Left-right spin asymmetries in lepton-nucleon collisions[†]

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The field of transverse single-spin asymmetries (SSAs) in hard semi-inclusive processes began close to 40 years ago when large effects were found at FermiLab that could not be generated within the collinear parton model. Here we focus on the left-right azimuthal asymmetry that can be defined in single-inclusive leptoproduction of hadrons if the nucleon is transversely polarized, $\ell N^\uparrow \to hX$. This asymmetry is similar to the transverse single-spin asymmetry A_N that occurs in $p^\uparrow p \to h\,X$, which has been intensely studied at RHIC. Recently, the HERMES Collaboration[1)] and the Jefferson Lab Hall A Collaboration[2)] reported the first ever measurements of A_N in lepton-nucleon scattering. In general, one may expect that A_N in this reaction could give new insight into the underlying mechanism of A_N in hadronic collisions that is the subject of longstanding discussions.

We compute A_N for $\ell N^\uparrow \to hX$ in collinear factorization, where one can have twist-3 effects in the transversely polarized nucleon or in the unpolarized outgoing hadron. The former involves the so-called Qiu-Sterman function F_{FT} — a specific quark-gluon-quark correlator that has an intimate connection with the transverse momentum dependent (TMD) Sivers function $f_{1T}^\perp$, while the latter arises from parton fragmentation, specifically through the functions $\hat{H}$, H, and $\hat{H}_{FU}^{\Im}$, where the first is related to the TMD Collins function. Both of these mechanisms have been studied in $p^\uparrow p \to h\,X$ within collinear factorization, e.g., in [3–6)]. Note that $\ell N^\uparrow \to hX$ has also been computed in the so-called Generalized Parton Model (GPM) (most recently in [7)]), which uses TMD parton correlation functions.

We will estimate A_N based on leading-order formulas, which we refrain from showing here explicitly for brevity, and study the contributions from the distribution term involving F_{FT}, and the fragmentation term involving $\hat{H}$, H, and $\hat{H}_{FU}^{\Im}$. It is important to realize that for the process at hand, $\ell\,N \to h\,X$, only the hadron transverse momentum $P_{h\perp}$ can serve as the hard scale. Here we give a sample of our results, namely some for HERMES and an EIC. In Fig. 1 we plot (in the top panel) A_N as a function of $x_F^{\mathrm{H}} = -x_F$ for π^+ production with $1 < P_{h\perp} < 2.2$ GeV ($\langle P_{h\perp}\rangle \simeq 1$ GeV) for lepton-proton collisions at HERMES energy $\sqrt{S} = 7.25$ GeV. Also shown (in the bottom panel) is our prediction for π^0 production at EIC energy $\sqrt{S} = 63$ GeV and $P_{h\perp} = 3$ GeV. Note that for $p^\uparrow p \to \pi\,X$ in the forward region ($x_F > 0$) very large values for A_N have been observed. We find that a non-zero A_N is predicted in this region at an EIC.

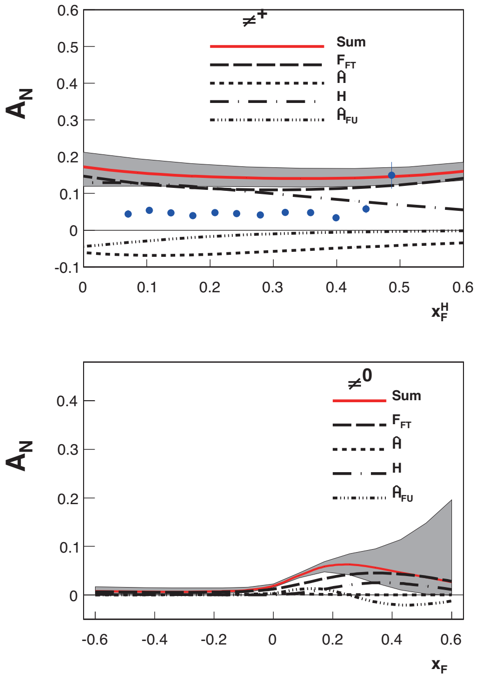

Fig. 1. A_N as a function of $x_F^H = -x_F$ for π^+ at HERMES kinematics (top), and a prediction for A_N as function of x_F for π^0 at EIC kinematics (bottom).

We see that our theoretical estimates for A_N agree with the HERMES results in sign and roughly in shape, but in terms of magnitude they are typically above the data. Such a discrepancy cannot be considered a failure of the collinear twist-3 formalism, but rather shows the need for for a next-to-leading order calculation, especially in the region of lower $P_{h\perp}$. It will also be important to better constrain the 3-parton fragmentation correlator $\hat{H}_{FU}^{\Im}$ through measurements, e.g., of $A_N^{\pi^-}$, which might allow one to test the recent extraction of $\hat{H}_{FU}^{\Im}$ that can play a crucial role in A_N in pp collisions[6)], and to discriminate between the GPM and the twist-3 frameworks.

References

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