

# Precise Measurement of the Transverse Asymmetry in Quasielastic ${}^3\text{He}(\vec{e}, e')$ and the Neutron Magnetic Form Factor

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We have measured the transverse asymmetry  $A_{T'}$  in  ${}^3\text{He}(\vec{e}, e')$  quasielastic scattering with high statistical precision for  $Q^2$ -values from 0.1 to 0.6 (GeV/c)<sup>2</sup>. The data are expected to allow extraction of the neutron magnetic form factor  $G_M^n$  with an uncertainty similar to that of recent experiments on deuterium. Data analysis is currently in progress.

## 1. INTRODUCTION

Electromagnetic form factors are of fundamental importance for an understanding of the underlying structure of nucleons. Accurate knowledge of the distribution of charge and magnetization within the nucleon provides sensitive tests of nucleon models as well as a basis for calculations of nuclear electromagnetic processes. While the proton form factors are known with excellent precision over a large range of four-momentum transfer  $Q^2$ , the corresponding data for the neutron are of inferior quality due to the lack of free neutron targets. Over the past decade, with the advent of improved experimental techniques, the precise determination of both the electric form factor,  $G_E^n$ , and the magnetic form factor,  $G_M^n$ , has become a focus of experimental activity. While improving the precision of  $G_M^n$  is interesting in itself, it also benefits experiments designed to determine  $G_E^n$ , which usually measure the ratio  $G_E^n/G_M^n$ .

Until recently, most data on  $G_M^n$  had been deduced from elastic and quasielastic electron-deuteron scattering. For inclusive measurements, this procedure requires the subtraction of a large proton contribution and suffers from large theoretical uncertainties due to the deuteron model employed and corrections for final-state interactions (FSI) and meson-exchange currents (MEC), limiting the precision of  $G_M^n$  to  $\sim 20\%$  at low  $Q^2$ . The proton subtraction is avoided in coincidence  $d(e, e'n)$  experiments [1], and the sensitivity to nuclear structure can be greatly reduced by measuring the cross section ratio  $d(e, e'n)/d(e, e'p)$  in quasielastic kinematics. Several recent experiments [2–4] have employed the latter technique to extract  $G_M^n$  with uncertainties of  $< 2\%$  in the momentum transfer range  $Q^2 = 0.1$  to  $0.8$  (GeV/c)<sup>2</sup>. While this precision is excellent, the results of the experiments [1–4] are not fully consistent (cf. Figure 1), and further data are desirable to clarify the situation.

An alternative approach to a precision measurement of  $G_M^n$  is the inclusive reaction  ${}^3\text{He}(\vec{e}, e')$ . In comparison to deuterium experiments, this technique employs a different

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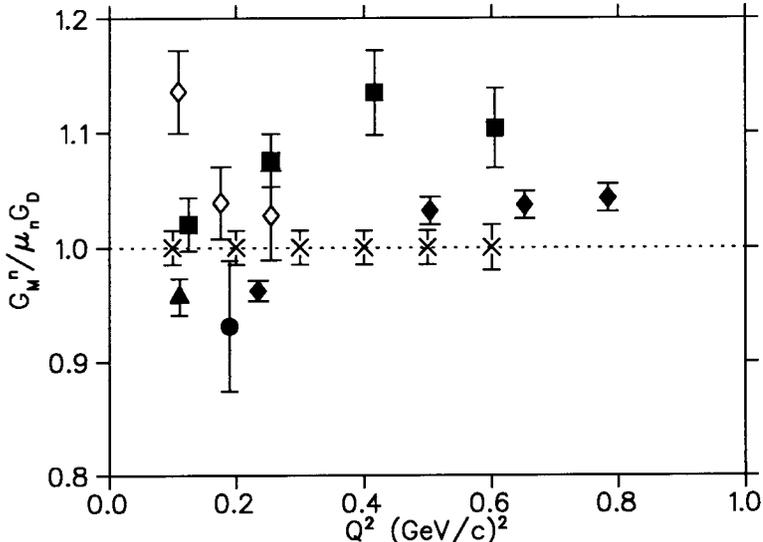


