The Proton Electric to Magnetic Form Factor Ratio at Low Q^2

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Abstract. At the MIT-Bates Linear Accelerator Center, the ratio G_E^p/G_M^p has been measured by means of elastic scattering of polarized electrons from polarized hydrogen, $^1\vec{\mathrm{H}}(\vec{\mathrm{e}},\mathrm{e'p})$. The measurements have been carried out with the symmetric Bates Large Acceptance Spectrometer Toroid (BLAST). For values of Q^2 between 0.15 and 0.85 (GeV/c)^2, the combination of the two simultaneously measured spin-dependent asymmetries in the left and right sectors of BLAST provides the form factor ratio G_E^p/G_M^p with high precision and minimal systematic errors. In these proceedings, we will present preliminary results from the BLAST program.

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The electromagnetic form factors are fundamental quantities of the nucleon, describing the charge and magnetization distributions. Measurements of nucleon form factors at $Q^2 < 1$ (GeV/c)^2, where the pion cloud is expected to play a significant role [1], present a sensitive test of nucleon models and QCD-inspired theories.

The Rosenbluth separation technique [2] has been the primary method to study the proton electric and magnetic form factors, utilizing unpolarized *ep* elastic scattering. Recent advances in polarized beams and targets have allowed a new class of experiments using spin observables. Extracting the form factor ratio from the polarized *ep* elastic scattering cross section has two major advantages over unpolarized experiments. The first advantage relates to the interference term between G_E^p and G_M^p, which allows us to extract the form factor ratio directly. Second, we can use spin degrees of freedom for the measurement. By using this extra variable and a symmetric detector like BLAST, one can reduce the systematic errors by not changing the beam energy and the scattering angle as in the Rosenbluth separation. Recent precison measurements [3, 4] utilizing polarized data showed fascinating results at high Q^2, where the form factor ratio deviates dramatically from that using unpolarized data. Further investigation of this inconsistency is clearly needed.

EXPERIMENTAL SETUP AND DATA ANALYSIS

The BLAST program was carried out in the South Hall Ring of the MIT Bates Linear Accelerator Center. The ring was filled with a longitudinally polarized electron beam with a peak current of up to 225 mA. The longitudinal polarization of the electron was preserved using a full Siberian Snake situated opposite to the interaction point in the ring, and was continuously measured by a Compton polarimeter located upstream of the internal target. The average electron polarization during this measurement was $P_b \approx 0.66$. A polarized proton target was achieved using an Atomic Beam Source (ABS), which injected the polarized hydrogen into an aluminum target tube, 15 mm diameter and 60 cm long, from which the electrons were scattered. The average polarization of the ABS H_2 target was roughly $P_t \approx 0.72$, and the luminosity was $1.6 \times 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The spin orientation of the polarized protons was adjusted using holding field coils.

The scattered electron and the recoil proton were tracked in a 3.8 kG toroidal magnetic field around the beam axis using an identical set of wire drift chambers on the left and the right sides of the beam, each covering roughly $\Delta\phi = 34^\circ$ azimuthal angle. In each sector we had a set of 1 cm thick aerogel Čerenkov detectors providing electron identification, and a set of time-of-flight (TOF) detectors providing trigger and timing covering $20^\circ < \theta < 80^\circ$ polar angle. In addition to the primary TOF detectors, we had back-angle-TOFs for the higher Q^2 region, covering $95^\circ < \theta < 115^\circ$ polar angle.

