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Results on Double-polarization Asymmetries in Quasielastic Scattering from Polarized ^{3}He

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Abstract. The ^{3}He nucleus has become extremely important in the investigation of the neutron's spin structure. When polarized, ^{3}He acts as an effective polarized neutron target and hence facilitates our understanding of the neutron's internal structure. However, to be used in this manner, our understanding of the internal structure of ^{3}He is of extreme importance. As the precision of experiments has improved, the extraction of polarized neutron information from ^{3}He leads to an ever larger share of the systematic uncertainty for these experiments. In these proceedings, I present a precise measurement of beam-target asymmetries in the $^3\vec{\mathrm{He}}(\vec{e}, e'd)$ and $^3\vec{\mathrm{He}}(\vec{e}, e'p)$ reactions. The former process is a uniquely sensitive probe of hadron dynamics in ^{3}He and the structure of the underlying electromagnetic currents. The measurements have been performed around the quasi-elastic peak at $Q^2 = 0.25$ (GeV/c)^2 and 0.35 (GeV/c)^2 for recoil momenta up to 270 MeV/c. The experimental apparatus, analysis and results were presented together with a comparison to state-of-the art Faddeev calculations.

1 Introduction

Protons and neutrons, collectively referred to as nucleons, comprise the nuclei of atomic elements. While many of the characteristics and underlying dynamics of the proton have been reasonably measured, the neutron is not understood to a desirable accuracy in particular regarding its charge, magnetization and spin distributions. Direct measurements on the neutron are difficult due to its short half-life outside the nucleus of an atom. Physicists have had to rely on indirect measurements using the appropriate nuclear targets to unveil the internal structure of the neutron. The two most common nuclei used to investigate the neutron are the deuteron (proton + neutron) and ^{3}He (two protons + neutron). However, detailed knowledge on the structure of light nuclei is crucial for extracting precise information on neutron structure. In these proceedings, we will focus on the ^{3}He nucleus.

^{3}He nuclei are interesting because theoretical predictions of their nuclear structure can be compared with data to an increasingly accurate degree. Understanding the ground-state spin aids in experiments that attempt to extract neutron information from polarized ^{3}He targets such as the inelastic structure functions g_1^n and g_2^n. However, the statistical precision of the experimental measurements on ^{3}He is now similar to the systematic uncertainty, which is related to our imperfect knowledge of the polarization of the nucleons within the ^{3}He nucleus. Theoretical calculations have predicted that there

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are three main components in the ^{3}He ground-state wave functions, and our knowledge of the small components aids our understanding of the "standard model" of the few-body system.

A complete understanding of the ground-state wave function, reaction-mechanism effects such as final-state interactions (FSI) and meson-exchange currents (MEC) along with the roles of two- and three-nucleon forces are necessary to obtain good agreement between theory and experimental data. The experimental data reported here are compared with two independent full Faddeev calculations from the Bochum-Krakow (BK) [1, 2] and Hannover-Lisbon (HL) [3–6] groups. Additionally, calculations from the Pisa [7] group, though not Faddeev calculations, are expected to account for all relevant reaction mechanisms. The calculations have shown that the $^3\vec{\mathrm{He}}\,(\vec{e}, e'd)$ scattering process is strongly sensitive to the subleading components of the ^{3}He ground-state wave function and that the components have different signatures as functions of the missing momentum, $p_m = |\mathbf{q} - \mathbf{p_d}|$, which is the difference between the transferred and the detected deuteron momentum.

2 Experimental Details

During the experiment, the ^{3}He nucleus was examined by electron-induced knock-out of protons and deuterons. In the reactions, the electrons with incident energy E transfer energy ω and three-momentum $\mathbf{q}$ to the nucleus. These processes are measured as a function of the magnitude of the particle's missing momentum, which corresponds to the momentum of the recoiled particle. The experiment [8] was conducted at Jefferson Lab in Hall A [10] using the polarized electron beam with an energy of 2.425 GeV and currents $> 10\ \mu$A. The beam polarization was measured by a Møller polarimeter to be $\sim$ 84%, and the helicity of the beam was flipped at 30 Hz using a pseudorandom sequence. The electron beam was scattered from a polarized ^{3}He target.

The polarized ^{3}He target consisted of a 40-cm long glass cell filled with ^{3}He gas to approximately 9 atm and was polarized using spin-exchange optical pumping of a Rb-K alkali admixture [9]. The orientation of the target polarization was maintained by two pairs of Helmholtz coils, and the target polarization was measured by nuclear magnetic resonance and electron paramagnetic resonance throughout the experiment.

