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Potential for a Tensor Asymmetry A_{zz} Measurement in the $x > 1$ Region at Jefferson Lab

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Abstract. The tensor asymmetry A_{zz} in the quasi-elastic region through the tensor polarized $\mathrm{D}(e, e')\mathrm{X}$ channel is sensitive to the nucleon-nucleon potential. Previous measurements of A_{zz} have been used to extract b_1 in the DIS region and T_{20} in the elastic region. In the quasi-elastic region, A_{zz} can be used to compare light cone calculations with variation nucleon-nucleon calculations, and is an important quantity to determine for understanding tensor effects, such as the dominance of pn correlations in nuclei. In the quasi-elastic region, A_{zz} was first calculated in 1988 by Frankfurt and Strikman using the Hamada-Johnstone and Reid soft-core wave functions [1]. Recent calculations by M. Sargsian revisit A_{zz} in the $x > 1$ range using virtual-nucleon and light-cone methods, which differ by up to a factor of two [2]. Discussed in these proceedings, a study has been completed that determines the feasibility of measuring A_{zz} in the quasi-elastic $x > 1$ region at Jefferson Lab's Hall C.

1. Background

It was suggested for some time [3] that to resolve the microscopic structure of nuclei one needs to study scattering at sufficiently large momentum transfer and large relative momenta of the produced nucleons. This logic was confirmed [4] by a series of experiments at SLAC [5] and JLab [6, 7] that directly observed short-range correlations (SRC) in a series of nuclei, and established a similar effect of SRC in the deuteron and in heavier nuclei with pn correlations giving the dominant contribution. Hence, the deuteron serves as a "hydrogen atom" for the studies of the microscopic short-range structure of the nuclei since it is the simplest nuclei that follows SRC scaling. To achieve further progress, it is necessary to improve our knowledge of the deuteron wave function and nucleon-nucleon interactions at high momenta.

Due to their small size and simple structure, tensor polarized deuterons are ideal for studying nucleon-nucleon interactions. Tensor polarization enhances the D-state contribution and is sensitive to short-range QCD effects [8]. Understanding the nucleon-nucleon potential of the deuteron is essential for understanding short-range correlations, as they are largely dependent on the tensor force [4].

By taking a ratio of cross sections of electron scattering from tensor-polarized and unpolarized deuterons, the S and D-wave states can be disentangled, leading to a fuller understanding of the repulsive nucleon core. A measurement of A_{zz} is sensitive to the $\frac{D^2-SD}{S^2+D^2}$ ratio and its evolution with increasing minimal momentum of the struck nucleon. Originally calculated by L. Frankfurt and M. Strikman [1], this has recently been revisited by M. Sargsian who calculated A_{zz} at $Q^2 = 1.5$ $(\mathrm{GeV}/c)^2$ and $0.6 < x < 1.8$ using both a light cone and virtual nucleon approach [2].

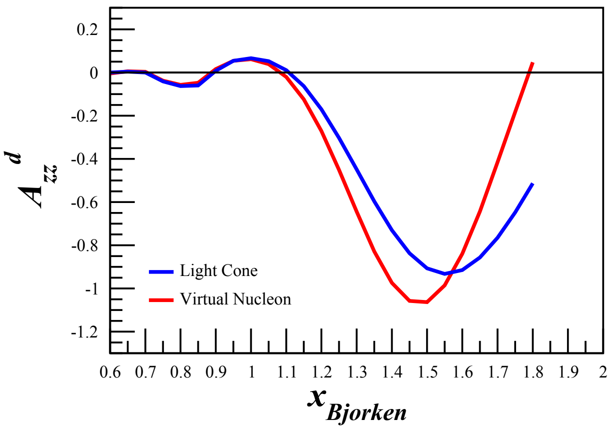

Figure 1. The A_{zz} observable calculated at $Q^2 = 1.5$ (GeV/c)^2 using the light-cone and virtual nucleon models. Calculations provided by M. Sargsian.

