A PRECISION MEASUREMENT OF G_E^p/G_M^p AT BLAST

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We are undertaking a measurement of G_E^p/G_M^p at $Q^2 = 0.1$–$0.9\,(\mathrm{GeV/c})^2$ in the South Hall Ring of the MIT-Bates Linear Accelerator Facility. This experiment uses a polarized electron beam, a pure hydrogen internal polarized target, and the symmetric Bates Large Acceptance Spectrometer Toroid (BLAST) detector. By measuring the spin-dependent elastic $\vec{\mathrm{H}}(\vec{\mathrm{e}},\mathrm{e'p})$ asymmetry in both sectors simultaneously, we can extract the form factor ratio independent of beam and target polarization. This is the first experiment to measure G_E^p/G_M^p using a polarized target, which is complementary to recoil polarimetry experiments. Preliminary results are presented.

1. Introduction

The electromagnetic form factors of the nucleon, G_E and G_M, are fundamental descriptions of its charge and magnetic distributions. The measurement of these quantities is an important test of various Vector Meson Dominance (VMD) and Constituent Quark (CQM) models as well as Lattice QCD calculations[1] of the nucleon form factors. The nucleon form factors have been measured during the last half century using L-T separations from unpolarized elastic electron-proton differential cross sections. Recent advances with polarized beams, targets, and polarimetry have brought forth a new generation of precision measurements of G_E^p/G_M^p. Such experiments benefit from interference terms between G_E and G_M in the polarized response functions. Recent polarization transfer measurements of G_E^p/G_M^p at Jefferson Lab[2,3] deviated significantly from the previous L-T separations at $Q^2 > 1\,(\mathrm{GeV/c})^2$, which has prompted new investigations to reconcile these two methods.

We are performing an experiment at MIT-Bates to measure G_E^p/G_M^p at $Q^2 = 0.1$–$0.9\,(\mathrm{GeV/c})^2$. This region, which overlaps the lowest Jefferson Lab Q^2 point, is sensitive to the structure of the meson cloud of the nucleon.

This experiment exploits unique features of the Atomic Beam Source (ABS) target in an electron storage ring and the BLAST spectrometer to reduce systematic errors.

2. Formalism

The experimental double-spin asymmetry for elastic $\vec{\mathrm{H}}(\vec{\mathrm{e}},\mathrm{e}'\mathrm{p})$ scattering is the product of the beam and target polarizations, P_b and P_t, and the ratio of the polarized over the unpolarized hydrogen elastic cross section[4]:

$$A_{exp} = P_b P_t \frac{z^* {G_M^p}^2 + x^* G_E^p G_M^p}{\tau {G_M^p}^2 + \epsilon {G_E^p}^2}, \tag{1}$$

where $\tau = Q^2/4M^2$, $\epsilon = 1/(1 + 2(1{+}\tau)\tan^2(\theta_e/2))$ is the longitudinal polarization of the virtual photon, and θ_e is the electron scattering angle. The terms including the kinematic factors z^* and x^* are proportional to the longitudinal and transverse components of the proton polarization with respect to the momentum transfer, $\boldsymbol{q}$.

By simultaneously measuring the asymmetry for two different spin orientations at fixed Q^2, one can form a super-ratio R_A of the asymmetries in which the beam and target polarizations and the unpolarized cross section all cancel. Given a symmetric detector, both asymmetries can be measured at the same time by orienting the target spin at the angle $\beta = 45°$ to the left of the beam, so the asymmetry A_L (A_R) for electrons scattering to the left (right) is predominantly transverse (longitudinal). Then the form factor ratio $R = G_E^p/G_M^p$ can be extracted by inverting

$$R_A = \frac{A_L}{A_R} = \frac{z_L^* + x_L^* R}{z_R^* + x_R^* R}. \tag{2}$$

3. Experimental Setup

This experiment is being performed in the South Hall Ring[5] at the MIT-Bates Linear Accelerator Center, which can store a polarized electron beam ($P_b = 0.65 \pm 0.03$) of up to 250 mA at an energy of 850 MeV. A Siberian snake preserves the polarization, which is continuously monitored by a Compton polarimeter[6].

The internal target[7], consisting of an Atomic Beam Source (ABS) and a cryogenic storage cell, is embedded in the BLAST spectrometer. The ABS produces a highly polarized isotopically pure atomic beam, which is injected into a 15 mm diameter by 60 cm long T-shaped open-ended storage cell. The

ABS is operated in single state mode in order to avoid depolarization due to hyperfine interactions. The ABS switches between states every five minutes while the ring is filled with alternating polarizations every half hour.