The quasi-elastically scattered electrons and knocked-out deuterons (protons) were detected by a High Resolution Spectrometer (HRS) [10] and the BigBite Spectrometer (using a hadron detector package) [11], respectively. The HRS was located at an electron scattering angle of either 12.5° or 14.5°, which translates into an average four-momentum transfer squared $Q^2 = \mathbf{q^2} - \omega^2$ of 0.25 (GeV/c)^2 or 0.35 (GeV/c)^2. Additional experimental details are available in Ref. [8].

The measured asymmetries are given by the expression:

$$A\,(\theta^*, \phi^*) = \frac{(d\sigma/d\Omega)_+ - (d\sigma/d\Omega)_-}{(d\sigma/d\Omega)_+ + (d\sigma/d\Omega)_-}, \tag{1}$$

where the subscript on the differential cross section $(d\sigma/d\Omega)$ indicates the helicity of the beam. These asymmetries were measured for both the $^3\vec{\mathrm{He}}\,(\vec{e}, e'd)$ and $^3\vec{\mathrm{He}}\,(\vec{e}, e'p)$ processes, though only preliminary results are available for the latter reaction. The orientation of the target polarization vector is defined by the the polarization angles θ^* and ϕ^*, where the z axis is along the $\mathbf{q}$-vector and the y axis is defined by the cross product of the incident electron and scattered electron vectors. During the experiment, the Helmholtz coils were used to orient the ^{3}He spin vector to measure the asymmetries: $A\,(160°, 0°)$ and $A\,(71°, 0°)$. The values of the spin angles are averages over the spectrometer acceptance. The measured asymmetries are corrected for helicity-dependent effects such as the beam charge asymmetry and dead time. The physics asymmetries are then determined by correcting for the beam and target polarizations. Radiative corrections were also applied.

3 Results and Comparisons to Theory

Figure 1 shows the asymmetries versus missing momentum (left panel) and ω (right panel). The top panels provide the results on $A(71°, 0°)$, whereas the bottom panels illustrate the results for $A(160°, 0°)$. The error bars on the data represent the statistical (inner) and total uncertainties (outer), where the total uncertainty is the statistical and systematic uncertainties added linearly. The total systematic uncertainty is 7% relative, in which the systematic uncertainties have been added in quadrature.

In Fig. 1, the results of the state-of-the-art calculations of the BK [1, 2], HL [3–6] and Pisa [7] groups are shown with the data. Due to the spread in θ^* and ϕ^* caused by the finite acceptances of the spectrometers, the theory calculations were acceptance averaged in the procedure detailed in Ref. [12]. The shaded (light blue in color) bands represent the uncertainties caused by the acceptance-averaging procedure. In the figure, they have been placed on the HL curves, since that calculation was averaged over the finest mesh. It is clear from the comparison that neither of the theoretical curves matches the data well, though improvement is seen when a cut is placed on $\omega < 140$ MeV to isolate the quasielastic region (thin solid curve). This improvement is expected, since all present calculation are known to preform better in the region of the quasielastic peak. This is caused by the production of pions and the influence of the resonances, which have not been included in the calculations. The high precision of these data reveal deficiencies in the theories, which may require further refinement in the treatment of their two-and/or three-body dynamics.

