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Approaching the spin structure of ^{3}He by polarization observables

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Abstract. The E05-102 experiment at Jefferson Laboratory (TJNAF) was devised to study the double-polarization asymmetries in electron-induced deuteron, proton, and neutron knockout from polarized ^{3}He at low momentum transfers, in a wide range of missing momenta. With this advanced experimental technique, we strive to obtain a much clearer insight into the ground-state structure of ^{3}He, the cornerstone nucleus widely used as the effective neutron target. An order of magnitude improvement in the statistical uncertainties with respect to existing measurements is anticipated. We report on the status of the ongoing data analysis.

1 Physics motivation

The primary motivation to study electron-induced processes involving the ^{3}He nucleus (see [1] and references therein) is to understand the ground-state structure of this nucleus. This structure is not only interesting by itself; it is also important to study it in order to be able to interpret all data "on the neutron" for which ^{3}He acts as an effective target to a very good approximation. Contrary to common belief, there is no widely adopted consensus about the exact level at which this approximation can be treated as "good" or "good enough".

A precise understanding of the transition between the experimental data acquired on ^{3}He targets and the observables corresponding to the neutron has become a burning issue since the statistical precision of recently performed (or future) experiments is so large that the systematical uncertainties of this computational transition procedure have become comparable to it. Some of the most interesting observables fall into this category, like e.g. the neutron elastic form-factors

$$G_E^n, \quad G_M^n,$$

and the polarized quark structure functions corresponding to the neutron,

$$G_E^n, \quad G_M^n, \quad A_1^n, \quad g_1^n, \quad g_2^n,$$

as well as the studies of the GDH sum rule.

One of the main complications, of course, is that the protons in ^{3}He partly polarized due to the presence of S'- and D-state components of the ground-state wave-function. (The ground-state configuration of ^{3}He is intimately connected to another open question of differences in RMS-radii, $\langle r^2\rangle^{1/2}$, of ^{3}H as opposed to ^{3}He, a matter largely unresolved due to an almost complete lack of measurements on tritium.) The manifestations of the distribution of spin, orbital angular momentum and isospin within ^{3}He appear to be most prominent and unambiguous in double-polarization asymmetries for electron-induced deuteron, proton, and neutron knockout from polarized ^{3}He. Numerous discrepancies among the state-of-the-art theories persist for these observables.

In short, understanding the role of D and S' states as the two most relevant sub-leading components of the ^{3}He wave-function, and of the spin- and isospin-dependence of reaction mechanisms on ^{3}He is one of the key issues in the "Standard Model" of few-body theory.

2 The measurements

The exclusive cross-section for electron-induced deuteron knockout (with both the beam and the target polarized) has the form

$$\frac{d\sigma(h, \mathbf{S})}{d\Omega_e\, dE_e\, d\Omega_d\, dp_d} = \frac{d\sigma_0}{d\Omega_e\, dE_e\, d\Omega_d\, dp_d} \left[1 + \mathbf{S} \cdot \boldsymbol{A}^0 + h(A_e + \mathbf{S} \cdot \boldsymbol{A}) \right] .$$

In the experiment described in this contribution, we measured two components of $\boldsymbol{A}$ (or linear combinations thereof), which correspond to the transverse and longitudinal double-polarization asymmetries

$$A_{x,z} = \frac{[d\sigma_{++} + d\sigma_{--}] - [d\sigma_{+-} + d\sigma_{-+}]}{[d\sigma_{++} + d\sigma_{--}] + [d\sigma_{+-} + d\sigma_{-+}]} ,$$

where the subscript signs denote the helicities of the electron beam and the orientation of the target spin. The target was polarized along the beam-line and perpendicular to it (in both sideways directions). Similarly, the asymmetries for exclusive processes in which the proton and the neutron were knocked out (with obvious modifications to the above formulas) have been measured.

Since the transverse and longitudinal asymmetries in each channel have very distinct sensitivities to the dominant S and the sub-dominant D and S' component of the ^{3}He as functions of missing momentum, our experiment carries an immense resolving power for testing theories mentioned below. The fact that several exclusive channels were measured at the same time at approximately the same four-momentum transfer of about 0.2 to 0.3 $(\mathrm{GeV}/c)^2$, in a large range of missing momenta, and with excellent statistical and systematical uncertainties, is another landmark feature of this experiment.

The resulting asymmetries will be compared to state-of-the-art theories of the ^{3}He nucleus. We exploit the calculations of the Bochum/Krakow group [4] that apply a full Faddeev approach with the AV18 NN-potential and the Urbana IX three-nucleon force, together with a complete treatment of final-state interactions (FSI) and meson-exchange currents (MEC).

Also available to use are the calculations of the Hannover/Lisbon group [5] that are also full Faddeev, but with a coupled-channel extension and refit of the CD-Bonn NN-potential. They also incorporate FSI and MEC, while the effective three-nucleon force and two-body currents are provided by inclusion of the Δ as an active degree-of-freedom. Coulomb interaction for outgoing charged baryons is also included.

