Twist-3 double-spin asymmetries in lepton-nucleon collisions†

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Hadrons, the strongly interacting particles that comprise almost all of the visible matter in the universe, have been shown to possess a complex inner-structure that goes beyond a simple quark picture. For example, experimental results in the 1970s on transverse single-spin asymmetries (SSAs) revealed the crucial role that quark-gluon-quark correlations could play in hadrons. This is a consequence of the fact that such observables are twist-3 effects. Much work over the last 40 years has been performed in the study of transverse SSAs from both the experimental and theoretical sides. In addition, one also has twist-3 double-spin asymmetries (DSAs), namely those where one particle is longitudinally polarized and the other is transversely polarized. We will denote these by A_{LT}. The classic process for which this effect has been analyzed is A_{LT} in inclusive deep-inelastic lepton-nucleon scattering (DIS). In that case the entire result can be written in terms of the collinear twist-3 function $g_T(x)$. Furthermore, this asymmetry has been studied in the Drell-Yan process involving two incoming polarized hadrons[1-4]; in inclusive lepton production from W-boson decay in proton-proton scattering[5]; for jet production in lepton-nucleon collisions[6]; and for direct photon production[7], jet/hadron production[8], and D-meson production[9] in nucleon-nucleon collisions.

Here we consider the reaction $\vec{\ell} N^{\uparrow} \to h\, X$, where one can have twist-3 contributions from both the distribution (incoming nucleon) and the fragmentation (outgoing hadron) sides. The leading-order (LO) analytical formulas for these terms are new results from this work, but we refrain from showing them explicitly for brevity. Based on this computation we will give numerical estimates for $\vec{e} N^{\uparrow} \to \pi\, X$, where $N = p, n$. We will only look at the distribution piece, where we need LO input for the non-perturbative functions $D_1(z)$ (unpolarized fragmentation function), $\tilde{g}(x)$ ("worm-gear"-type function), $g_T(x)$, and $g_1(x)$ (helicity distribution), where $\tilde{g}(x)$ is the least known of these functions and has gained quite some interest over the years.

Since we have little information on $\tilde{g}(x)$, we look at two scenarios: i) using the approximate relation $\tilde{g}(x) \approx -f_{1T}^{\perp(1)}(x)$, where $f_{1T}^{\perp}$ is the Sivers function; and ii) using a Wandzura-Wilczek (WW)-type approximation $\tilde{g}(x) \approx x \int_x^1 \frac{dy}{y} g_1(y)$, which was also used elsewhere in the literature and holds relatively well in certain models. In both cases for $g_T(x)$ we use the WW approximation, $g_T(x) \approx \int_x^1 \frac{dy}{y} g_1(y)$. In Fig. 1 we show a sample of our results, namely for HERMES and JLab6, where finalized data is expected soon from both groups.

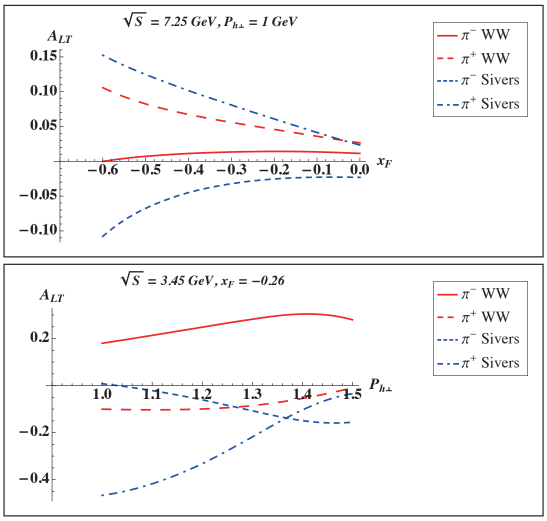

Fig. 1. A_{LT} vs. x_F for HERMES (top) and A_{LT} vs. $P_{h\perp}$ for JLab6 (bottom), where $x_F = 2P_{hz}/\sqrt{S}$ with P_{hz} ($P_{h\perp}$) the hadron's longitudinal (transverse) momentum.

We see from our plots that the "Sivers" input and "Wandzura-Wilczek" input can give quite different results due to the different behavior of $\tilde{g}(x)$. Thus, even a qualitative comparison of our predictions with experiment could help distinguish between the Sivers and WW scenarios. Moreover, if the magnitude of the data is in line with our results, one could have direct access to the "worm-gear"-type function $\tilde{g}(x)$, which has received some attention recently. If the magnitude is not in agreement, this observable could give insight into the importance of quark-gluon-quark correlations in the nucleon and/or twist-3 fragmentation effects in unpolarized hadrons. However, one always has to keep in mind the potential large impact of next-to-leading order terms. In general, we found the best chance to measure a nonzero asymmetry is at HERMES, JLab, and COMPASS, as the high center-of-mass energy of an EIC leads to a very small effect. We expect this conclusion to be rather robust.

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