Twist-3 fragmentation and transverse single-spin asymmetries†

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Transverse single-spin asymmetries (TSSAs) in inclusive hadron production (denoted by $A_N$) have been the subject of intense study since the late 1970s. These are defined as

$$A_N = \frac{d\sigma(\vec{S}_\perp) - d\sigma(-\vec{S}_\perp)}{2d\sigma_{unp}},$$

(1)

where $d\sigma(\vec{S}_\perp)$ ($d\sigma(-\vec{S}_\perp)$) is the cross section with transverse spin $\vec{S}_\perp$ oriented “up” (“down”) and $d\sigma_{unp}$ is the unpolarized cross section. Experiments have measured large effects for these observables (with the most recent results from proton-proton collisions at RHIC1–5, at RHIC1–5), which contradict the prediction of the naive collinear parton model6). However, a framework using twist-3 multi-parton correlators can potentially describe these large TSSAs6–7).

The assumption for many years was that the so-called soft-gluon pole (SGP) piece dominates over the other contributions8). This part involves the non-perturbative twist-3 Quig-Sterman (QS) function $T_F(x, z)$9), which was extracted several years ago9). However, a later analysis revealed that this extraction of $T_F(x, z)$ does not satisfy the model-independent relation with the Sivers function extracted from semi-inclusive deep-elastic scattering (SIDIS) off a transversely polarized proton: the two different extractions disagree in sign9). This “sign mismatch” crisis has led to a reexamination of whether the QS function is the most significant part of TSSAs in inclusive hadron production — see, e.g., the recent discussion10). The focus has now shifted to whether a contribution involving twist-3 fragmentation functions can resolve the “sign mismatch” and provide the dominant effect.

The complete analytic result for the twist-3 fragmentation term in the single-spin dependent cross section for $p^+ p \to hX$ was given for the first time by the present author and A. Meta5):

$$\frac{P^0_h d\sigma(\vec{S}_\perp)}{d^4p_h} = -2\alpha_s^2 M_h \frac{S}{\bar{S}} \epsilon_{\alpha\beta} S_{\perp}^\alpha P_{\perp, \alpha}^\beta$$

$$\times \sum_i \sum_{a, b, c} \frac{1}{x^3} \int_{x_{min}}^{1} \frac{dz}{x} \int_{x_{min}}^{1} \frac{dx}{x} \int_{x_{min}}^{1} \frac{dx'}{x'} \frac{1}{x} \frac{1}{x'} S_{\perp}^\alpha P_{\perp, \alpha}^\beta$$

$$\times \frac{1}{-x - x'} H_c^a(x) f_3^b(x') \left( \left[ H^z(z) - \frac{dH^z(z)}{dz} \right] S_{\perp}^\alpha \right) + \frac{1}{z} H^z(z) S_{\perp}^\alpha,$$

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See the paper11) for more details. In particular, Appendix A of the aforementioned reference contains the hard scattering coefficients $S_i$ in (2).

The piece in (2) also involves two independent non-perturbative functions: $H(z)$ and $H_{FU}^3(z, z_1)$. (The function $H(z)$ can be written in terms of the other two.) In principle one has information on $H(z)$ through its relation to the Collins function in SIDIS. One must then parameterize the unknown function $H_{FU}^3(z, z_1)$ and see if a fit to the data1–3) is possible. We propose the following form for this (3-parton) fragmentation correlator that is consistent with its support properties:

$$H_{FU}^3(z, z_1) = N z^\alpha (z/z_1)^\beta (1 - z)^\gamma (1 - z/z_1)^\delta \times D_1(z) D_1(z/z_1)$$,

(3)

where $D_1$ is the unpolarized fragmentation function. We are in the process of carrying out a numerical study of $A_N$ in $p^+ p \to \pi X$ using (3). This will be an important step towards solving an almost 40 year problem of what causes large TSSAs in inclusive hadron production from proton-proton collisions.

References