The calculations vary by up to a factor of 2, which, combined with the 12 GeV Jefferson Lab upgrade and the new Super High Momentum Spectrometer (SHMS) to be installed in Hall C, make A_{zz} an ideal candidate to revisit experimentally.

Additionally, measuring A_{zz} in the quasi-elastic region will fill a gap in measurements performed on tensor polarized deuterons. In the elastic region, A_{zz} is directly proportional to T_{20} ($A_{zz} \propto T_{20}$). In the deep inelastic region, A_{zz} will soon be measured to extract the tensor structure function b_1 by the relation $A_{zz} \propto \frac{b_1}{F_1^D}$. Not only would measuring A_{zz} in the quasi-elastic region provide information necessary for understanding the high-momentum properties of the deuteron and contributions from the tensor force, but it would be the first experiment to bridge a gap in measurements of electron scattering from tensor-polarized deuterons.

2. Feasibility Study

We discuss here the feasibility of a measurement of the tensor asymmetry A_{zz} from inclusive electron scattering from polarized deuterons in the quasi-elastic region of $0.80 < x < 1.75$, 0.3 (GeV/c)^2 $< Q^2 <$ 1.5 (GeV/c)^2, and $0.59 < W < 1.09$ GeV at Jefferson Lab using a DNP solid polarized ND_3 target and the Hall C HMS and SHMS spectrometers at forward angles.

2.1. Definitions

The measured double differential cross section for a spin-1 target is characterized by a vector polarization, P_z, and tensor polarization, P_{zz}, expressed as,

$$\frac{d^2\sigma_p}{d\Omega dE'} = \frac{d^2\sigma_u}{d\Omega dE'}\left(1 - P_z P_B A_1 + \frac{1}{2}P_{zz}A_{zz}\right), \tag{1}$$

where, σ_p (σ_u) is the polarized (unpolarized) cross section, P_B is the incident electron beam polarization, and A_1 (A_{zz}) is the vector (tensor) asymmetry of the virtual-photon deuteron cross section. This allows us to write the polarized tensor asymmetry with positive tensor polarization using an unpolarized electron beam as

$$A_{zz} = \frac{2}{P_{zz}}\left(\frac{\sigma_p - \sigma_u}{\sigma_u}\right). \tag{2}$$

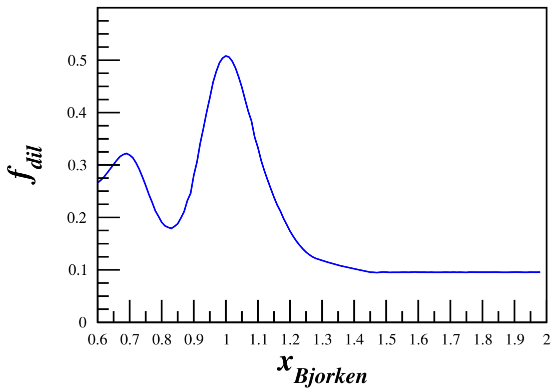

Figure 2. The estimated dilution factor, in this case at $Q^2 = 1.5$ (GeV/c)^2, drops off at high x until it reaches the SRC plateau region.

The tensor polarization is given by

$$P_{zz} = \frac{n_+ - 2n_0 + n_-}{n_+ + n_- + n_0}, \tag{3}$$

where n_m represents the population in the $m_j = +1, -1$, or 0 state.

Eq. 2 reveals that the asymmetry A_{zz} compares two different cross sections measured under different polarization conditions of the target: positively tensor polarized and unpolarized. To obtain the relative cross section measurement in the same configuration, the same target cup and material will be used at alternating polarization states (polarized vs. unpolarized), and the magnetic field providing the quantization axis will be oriented along the beamline at all times. This field will always be held at the same value, regardless of the target material polarization state. This process ensures that the acceptance remains consistent within the stability (10^{-4}) of the super conducting magnet.