The relatively low luminosity ($\mathcal{L} = 1.6 \times 10^{31}\,\mathrm{cm^{-2}s^{-1}}$) of the internal gas target is compensated for by the large acceptance spectrometer. The detector package is built around eight copper coils which provide the 0.4 T BLAST toroidal magnetic field. Two of the sectors are instrumented with three drift chambers each for momentum, angular, and positional resolution, scintillators for triggering and time-of-flight, and Čerenkov detectors for pion rejection. Additional scintillators at backward angles beyond the drift chambers extend the acceptance to $Q^2 = 0.85\,(\mathrm{GeV/c})^2$.

4. Preliminary Results

The first production run in December 2003 accumulated $3.4\,\mathrm{pb^{-1}}$ of integrated luminosity with the target polarization $P_t = 0.48 \pm 0.04$ and the BLAST field reversed to extend to lower Q^2. The second run in April 2004 accumulated $9.6\,\mathrm{pb^{-1}}$ with $P_t = 0.42 \pm 0.04$ and the nominal BLAST field. We project another $67\,\mathrm{pb^{-1}}$ will be accumulated in the third run to be complete in December 2004, with target polarization improved to $P_t \sim 0.75$.

The elastic events are selected based on cuts from the reconstructed kinematic variables including coplanarity and timing cuts from the scintillators. The timing cuts alone produce a clean elastic dataset with less than 1% background contamination in all Q^2 bins.

Since the product of beam and target polarizations $P = P_b P_t$ is independent of Q^2, the form factor ratio $R_i = G_E^p(Q_i^2)/G_M^p(Q_i^2)$ can be extracted by fitting the asymmetries to $A_{ij} = P(z_{ij}^* + x_{ij}^* R_i)/(\tau_i + \epsilon_i R_i^2)$, where the Q^2 bin is labeled by i and the left/right sector by j. This method gives reduced statistical errors compared to the pure super-ratio method, which is equivalent to solving for both P_i and R_i independently in each Q^2 bin.

There are two important systematic errors which are currently being addressed. The first is in the uncertainty of z^* and x^*, which depend on $\theta^* = \beta - \theta_q$. The target spin angle β can be measured from tensor polarized $\vec{\mathrm{D}}(\vec{\mathrm{e}},\mathrm{e}'\mathrm{p})$ elastic scattering in BLAST, and the momentum transfer angle θ_q is overdetermined in elastic kinematics from both the momentum and scattering angle of the electron and proton. The second main contribution comes from the two detectors not being exactly symmetric, and we must account for the difference in Q^2 between the left and right sectors. The experimental asymmetry can be formed in four different ways from our

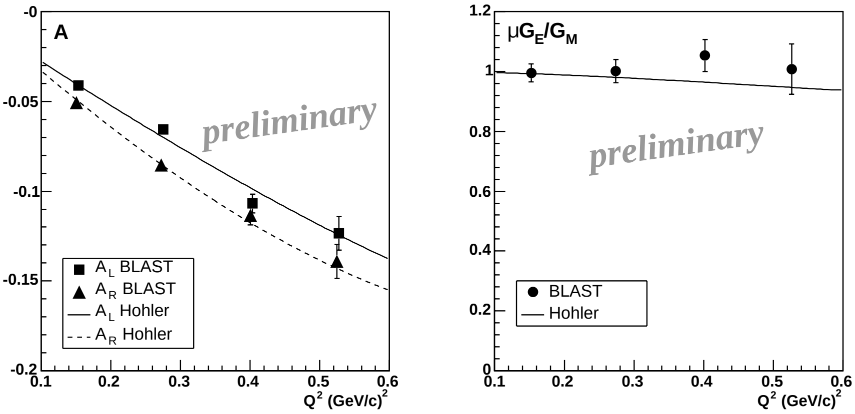

Figure 1. Left: the $\vec{\mathrm{H}}(\vec{\mathrm{e}},\mathrm{e}'\mathrm{p})$ asymmetry in the left and right sectors of BLAST, compared to the asymmetry from the Höhler[8] parametrization of G_E^p and G_M^p. Right: preliminary results of $\mu G_E^p/G_M^p$ from the partial dataset also compared to Höhler.

experiment by reversing both the beam helicity and the target polarization directions in order to minimize the experimental false asymmetry.

Preliminary results are shown in Fig. 1 with statistical errors only. These results do not include the December 2004 run, in which we project to increase our effective statistics by a factor of 16.2. We have also taken $76\,\mathrm{pb}^{-1}$ of elastic $\vec{\mathrm{D}}(\vec{\mathrm{e}},\mathrm{e}'\mathrm{p})$ data of target vector polarization $P_z \sim 0.72$ with BLAST which may be used to extract G_E^p/G_M^p from the deuteron.

Acknowledgments

This work is supported in part by the U.S. Department of Energy under contract number DE-FC02-94ER40818 and DE-FG02-03ER41231.

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