A Measurement of the Vector Analyzing Power T_{11}^e at Low Q^2 in Polarized Elastic Electron-Deuteron Scattering

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A measurement of the vector analyzing power T_{11}^e in elastic electron-deuteron scattering has been performed at the MIT-Bates Linear Accelerator Center using a polarized electron beam, an internal polarized atomic deuterium target, and the symmetric BLAST (Bates Large Acceptance Spectormeter Toroid) detector in the Bates South Hall Ring. The beam helicity dependent target vector asymmetries, simultaneously measured in both sectors of BLAST, allow the extraction of T_{11}^e. This is the first use of a polarized target to determine T_{11}^e.

INTRODUCTION

The deuteron vector polarization observable T_{11}^e can provide an additional χ_ν^2 degree of freedom in an extraction of the magnetic dipole form factor G_M. Herein we describe the first known measurement of T_{11}^e in doubly polarized electron deuteron elastic scattering. Until now, the primary source for determining G_M has been the structure function $B(Q^2)$ via a Rosenbluth separation. In principle, the tensor polarization observable T_{22} can also be used to determine G_M but a statistically significant measurement is difficult to make due to the small magnitude of this observable. Prior measurements of T_{11}^e have not been possible due to the absence of experiments with both an intense polarized electron beam and a polarized deuterium target. The Bates Large Acceptance Spectrometer Toroid (BLAST) experiment at the MIT-Bates has yielded results for T_{11}^e that help to constrain potential models of the deuteron in the low Q^2 region.

The electromagnetic structure of the deuteron, as observed through elastic electron scattering, can be described by the three form factors G_C, G_Q, and G_M. These represent the electric monopole, the electric quadrupole, and the magnetic dipole distributions of the deuteron respectively. The vector analyzing power T_{11}^e, as written in terms of these form factors, is

$$\begin{aligned} T_{11}^e(Q^2,\theta_e) &= \frac{1}{F^2(Q^2,\theta_e)}\frac{\sqrt{3}}{2}\frac{4}{3}[\tau(1+\tau)]^{1/2} \\ &\times \quad \tan^2\frac{\theta_e}{2}G_M(G_C+\frac{\tau}{3}\tau G_Q) \end{aligned} \qquad (1)$$

where $F^2(Q^2,\theta_e) = A(Q^2) + B(Q^2)\tan^2(\theta_e/2)$. The deuteron structure functions $A(Q^2)$ and $B(Q^2)$ as well as the factor $\tau = Q^2/(4M_d^2)$ are functions of the four-momentum transfer $Q^2 = 4EE'\sin^2(\theta_e/2)$, where M_d is the deuteron mass, E and E' are the incident and scattered electron energies and θ_e is the electron scattering angle. The superscript 'e' on T_{11}^e indicates that a polarized electron beam is required for this measurement. From this, one can see that

T^e_{11} is dominated by the interference of G_M and G_C at low Q^2. The sensitivity of T^e_{11} to isoscalar meson exchange currents increases with Q^2 [2] but is not negligible below $Q^2 = 0.4$ [GeV/c]^2.

EXPERIMENTAL APPARATUS

The experiment was performed in the South Experimental Hall of the Massachusetts Institute of Technology's Bates Linear Accelerator Center in Middleton, MA. Longitudinally polarized electrons were accelerated to 850 MeV and injected into the Bates South Hall Storage Ring with peak and average currents of approximately 200 and 100 mA respectively. Once in the ring, the beam circulated through the large acceptance BLAST detector [3] which surrounded the polarized internal atomic beam source (ABS) target [4]. The g-2 precession of the electrons in the ring was countered by two Siberian Snake solonoid magnets 180° of of phase with the target region [5]. The polarization, h, of the beam measured in real time via a compton polarimeter was 0.6558±0.0007(stat), ±0.04 (sys). The windowless ABS target provided an atomic beam of deuterons with an intensity of $\simeq$2.6×10^{16} [atoms/sec]. The quantity of interest in this analysis is the product of the beam and target polarizations, hP_z, which was simultaneously obtained from the BLAST quasielastic d(e,e'p)n analysis. The measured values for hP_z were 0.558±0.009 (stat), ±0.013 (sys) for the 2004 dataset [6] and 0.441±0.003 (stat), ±0.013 (sys) for the 2005 dataset [7].

The BLAST detector angular acceptance covered a polar angle, as measured from the downstream beam axis, of $20° \leq \theta \leq 80°$, and an azimuthal angle about the beam of $-22° \leq \phi \leq 22°$ giving BLAST nearly 0.6 sr solid angle coverage. In terms of momentum transfer, BLAST covered a range of $0.1 \leq Q^2 \leq 0.9$ [GeV/c]^2. This relatively large acceptance, in combination with the polarized internal target and intense polarized electron beam make the BLAST experiment rather unique in medium energy nuclear physics.

