. INTRODUCTION

The elastic form factors of the proton and neutron are fundamental quantities which have been studied for decades. The dominant features of the larger form factors G_M^p, G_E^p, and G_M^n are described by the dipole form $G_D = (1 + Q^2/0.71)^{-2}$ within the experimental uncertainties. Current directions in the field include precise measurements of the neutron electric form factor,[1] extractions of the strange electric and magnetic form factors for the proton,[2] as well as time-like form factors.[3] There has been renewed theoretical interest on several fronts.[4] First, models of the nucleon ground state can often be used to predict several of these quantities, and it has proved to be very difficult to describe all of the modern data simultaneously in a single approach. Second, lattice calculations are now becoming feasible in the few-GeV^2 range, and over the next decade these calculations will become increasingly precise. Finally, since elastic form factors are a limiting case of the generalized parton distributions (GPDs), they can be used to constrain GPD models.[5] High precision and large Q^2 coverage is important.[5] At present the neutron magnetic form factor at large Q^2 is more poorly known than the proton form factors.

2. THE CLAS MEASUREMENT

This measurement[6] makes use of quasielastic scattering on deuterium where final state protons and neutrons are detected. The ratio of $^2\mathrm{H(e,e'n)}$ to $^2\mathrm{H(e,e'p)}$ in quasi-free kinematics is approximately equal to the ratio of elastic scattering from the free neutron and proton. The ratio is:

$$R_D = \frac{\frac{d\sigma}{d\Omega}[^2\mathrm{H(e,e'n)_{QE}}]}{\frac{d\sigma}{d\Omega}[^2\mathrm{H(e,e'p)_{QE}}]} = a \cdot \frac{\frac{(G_E^n)^2+\tau(G_M^n)^2}{1+\tau} + 2\tau(G_M^n)^2\tan^2(\frac{\theta}{2})}{\frac{(G_E^p)^2+\tau(G_M^p)^2}{1+\tau} + 2\tau(G_M^p)^2\tan^2(\frac{\theta}{2})} \tag{1}$$

Using deuteron models one can accurately compute the correction factor $a(Q^2, \theta_{pq})$ where θ_{pq} is the angle between the neutron nucleon direction and the three-momentum transfer. It is nearly unity for quasielastic kinematics and higher Q^2. The value of G_M^n is then obtained from the measured value of R_D and the experimentally known values of G_E^n, G_M^p, and G_E^p. This method has been used previously.[7] The $(e, e'n)$ and $(e, e'p)$ reactions were measured in CLAS at the same time from the same target. Use of the ratio R_D under these circumstances reduces or eliminates several experimental uncertainties, such as those associated with the luminosity measurement or radiative corrections. The remaining major correction is the neutron detection efficiency.

Neutrons were measured in two CLAS scintillator-based detectors: the forward-angle electromagnetic shower calorimeters and the time-of-flight (TOF) scintillators. The efficiency measurement was performed using tagged neutrons from the $^1\mathrm{H(e,e'\pi^+)X}$ reaction where the mass of the final state M_X was chosen to be that of the neutron. Since the precise value of the detection efficiency can vary with time-dependent and rate-dependent quantities such as photomultiplier tube gain, the detection efficiency was measured *simultaneously* with the primary deuterium measurement. Two separate targets were positioned in the beam at the same time, one for deuterium and the other for hydrogen, separated by less than 5 cm. Plots of the resulting neutron detection efficiencies are shown in Fig. 1. The main plot shows the results for the forward electromagnetic shower calorimeter, while the inset shows the results for the time of flight scintillators. Note the agreement between the two different beam energies. The systematic uncertainty