Since many of the factors involved in the cross sections cancel in the ratio, Eq. 2 can be expressed in terms of the charge normalized and efficiency corrected numbers of tensor polarized (N_p) and unpolarized (N_u) counts,

$$A_{zz} = \frac{2}{fP_{zz}}\left(\frac{N_p - N_u}{N_u}\right). \tag{4}$$

The dilution factor f corrects for the presence of unpolarized nuclei in the target and is defined by

$$f = \frac{N_D\sigma_D}{N_N\sigma_N + N_D\sigma_D + \sum\limits_A N_A\sigma_A}, \tag{5}$$

where N_D is the number of deuterium nuclei in the target and σ_D is the corresponding inclusive double differential scattering cross section, N_N is the number of nitrogen nuclei with cross section σ_N, and N_A is the number of other scattering nuclei of mass number A with cross section σ_A. As has been noted in previous work [1], the dilution factor at high x drops off considerably until the SRC plateau region, as shown in Fig. 2. Although this effect makes A_{zz} in the large x region difficult to measure at large Q^2, the Jefferson Lab 12 GeV upgrade and the new SHMS spectrometer provide the experimental infrastructure necessary to overcome it.

The dilution factor can be written in terms of the relative volume ratio of ND_3 to LHe in the target cell, otherwise known as the packing fraction p_f. In the case of a cylindrical target cell

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Source	Systematic
P_{zz} Polarimetry	12%
Dilution Factor	6.0%
Packing Fraction	3.0%
Trigger/Tracking Efficiency	1.0%
Acceptance	0.5%
Charge Determination	1.0%
Detector Resolution and Efficiency	1.0%
Total	14%

Table 1. Estimates of the scale dependent contributions to the systematic error of A_{zz}.

oriented along the magnetic field, the packing fraction is exactly equivalent to the percentage of the cell length filled with ND_3.

If the time is evenly split between scattering off of polarized and unpolarized ND_3, the time necessary to achieve the desired precision δA is

$$T = \frac{N_p}{R_p} + \frac{N_u}{R_u} = \frac{8}{f^2 P_{zz}^2} \left(\frac{R_p(R_u + R_p)}{R_u^3} \right) \frac{1}{\delta A_{zz}^2}, \tag{6}$$

where $R_{p(u)}$ is the polarized (unpolarized) rate and $N_{p(u)}$ is the total estimated number of polarized (unpolarized) counts to achieve the uncertainty δA_{zz}.

2.2. Statistical Uncertainty Estimate

To investigate the statistical uncertainty, we start with the equation for A_{zz} using measured counts for polarized data (N_p) and unpolarized data (N_u),

$$A_{zz} = \frac{2}{f P_{zz}} \left(\frac{N_p}{N_u} - 1 \right). \tag{7}$$

The statistical error with respect to counts is then

$$\delta A_{zz} = \frac{2}{f P_{zz}} \sqrt{\left(\frac{\delta N_p}{N_u} \right)^2 + \left(\frac{N_p \delta N_u}{N_u^2} \right)^2}. \tag{8}$$

For $\delta N_{p(u)} = \sqrt{N_{p(u)}}$, the uncertainty becomes

$$\delta A_{zz} = \frac{2}{f P_{zz}} \sqrt{\frac{N_p(N_u + N_p)}{N_u^3}}, \tag{9}$$

which isn't simplified further due to the expected large asymmetry.

The number of counts was calculated using a combination of P. Bosted's [9] and M. Sargsian's [10] cross-section calculation code. The Bosted code was used for the lowest Q^2 setting, where effects of SRC scaling are expected to be negligible, and for $x < 1.1$ to accurately determine the quasi-elastic peak. The Sargsian code was used for the higher Q^2 settings at $x > 1.1$ due to its inclusion of SRC scaling effects that represent a more accurate dilution factor.

Spectrometer Setting		E_0 (GeV)	Q^2 (GeV^2)	E' (GeV)	$\theta_{e'}$ (°)	Rates (kHz)
SHMS	A	8.8	1.5	8.36	8.2	0.43
SHMS	B	6.6	0.7	6.50	8.2	3.19
SHMS	C	2.2	0.3	2.11	14.4	3.73
HMS	C	2.2	0.3	2.11	14.9	2.92

Table 2. Summary of the central kinematics and trigger rates expected using the Jefferson Lab Hall C spectrometers at three settings (A, B, and C).