A schematic of the BLAST detector is shown in Figure 1. The BLAST magnetic field peaked at 3800 kG in the region of multi-wire drift chambers which provided angular and momentum information through particle tracking. Time-of-flight (TOF) scintillation detectors provided fast timing information as well as forming the basis for a first level coincidence trigger for the BLAST data acquisition (DAQ) system. The drift chambers were incorporated into a second level trigger which required good reconstructed tracks to be linked to the proper TOF detector. A trigger supervisor allowed for event selection based upon variation of these and additional criteria.

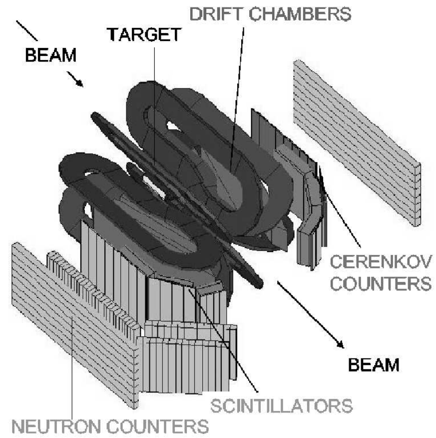

FIG. 1: The BLAST Detector

DATA ANALYSIS

Once fiducial cuts were made in the data, elastically scattered deuteron events were selected through kinematics and time-of-flight constraints. The two-body final state of ed-elastic scattering results in the outgoing electron and deuteron being coplanar with the beam axis. Therefore a cut was placed on events having opposing sector azimuthal track angles 180°±3° apart.

The electrodisintegration of the deuteron leads to a prominent proton background in this experiment. The discrimination against these quasielastic events was key in the extraction of the elastic observable T^e_{11}. The factor of two larger mass of the deuteron allowed for clear discrimination of proton events due to the longer flight times of the deuterons for the same corresponding momenta.

To minimize the statistical error, the Q^2 range was limited to be less than 0.4 [GeV/c]^2 and the data were spread over two bins only.

Various asymmetries can be defined from the cross section for the scattering of polarized electrons from a polarized deuterium target. Of these, the beam-target vector asymmetry, A^V_{ed}, can be written in terms of the vector analyzing powers T^e_{10} and

T^e_{11} [10],

$$A^V_{ed} \equiv \sqrt{3}\Big[\frac{1}{\sqrt{2}}\cos\theta^* T^e_{10}(Q^2,\theta_e) - \sin\theta^*\cos\phi^* T^e_{11}(Q^2,\theta_e)\Big] \quad (2)$$

where the θ^* and ϕ^* relate the three momentum transfer $\mathbf{q}$ to the target polarization vector in the reaction frame as shown in Figure 2.

The polarized cross section can also be cast ex-

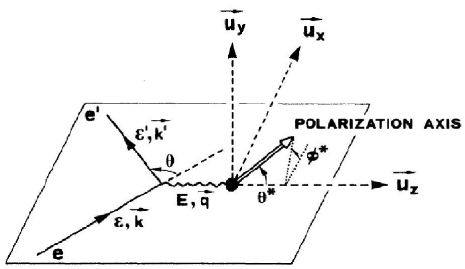

FIG. 2: Reaction Coordinate System Conventions [10]

plicitly in terms of beam, target, and beam-target asymmetries [1]

$$\sigma(h,P_z,P_{zz}) = \sigma_0[1 + P_z A^V_d + P_{zz} A^T_d + h(A_e + P_z A^V_{ed} + P_{zz} A^T_{ed})] \quad (3)$$

where σ_0 is the unpolarized cross section, h is the beam helicity and polarization, P_z is the target vector polarization, P_{zz} is the target tensor polarization, A^d_V and A^d_T are the target vector and tensor asymmetries, and A^V_{ed} and A^T_{ed} are the beam-target vector and tensor asymmetries. For elastic scattering in the OPE approximation, equation 3 simplifies as $A_e = A^V_d = A^T_{ed} = 0$. Experimentally, one can use a particular combination of beam and target polarization states to obtain the beam-target vector asymmetry A^V_{ed}.

The beam helicity, which was flipped each time the South Hall Ring was filled, and the target state, which was changed several times per fill, were digitized in a bit register ADC on an event by event basis [8]. These data were also written to scalers along with the accumulated beam-charge collected for each state.

With the target polarization vector, $\hat{\boldsymbol{\theta}}_T$, directed beam-left we define parallel and perpendicular kinematics to be events where the electron is scattered into the right and left sectors of BLAST respectively. In this way, the three momentum transfer, $\mathbf{q}$, is approximately parallel and perpendicular to $\hat{\boldsymbol{\theta}}_T$ respectively. As BLAST has a symmetrical geometry out to the TOF detectors, we can thus measure two asymmetries, $A^V_{ed\,\parallel}$ and $A^V_{ed\,\perp}$, simultaneously.

