Transverse beam asymmetries measured from ^4He and hydrogen targets

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Abstract. The HAPPEX Collaboration at Jefferson Lab has measured the transverse beam spin asymmetries (A_T) for elastic electron scattering from proton and ^4He targets. The experiment was conducted using a vertically polarized electron beam of energy ~ 3 GeV at a $Q^2 \sim 0.1$ GeV 2 and a scattering angle $\theta_{lab} \sim 6^\circ$. The preliminary results are reported here. The ^4He measurement is the first measurement of A_T from a nucleus. A_T for ^4He is non-negligible; therefore, it will be necessary to make measurements of A_T for future parity-violating experiments using nuclear targets.

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1 Introduction

The asymmetry A_T arises from the interference between one-photon (1γ) and two-photon (2γ) exchange when elastically scattering transversely polarized electrons from an unpolarized target. The HAPPEX experiment measures the asymmetry for vertically polarized electrons scattering from ^4He and proton targets. The asymmetry is defined as

$$A_T = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} \quad (1)$$

where $\sigma_{\uparrow}$ ($\sigma_{\downarrow}$) is the cross-section for electrons polarized parallel (antiparallel) to the normal of the scattering plane. The asymmetry manifests itself as a spatial asymmetry because

$$A_T \propto \mathbf{S}_e \cdot \frac{\mathbf{k}_e \times \mathbf{k}'_e}{|\mathbf{k}_e \times \mathbf{k}'_e|} \quad (2)$$

where $\mathbf{S}_e$ and $\mathbf{k}_e$ are the spin vector and momentum vector, respectively, of the incoming electron and $\mathbf{k}'_e$ is the momentum vector of the scattered electron. A_T is suppressed by several factors such as the fine-structure constant, α , the Lorentz boost of the incoming electron, and the very-forward scattering angle. In the approximation of 1γ exchange or 2γ exchange with contributions only from ground state interactions, $A_T \ll 10^{-6}$.

The extraction of the ratio of the nucleon electric and magnetic form factors is influenced by the real part of the 2γ amplitude. The discrepancy between the Rosenbluth and polarization data measuring this ratio has motivated interest in studying the 2γ exchange. A_T is only sensitive to the imaginary part of the 2γ exchange and is of interest to parity-violating (PV) experiments because it is a possible background to the PV asymmetry. Studying

the 2γ exchange provides a clear and accessible window on the treatment of hadronic intermediate states in box diagrams.

PV experiments are ideal for measuring small asymmetries such as A_T because of their high-luminosity and low-background environment. PV experiments are already setup to control false asymmetries, to rapidly flip the beam polarization in order to control slow drifts, and to cancel beam asymmetries with symmetric detector configurations. All PV experiments measure A_T in order to control possible systematic errors. As a result, measurements of A_T exist over a wide range of kinematics [1–3].

2 Experiment

The experiment took place in Hall A at Jefferson Lab (JLab) in Virginia using the standard HAPPEX experimental equipment and techniques. The differences from the PV HAPPEX measurement are the setup of the beam polarization (discussed in Sect. 2.1) and the measurement of the beam polarization (discussed in Sect. 2.2). The transverse asymmetry was measured as a background to the PV HAPPEX measurement in 2004 and 2005 for the proton and ^4He respectively.

The experiment uses a 20 cm liquid hydrogen (LH_2) target for the proton measurement and a 20 cm cold, dense ^4He gas target for the helium measurement. The scattered electrons are focused onto the focal-plane detectors using the Hall A High Resolution Spectrometers (HRS). A septum magnet located upstream of the HRS bends the 6° scattered electrons into the entrance of the HRS (at 12.5°). The signal from the focal-plane detectors are then integrated in the HAPPEX data acquisition (DAQ).

The beam helicity is chosen pseudorandomly at 15 Hz. The beam remains in this helicity state for 33.3 ms and then is switched to the opposite helicity state for the same amount of time. Each period of constant helicity is referred to as a “window”. The asymmetry is calculated for adjacent helicity windows called a “pair”. In addition to the detectors, the beam current and position monitors’ signals are also integrated in the DAQ in order to measure and control false asymmetries on the beam. For more detail of the experimental apparatus, see [4,5].

2.1 Setup of Beam Polarization

The horizontal acceptance of the Hall A HRS requires vertical polarization for the measurement of A_T . Vertical polarization is not standard at JLab and requires a special setup procedure. The setup of the polarized source optics for the vertical beam polarization and the helicity-correlated beam properties are the same as for the PV measurement. The vertical alignment of the electron spin in the injector is discussed below.

When the electrons leave the cathode, they are aligned parallel or antiparallel to the beam direction. The Wien filter consists of perpendicular electric and magnetic fields (both of which are perpendicular to the electron’s trajectory) in order to rotate the electron spin horizontally without deflecting the electron’s trajectory. The Wien filter settings are optimized such that after passing through the Wien filter, the electron spin is horizontal to the beam direction.