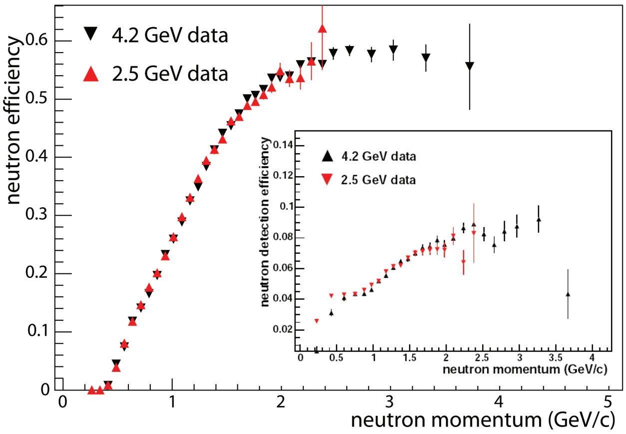

Fig. 1. Detection efficiency versus momentum for neutrons detected in the forward-angle electromagnetic calorimeters at two different beam energies and in the TOF system (inset). The efficiency has been integrated over all six sectors of the CLAS spectrometer.

in the neutron detection efficiency was estimated by using different parameterizations of the fit to the data and extracting the difference as a function of momentum transfer. Uncertainties in the range 1-2% were obtained. The full inventory of systematic uncertainties is described elsewhere.[6] The total uncertainty is less than 2.5% across the full Q^2 range.

The CLAS extraction of $G_M^n(Q^2)$ consists of multiple overlapping measurements. The time of flight scintillators cover the full angular range of the spectrometer, while the forward calorimeters cover a subset of these angles so $G_M^n(Q^2)$ can be obtained from two independent measures of the neutron detection efficiency. In addition, the experiment was carried out with two different beam energies that had overlapping coverage in Q^2, so that the detection of the protons of a given Q^2 took place in two different regions of the drift chambers. As a result, essentially four measurements of $G_M^n(Q^2)$ have been obtained from the CLAS data that could have four independent sets of systematic errors. We have found the four measurements are consistent within the statistical errors, suggesting that the systematic errors are well-controlled and small.

3. RESULTS

The preliminary results for the neutron magnetic form factor are shown in Fig. 2 together with a sample of existing data. The error bars shown are due only to statistical uncertainties. Systematic uncertainties are represented by the red band. The data shown are the weighted averages of the four overlapping individual measurements. A few features are noteworthy. First, the quality and coverage of the data is a substantial improvement over the existing world's data set. Second, the dipole form describes the data over the Q^2 range measured, which is at variance at higher Q^2 with parameterizations based on previous data, which tend to show a more strongly decreasing trend for $G_M^n/(\mu_n G_D)$ with increasing Q^2.

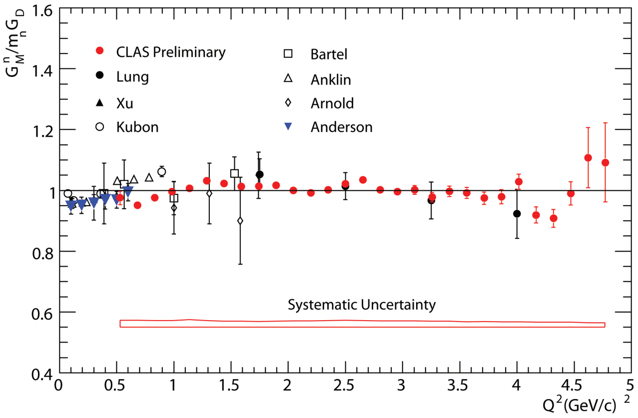

Fig. 2. Preliminary results for $G_M^n/(\mu_n G_D)$ from CLAS are compared with a selection of previous data[4,8]

References

1. R. Madey *et al.*, *Phys. Rev. Lett.* **91**, p. 122002 (2003).
2. K. A. Aniol *et al.*, *Phys. Lett.* **B365**, p. 275 (2006).
3. F. Iachello and Q. Wan, *Phys. Rev. C* **69**, p. 055204 (2004).
4. C. Hyde-Wright and K. deJager, *Ann. Rev. Nucl. Part. Sci.* **54**, p. 217 (2004).
5. M. Diehl, T. Feldmann, R. Jakob and P. Kroll, *Eur.Phys.J.C* **39**, p. 1 (2005).
6. J. D. Lachniet, A high precision measurement of the neutron magnetic form factor using the clas detector, PhD thesis, Carnegie-Mellon University, (Pittsburgh, PA, USA, 2005).
7. G. Kubon *et al.*, *Phys.Lett.* **B524**, 26 (2002).
8. B. Anderson *et al.*, *Phys. Rev. C* **75**, p. 034003 (2007).