RESULTS

Data were taken with the target polarization vector set to both 32° and 47° beam left in the plane of the South Hall floor. Results for the beam-target vector asymmetry for the target angle setting of θ_T =32° are shown in Figure 3. The curve is

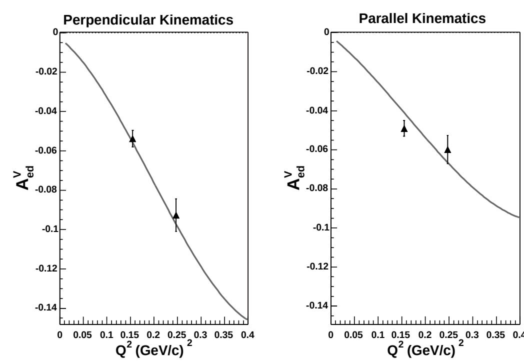

FIG. 3: Beam-Target Vector Asymmetries A^V_{ed} for parallel and perpendicular kinematics for $\theta_T = 32°$.

based on the Abbott parameterization I [11] of the world data for the form factors G_C, G_Q, and G_M. In this figure, the Abbott curve has been scaled by the product of the beam and target polarization hP_z. The statistical agreement of the data with the scaled parameterization provides a cross check in the analysis of the BLAST data.

With the two simultaneously measured asymmetries $A^V_{ed\,\parallel}$ and $A^V_{ed\,\perp}$, and averaging θ^* and ϕ^* over the two bins for each observable, we extract the vector analyzing powers T^e_{10} and T^e_{11}. The sources of systematic error in this measurement are the uncertainties in the reconstructed polar and azimuthal angles θ_e and ϕ_e, as well as the uncertainty in the knowledge of the target polarization vector θ_T. These quantities are implicit in the definitions of θ^* and ϕ^*, which are themselves explicit in the vector analyzing powers. The uncertainty in the product of the beam and target polarization, hP_z, produces a global shift in the data on the order of ±0.6% (stat), ±1.8% (sys). The extracted values for T^e_{10} and T^e_{11} as measured by

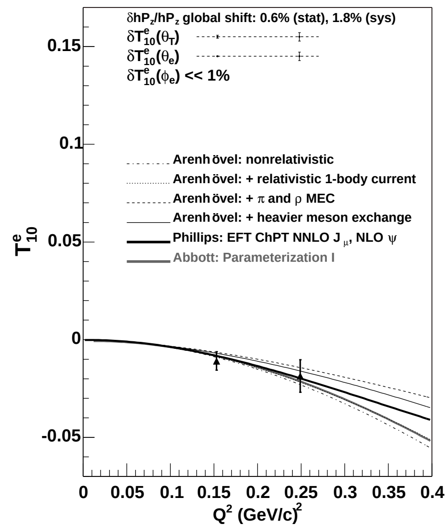

FIG. 4: Vector Analyzing Power T^e_{10}

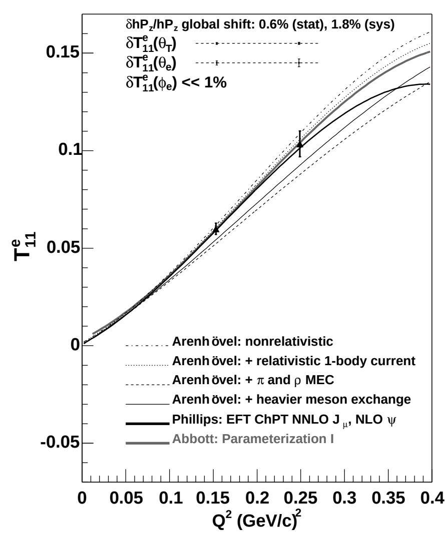

FIG. 5: Vector Analyzing Power T^e_{11}

BLAST are shown in Figures 4 and 5.

The relative error on T^e_{10} precludes a statistically significant measurement of this observable, whereas, the larger magnitude of T^e_{11}, allows for a good measurement to be made. From Figure 5 one can see that the BLAST data for T^e_{11} provide some constraint on the theoretical model dependence below Q^2 <0.4 [GeV/c]^2. More specifically we see a good agreement, within statistical and systematic error bars, of the data with Arenhövel's nonrelativistic (NR) and NR+1-body current predictions [12]. This is also true of Phillips effective field theory calculation [13] in this low Q^2 region.

It is the intention of the authors to combine these data with the BLAST data for the tensor polarization observables T_{20} and T_{21} [9], as well as the world data for $A(Q^2)$, to extract the magentic dipole form factor G_M. There does not exist much data on G_M at low Q^2 and the BLAST data can provide an additional degree of freedom in its measurement.

CONCLUSION

The beam-target vector asymmetry measurement for elastic scattering of longitudinally polarized electrons from vector polarized deuterium has allowed the extraction of the vector analyzing power T^e_{11} at Q^2 below 0.4 $[GeV/c]^2$. This observable will play a part in a new measurement of the magnetic dipole form factor G_M in this low Q^2 region. This work has been supported by DOE grants 181021 (UNH) and DEFC02-94ER40818 (MIT-Bates).

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