The beam-target double spin asymmetry has the following form:

$$A_{\mathrm{exp}} = P_b P_t \frac{-2\tau\nu_{T'}\cos\theta^* {G_M^p}^2 + 2\sqrt{2\tau(1+\tau)}\nu_{TL'}\sin\theta^*\cos\phi^* G_M^p G_E^p}{(1+\tau)\nu_L {G_E^p}^2 + 2\tau\nu_T {G_M^p}^2} \tag{1}$$

where θ^* and ϕ^* are the target spin polar and azimuthal angles defined relative to the three-momentum transfer vector of the virtual photon. The analysis [5] relied on having a symmetric detector layout and optimizing the target spin vector with respect to the momentum transfer vector for each sector. Thus, we had a simultaneous measurement of the asymmetry for electrons detected in the left sector, A_L, and for those detected in the right sector, A_R. The only difference then between these two measurements was due to the orientation of the target spin vector, which was tuned such that θ^* was either roughly perpendicular to the momentum transfer vector or roughly parallel to it. The asymmetry was thus dominated by the $\sin\theta^*$ or $\cos\theta^*$ terms as can be seen in Eqn. 1.

By simply taking the ratio of A_L and A_R we can resolve the form factor ratio as seen in the following equation:

$$R_A = \frac{A_L}{A_R} = \frac{z_L^* - x_L^* G_E^p/G_M^p}{z_R^* - x_R^* G_E^p/G_M^p} \tag{2}$$

It should be noted that this ratio minimizes the systematic errors as it eliminates most of the terms seen in Eqn. 1, including the beam and the target polarization.

RESULTS

The preliminary result for the proton electric to magnetic form factor ratio is seen in Fig.1 with statistical errors only. The data in the figure represent 13 pb^{-1} of accumulated luminosity, which is roughly 15% of the complete data set. It is compared to the Höhler parameterization [6] which seems to provide the best description of the data.

The systematic errors are currently under investigation. There are two important systematic errors, the most important due to the uncertainty in target spin angle which introduces an uncertainty in θ^* in Eqn. 1, or in x^* and z^* in Eqn. 2. We have three

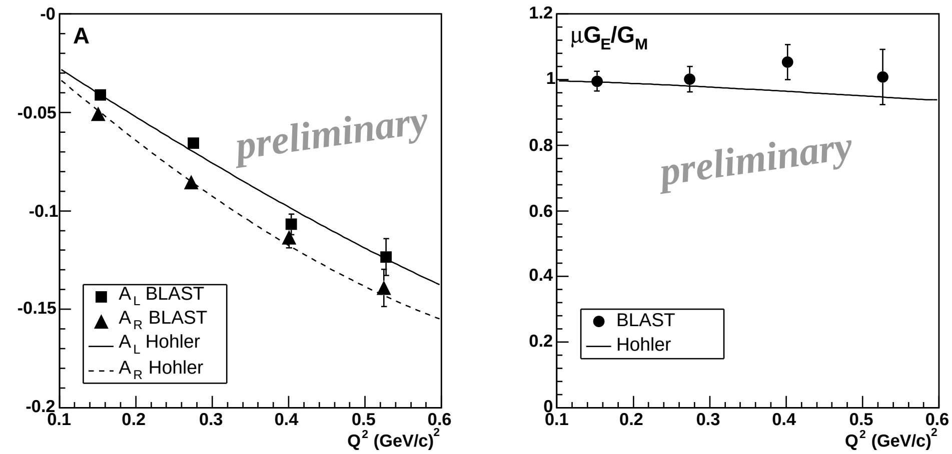

FIGURE 1. Left: The preliminary *ep* elastic asymmetry for the left (A_L) and the right (A_R) sector. Right: Electric form factor to magnetic form factor ratio. These results are compared to the Höhler parameterization [6]. The data are shown with statistical errors only.

preliminary measurements for the target spin angle. First, a direct measurement was made by mapping the holding field. Second, it was determined using the *ep* elastic asymmetry. Third, it was extracted from the tensor polarized *ed* elastic scattering part of the BLAST program, T_{20} measurement. All these preliminary results are currently consistent to about 1°. The second large contribution to the systematic error comes from the fact that the two sectors are not perfectly symmetric, which introduces a difference in Q^2 between left and right sectors.

The final results containing the complete data set with a factor of 2.5 improved statistical precision and addressing the systematic errors will be available in several months.

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