Figure 1. The neutron magnetic form factor  $G_M^n$  in units of the standard dipole parameterization,  $\mu_n G_D$ , in the low  $Q^2$  region, as determined in several recent measurements: Markowitz *et al.* [1] (open diamonds) using  $d(e, e'n)$ ; Anklin *et al.* [2] (triangle), Bruins *et al.* [3] (squares), and Anklin *et al.* [4] (solid diamonds) using the ratio  $d(e, e'n)/d(e, e'p)$ ; and Gao *et al.* [5] (circle) using  ${}^3\text{He}(\vec{e}, e')$ . The expected precision of the present experiment is shown as error bars marked by crosses.

target and relies on polarization degrees of freedom. It is thus subject to completely different systematics. A first such experiment was done at MIT-Bates [5], and a result for  $G_M^n$  was extracted as shown in Figure 1. Here, we report on a continuation of these measurements recently performed at Jefferson Lab (experiment E95-001).

Polarized  ${}^3\text{He}$  is a good candidate for an effective neutron target because its ground state wave function is dominated by the  $S$ -state in which the proton spins cancel and the nuclear spin is entirely due to the neutron. The cross section for the process  ${}^3\text{He}(\vec{e}, e')$  can be written in terms of four nuclear response functions  $R_K(Q^2, \nu)$  [6] as

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott} [v_L R_L + v_T R_T - h(\cos\theta^* v_T R_{T'} + 2 \sin\theta^* \cos\phi^* v_{TL'} R_{TL'})], \quad (1)$$

where  $\theta^*$  and  $\phi^*$  are the polar and azimuthal angles defining the direction of the target spin with respect to the momentum transfer vector  $\vec{q}$ , the  $v_K$  are kinematic factors,  $\nu$  is the electron energy loss,  $h$  is the helicity of the incident electron, and  $Q^2 \equiv \vec{q}^2 - \nu^2$ .  $R_{T'}$  and  $R_{TL'}$  are two responses arising from the polarization degrees of freedom. An experimentally clean signature of these observables is the spin-dependent asymmetry, defined as

$$A = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = -\frac{\cos\theta^* v_T R_{T'} + 2 \sin\theta^* \cos\phi^* v_{TL'} R_{TL'}}{v_T R_T + v_L R_L}, \quad (2)$$

where the subscript  $+$  ( $-$ ) refers to the electron helicity  $h$ . Orienting the target spin at  $\theta^* = 0^\circ$  selects the transverse asymmetry  $A_{T'}$  proportional to  $R_{T'}$ .

In plane wave impulse approximation (PWIA) the cross section for  ${}^3\text{He}(\vec{e}, e')$  at the center of the quasielastic peak is (roughly) proportional to the sum of the  $en$  plus twice the  $ep$  elastic cross section. The cross section for polarized electron-nucleon scattering is

$$\frac{d\sigma_{eN}}{d\Omega} = \sigma_{Mott} \frac{E'}{E} \left[ v_L(1 + \tau)G_E^2 + v_{TL'}2\tau G_M^2 - h\bar{p}_N(\cos\theta^*v_{T'}2\tau G_M^2 - 2\sin\theta^*\cos\phi^*v_{TL'}\sqrt{2\tau(1 + \tau)}G_M G_E) \right], \quad (3)$$

where  $\tau = Q^2/(4M^2)$ , and  $\bar{p}_N$  is the effective nucleon polarization. As a consequence of the  $S$ -state dominance, the neutron in  ${}^3\text{He}$  is almost fully polarized,  $\bar{p}_n \approx 1$ , at the quasielastic peak while the remaining small components of the  ${}^3\text{He}$  ground state, the  $D$  state ( $\sim 8\%$ ) and the mixed-symmetry  $S'$  state ( $\sim 1\%$ ), give rise to a small net proton polarization of  $\bar{p}_p \approx -0.03$  [7].

Combining the above equations, the transverse asymmetry can be written

$$A_{T'} \propto \bar{p}_n(G_M^n)^2 + \bar{p}_p(G_M^p)^2. \quad (4)$$

Since  $G_M^n$  and  $G_M^p$  are comparable in magnitude, but  $|\bar{p}_p| \ll |\bar{p}_n|$ ,  $A_{T'}$  is dominated by the neutron contribution and so is essentially proportional to  $(G_M^n)^2$ . Note that it is mostly the proton contribution that is sensitive to details of the  ${}^3\text{He}$  ground state wave function.