The group from Pisa has also provided us with their calculations based on the AV18 potential and the Urbana IX force in which the FSI are included by means of the variational pair-hyperspherical harmonics expansion, and MEC are also accounted for. This is not a Faddeev-type calcuation, but its accuracy is assumed to be completely equivalent to it [6]. All three predictions (full calculations only) are presented in comparison to the anticipated experimental uncertainties in Fig. 1.

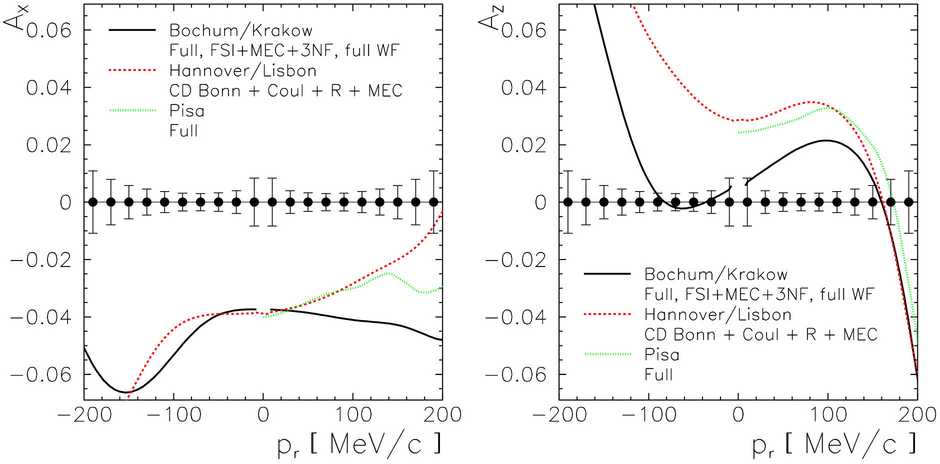

Fig. 1. The predictions for the asymmetries A_x and A_y in the quasi-elastic $^3\mathbf{He}(\mathbf{e}, e'd)$ process. The anticipated experimental uncertainties and three calculations by the Bochum/Krakow, Hannover/Lisbon and Pisa groups are shown.

3 Status of data analysis

The polarizations of the electron beam and the target have been established, and the beam and target monitoring apparatus have been calibrated. The magneto-optical properties of the BigBite spectrometer that was used to detect the charged hadrons have been determined [3], and the tracking and PID detectors have been calibrated, along with the neutron detector and the spectrometer used to detect the electrons. Presently the analysis work is focused on the correct averaging of the theoretical asymmetries over the relatively large experimental acceptance. To this purpose, we have obtained the calculations of the asymmetries on a rather dense grid of points in the (E_e, θ_e) plane that covers the majority of our acceptance, as shown in Fig. 2. The additional dimension in which averaging is performed is the deuteron (or proton) emission angle with respect to the virtual photon.

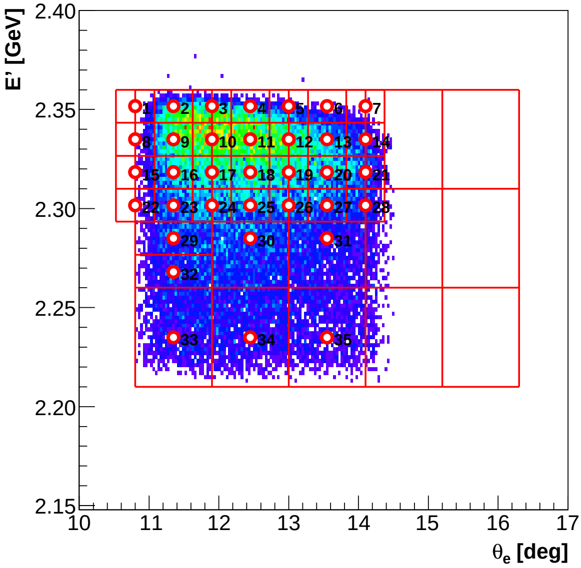

Fig. 2. The grid in (E_e, θ_e) plane on which the theoretical calculations will be performed, thus covering the most relevant parts of the experimental acceptance in the $^3\mathbf{He}(\mathbf{e}, e'd)$ channel. The high density of points is needed for reliable acceptance averaging because the asymmetries have a strong dependence on the energy transfer $E_e - E_e'$ (vertical axis).

The statistics of the data is sufficient to achieve a precision better than 2% on the asymmetries in each 20 MeV/c bin in missing momentum, ranging to about 200 MeV/c in the deuteron channel and about 300 MeV/c in the proton channels. Similar accuracy will be achieved in the neutron channel, and an even better one in the inclusive channels, which are a “bonus” of our experiment.

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