Downstream of the Wien filter are two solenoids which are counter wound. During normal beam operation, these solenoids are connected in series and run by the same power supply such that they provide equal and opposite magnetic fields along the beam direction to provide focusing of the beam. In order to rotate the electron spin to the vertical direction, there needs to be a net magnetic field in the beam direction. This field is achieved by running the solenoids with separate power supplies and thus different currents and magnetic fields. The current settings in each solenoid are optimized such that the magnetic field rotates the electron spin to be fully vertical.

2.2 Measurement of Beam Polarization

The beam polarization is measured with two different techniques. The polarization is measured by the Mott polarimeter in the 5 MeV region of the injector and by the Møller polarimeter in Hall A. The standard configuration of the Mott polarimeter is capable of providing a vertical beam polarization measurement. Because vertical polarization does not precess through the accelerator, the Mott polarimeter measures the same polarization as what is present in Hall A. The Hall A Møller polarimeter provides a cross-check to the Mott measurement.

The standard Hall A Møller polarimeter is insensitive to vertical polarization, but new targets were made for the polarimeter so that it would be sensitive to vertical

beam polarization. The new targets were tilted vertically by $\pm 20^\circ$ and are polarized along the length of the target. These targets provide an analyzing power in both the beam direction and the vertical direction. The analyzing power is seven times larger along the beam direction compared to the vertical direction. The two targets provide the opposite-sign analyzing-power in the vertical direction, and the use of both targets cancels the effects of the longitudinal target polarization. Although the low analyzing power of the Møller allows significant systematic errors, the Møller measurement provides a valuable cross-check of the absolute sign of the polarization. The Mott and Møller polarimeters measured a consistent polarization of $84 \pm 2\%$.

3 Results

The standard PV analysis techniques are used for the analysis of the A_T measurement and are discussed in more detail in [4,5]. The hydrogen data set consists of 3.1×10^5 pairs with a resolution 610 parts per million (ppm), and the helium data set consists of 9.4×10^5 pairs with a resolution of 1040 ppm. As is typical with PV asymmetry measurements, a half-wave plate (HWP) is used as a slow helicity reversal. The data set for each target is split into two approximately equal groups based on the state of the HWP. The two HWP data sets for each target are consistent. The raw detector asymmetry (A_{raw}) corrected for false asymmetries due to the beam (A_{beam}) is defined as $A_{\text{corr}} = A_{\text{raw}} - A_{\text{beam}}$. The correction to the hydrogen detector asymmetry is $A_{\text{beam}} = 0.14$ ppm, and $A_{\text{corr}} = -4.95 \pm 1.09$ (stat) ppm. The correction to the helium detector asymmetry is $A_{\text{beam}} = 0.11$ ppm, and $A_{\text{corr}} = -10.93 \pm 1.07$ (stat) ppm.

The physics result is achieved after correcting A_{corr} for the beam polarization and other normalization factors. The systematic errors are listed in Table 1. The three dominant sources of error are false asymmetries, polarization, and the $\sim 1\%$ aluminum quasi-elastic (QE) dilution. The preliminary results are shown below pending final polarization and background analyses. The proton result is

$$A_T^H = -6.58 \pm 1.47 \text{ (stat)} \pm 0.24 \text{ (syst) ppm}$$

for a beam energy $E_b = 3$ GeV, center-of-mass scattering angle $\theta_{CM} = 16^\circ$, and 4-momentum transfer $\langle Q^2 \rangle = 0.099$ GeV². The ^4He result is

$$A_T^{He} = -13.51 \pm 1.34 \text{ (stat)} \pm 0.37 \text{ (syst) ppm}$$

for $E_b = 2.75$ GeV, $\theta_{\text{lab}} = 6^\circ$, and $\langle Q^2 \rangle = 0.077$ GeV².

Previous calculations of A_T for the proton are not valid at the HAPPEX kinematics [6,7], but our result agrees well with a recent calculation using the optical theorem to relate A_T to the total photoabsorption cross-section [8]. An exact calculation of A_T for elastic electron- ^4He scattering predicts A_T to be of the order 10^{-10} assuming the nucleus remains in its ground state at all times [9]. The ^4He A_T result is 5 orders of magnitude larger than

Table 1. Systematic errors for A_T .

Systematic	Hydrogen (ppm)	Helium (ppm)
False Asymmetry	0.136	0.110
Polarization	0.165	0.300
Linearity	0.070	0.140
Al QE	0.064	0.130
^4He QE	—	0.01
Rescattering	0	0.070
Total	0.240	0.370

this calculation’s prediction; therefore excited states of the nucleus must contribute significantly to the asymmetry. The calculation using the optical theorem to relate A_T to the total photabsorption cross-section predicted a value [10] which is in reasonable agreement with our result.

4 Conclusion

We conclude that the hadronic intermediate states are important contributions to the imaginary part of the 2γ -exchange amplitude for elastic electron-proton and electron-nucleus scattering. This is the first measurement of A_T for elastic electron-nucleus scattering which clearly shows that the asymmetry is non-negligible as was previously thought. It will be especially important to measure A_T for upcoming experiments such as PREX [11], which measures the PV asymmetry for ^{208}Pb , because of the challenging experimental backgrounds.

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