The strong sensitivity of  $A_{T'}$  to  $(G_M^n)^2$  in quasielastic kinematics has been verified in a number of recent calculations [8–11]. The most advanced of these include corrections for FSI [10] and FSI and MEC [11], which are relatively small at the quasielastic peak. One may conclude that  $A_{T'}$  depends only weakly on the details of the  ${}^3\text{He}$  nuclear ground state and the reaction mechanism. Thus, a measurement of  $A_{T'}$  is suitable to extract  $G_M^n$ .

## 2. EXPERIMENT

The experiment was carried out in Hall A at Jefferson Lab in early 1999 using a longitudinally polarized CW electron beam at energies of 0.778 and 1.727 GeV and 10  $\mu\text{A}$  current. A high pressure  ${}^3\text{He}$  gas target was polarized via spin-exchange optical pumping at a density of  $2.5 \times 10^{20}$  nuclei/ $\text{cm}^3$ . To facilitate optical pumping, the target contained small admixtures of nitrogen ( $\sim 10^{18}$   $\text{cm}^{-3}$ ) and rubidium ( $\sim 10^{14}$   $\text{cm}^{-3}$ ). Background from the nitrogen was determined in calibration measurements and is corrected for in the analysis; the contribution from rubidium is negligible. The beam and target polarizations were approximately 70% and 30%, respectively. The beam helicity was reversed randomly at a rate of 1 Hz. A total beam charge of approximately 22 C was accumulated, resulting in a total data set of  $1.3 \times 10^9$  quasielastic events after background subtraction.

Six kinematic points were measured corresponding to  $Q^2 = 0.1$  to  $0.6$  ( $\text{GeV}/c$ )<sup>2</sup> in steps of  $0.1$  ( $\text{GeV}/c$ )<sup>2</sup>. To maximize sensitivity to  $A_{T'}$ , the target spin was oriented at  $-62.5^\circ$  with respect to the beam direction, resulting in a contribution to the asymmetry due to  $R_{TL'}$  of less than 2% for all kinematic points. The target spin direction was rotated by  $180^\circ$  every 24–48 hours for systematic checks, causing the asymmetry to change sign.

The scattered electrons were observed in the two Hall A High Resolution Spectrometers, HRSe and HRSh. Both spectrometers were configured to detect electrons in single-arm mode using nearly identical detector packages consisting of two dual-plane vertical drift

chambers for tracking, two planes of segmented plastic scintillators for trigger formation, and a CO<sub>2</sub> gas Cherenkov detector and Pb-glass total-absorption shower counter for particle identification. Pion background was rejected using the Cherenkov and shower counter information. The spectrometer momentum and angular acceptances were approximately  $\pm 4.5\%$  and 5 msr, respectively. The level of background from the walls of the glass target was measured at regular intervals with the target cell empty and was less than about 5% of the full target yield.

The HRSe was set for quasielastic kinematics while the HRSh detected elastically scattered electrons. The elastic asymmetry can be calculated to better than 2% using the well-known elastic form factors of <sup>3</sup>He [12], and so the elastic measurement allows precise monitoring of the product of beam and target polarizations. Standard Møller and NMR polarimetry was also performed and served as a cross-check.

### 3. EXPECTED RESULTS

A statistical precision in  $A_{T'}$  of better than 2.5% was achieved for each  $Q^2$  point in a  $\pm 10$  MeV bin around the center of the quasielastic peak. This precision is better by about a factor of five than that of our previous experiment on <sup>3</sup>He [5] at  $Q^2 = 0.2$  (GeV/c)<sup>2</sup>.

Extraction of  $G_M^n$  from the data requires use of a model. Currently the Bochum-Krakow group [11] is carrying out extensive calculations of  $A_{T'}$  as a function of  $G_M^n$  for the kinematics of this experiment. The calculations will be convoluted with the experimental acceptances, and  $G_M^n$  will be determined using a best fit of  $A_{T'}(G_M^n)$  to the data in the vicinity of the quasielastic peak. Fig. 1 shows the expected precision for  $G_M^n$ .

The data also allow a detailed analysis of the dependence of  $A_{T'}$  on the electron energy transfer  $\nu$ . The regions away from the quasielastic peak are expected to be sensitive to details of the reaction mechanism. Thus, the shape of  $A_{T'}(\nu)$  can be used to constrain calculations that include FSI and MEC corrections.

Data analysis is currently in progress and results are expected in late 1999.

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