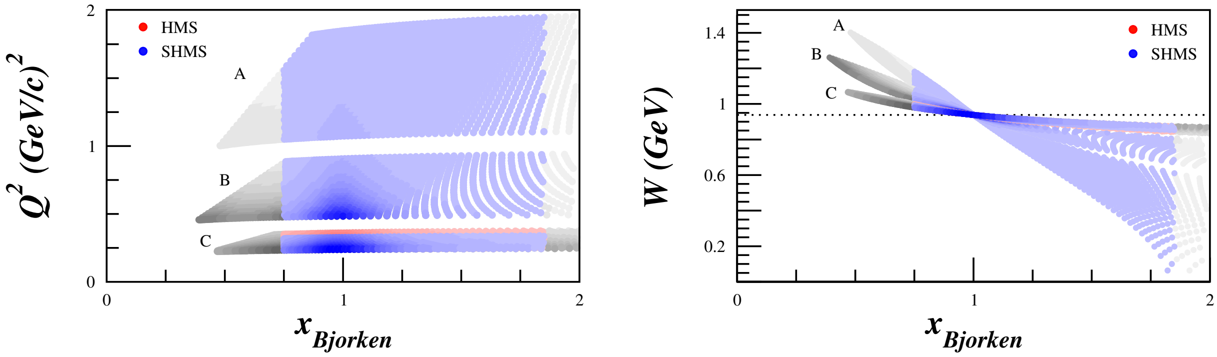

Figure 3. Kinematic coverage for central spectrometer settings at $Q^2 = 1.5$ (GeV/c)^2 (A), 0.7 (GeV/c)^2 (B), and 0.3 (GeV/c)^2 (C). The HMS is only used for setting C, and its coverage largely falls under the SHMS coverage. The grey regions are not included in our statistics estimates since they fall outside of $0.80 < x < 1.75$. Darker shading represents areas with higher statistics, and the dotted line in the W plot indicates nucleon mass.

2.3. Systematic Uncertainty Estimate

Table 1 shows a list of the scale dependent uncertainties contributing to the systematic error in A_{zz}. With careful uncertainty minimization in polarization, the relative error in vector polarization can be less than or equal to 3.9%, as was demonstrated for the proton in the recent E08-027/E08-007 experiment [11] and nearly as good for the deuteron using multiple techniques to measure the NMR signal as discussed in [12]. With the use of a positive tensor enhanced target, it has been projected to be able to achieve a relative error in P_{zz} better than 12% [12]. The uncertainty from the dilution in the polarized target is estimated to be about 6% over the range of kinematic points of interest. We consider separately the uncertainty in the packing fraction of the ammonia target to contribute at a level of less than 3%. Charge calibration and detector efficiencies are expected to be known better to 1%.

2.4. Kinematics

Utilizing the 12 GeV Jefferson Lab upgraded equipment in Hall C, the tensor asymmetry A_{zz} can be measured for $0.80 < x < 1.75$, 0.3 (GeV/c)^2 $< Q^2 <$ 1.5 (GeV/c)^2, and $0.59 < W < 1.09$ GeV. Fig. 3 demonstrates the potential kinematic coverage of such a measurement.

The experiment would use a solid tensor-polarized ND_3 target with the magnetic field held constant along the beamline. The target state would be alternated between a polarized and unpolarized state to measure A_{zz}. The tensor polarization and packing fraction used in the rates estimate are 30% and 0.65, respectively. The dilution fraction in the range of this measurement

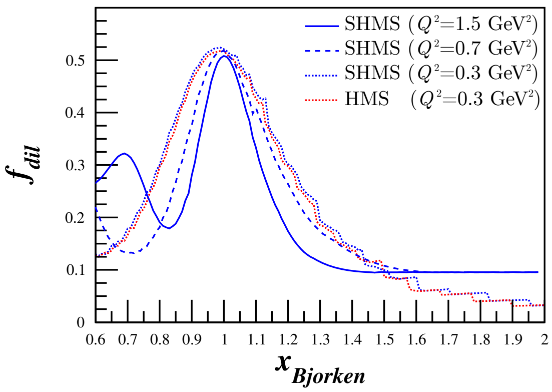

Figure 4. Projected dilution factor covering the entire x range to be measured.