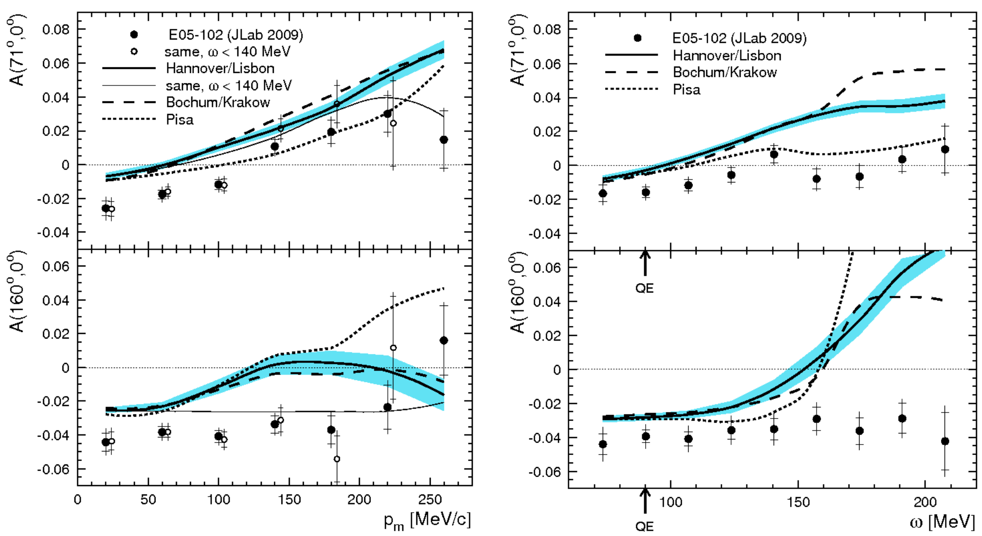

Figure 1. The asymmetries $A(71°, 0°)$ (top) and $A(160°, 0°)$ (bottom) in the quasielastic $^3\vec{\mathrm{He}}(\vec{e}, e'd)$ process versus missing momentum (left panel) and energy transfer (right panel). The arrows indicate the approximate location in ω of the quasielastic peak. Reproduced from Ref. [8]. See text for additional details.

In the right-side panel of Fig. 1, the asymmetries versus the energy transfer are shown along with the theoretical curves. At large ω, the measured asymmetries deviate substantially from the calculations, which indicates that the input of the reaction mechanisms in the dip region is incomplete. At lower ω, an absolute systematic offset between 1% and 2% is seen, though the trend of the data is reasonably reproduced by the theories.

Preliminary results for the $^3\vec{\mathrm{He}}\,(\vec{e}, e'p)$ reaction for $Q^2 = 0.25\ (\mathrm{GeV}/c)^2$ and $0.35\ (\mathrm{GeV}/c)^2$ are shown in Fig. 2. Due to the resolution of the relative momentum of the BigBite spectrometer ($\approx 2\%$), the two and three body-break up regions in this reaction are difficult to separate experimentally, and hence, the preliminary asymmetries are shown by including both regions. Analysis is continuing to provide comparisons of these data to the theoretical predictions. The depiction in between the graphs shows the ^{3}He spin vector orientation with respect to the incident electron beam momentum and **q**.

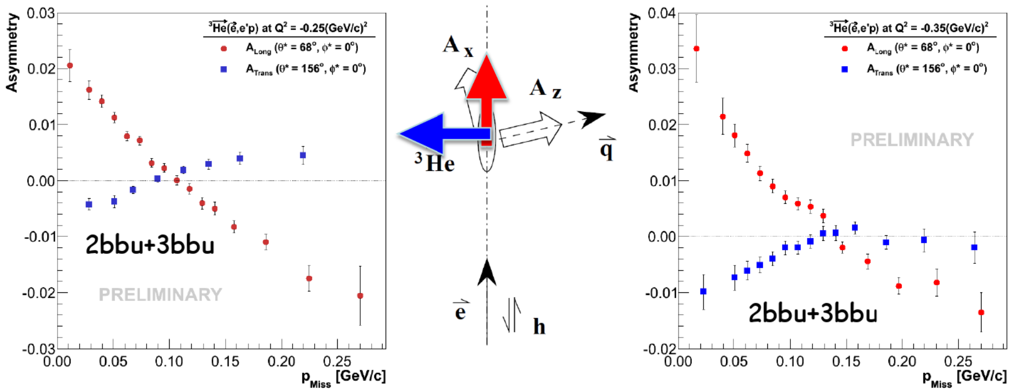

Figure 2. The asymmetries $A\,(68°, 0°)$ (circles) and $A\,(156°, 0°)$ (squares) in the quasielastic $^3\vec{\mathrm{He}}\,(\vec{e}, e'p)$ process versus missing momentum at $Q^2 = 0.25\ (\mathrm{GeV}/c)^2$ (left panel) and $0.35\ (\mathrm{GeV}/c)^2$ (right panel).

4 Conclusion

In these proceedings, the published results on the $^3\vec{\mathrm{He}}\,(\vec{e}, e'd)$ process were presented at $Q^2 = 0.25\ (\mathrm{GeV}/c)^2$ versus the missing momentum and energy transfer. This process is a sensitive probe of hadron dynamics in ^{3}He and the structure of the underlying electromagnetic currents. Asymmetries show a systematic offset compared to state-of-the-art theory predictions, but they are in fair agreement in terms of their functional dependencies with respect to p_m and ω. Data on the $^3\vec{\mathrm{He}}\,(\vec{e}, e'p)$ reaction were also presented, though the final comparison with the available theories is ongoing. Finally, data at $Q^2 = 0.35\ (\mathrm{GeV}/c)^2$ also exist for both reactions, though no calculations are currently available to compare against them. The new data along with the theoretical calculations will significantly advance our knowledge of the three-nucleon system.

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