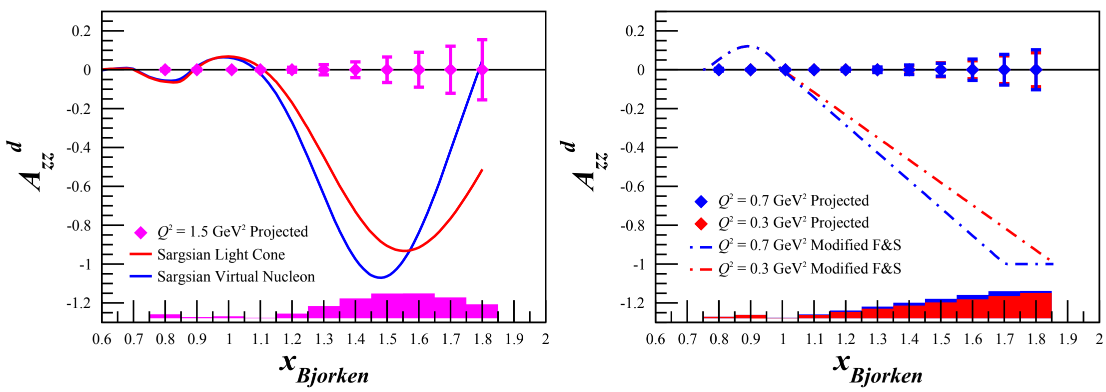

Figure 5. Projected statistical errors for the tensor asymmetry A_{zz} with 30 days of beam time. The band represents the systematic uncertainty. Also shown are calculations provided by M. Sargsian for using a light cone and virtual nucleon model for $Q^2 = 1.5$ (GeV/c)^2, and a modified Frankfurt and Strikman model [1] that estimates the peak shifts in x expected due to the SRC scaling changing with Q^2 [13] for $Q^2 = 0.3$ and 0.7 (GeV/c)^2.

is shown in Fig. 4. With an incident electron beam current of 90 nA, the expected deuteron luminosity is 1.3×10^{35} cm^{-2}s^{-1}.

The momentum bite and the acceptance were assumed to be $\Delta P = \pm 8\%$ and $\Delta\Omega = 5.6$ msr for the HMS, and $\Delta P =^{+20\%}_{-8\%}$ and $\Delta\Omega = 4.4$ msr for the SHMS. For the choice of the kinematics, special attention was taken into the angular and momentum limits of the spectrometers: for the HMS, $10.5^\circ \leq \theta \leq 85^\circ$ and $1 \leq P_0 \leq 7.3$ GeV/c, and for the SHMS, $5.5^\circ \leq \theta \leq 40^\circ$ and $2 \leq P_0 \leq 11$ GeV/c. In addition, the opening angle between the spectrometers is physically constrained to be larger than 17.5°. The projected uncertainties in A_{zz} are shown in Fig. 5.

3. Summary

We have investigated the possibility of making high precision measurements of the quasi-elastic tensor asymmetry A_{zz} and found the opportunity compelling. By covering the kinematic range from the QE peak ($x = 1$) up to elastic scattering ($x = 2$), we expect that this data will provide valuable new insights about the high momentum components of the deuteron wavefunction.

We have found that A_{zz} can be measured with high precision at $Q^2 = 1.5$, 0.7, and 0.3 (GeV/c)^2 at Jefferson Lab in Hall C using identical equipment as the upcoming b_1 experiment

E12-13-011. Such a measurement would provide valuable insights into the NN potential and fill a gap in measurements of A_{zz} between the $T_{20} \propto A_{zz}$ elastic measurements and the $b_1 \propto \frac{A_{zz}}{F_1^d}$ deep-inelastic measurements.

4. References

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