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

$$A_N = \frac{d\sigma(\vec{S}_\perp) - d\sigma(-\vec{S}_\perp)}{2\, d\sigma_{unp}}\,, \tag{1}$$

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 RHIC[1–3]), which contradict the prediction of the naïve collinear parton model[4]. However, a framework using twist-3 multi-parton correlators can potentially describe these large TSSAs[5–7].

The assumption for many years was that the so-called soft-gluon pole (SGP) piece dominates over the other contributions[7,8]. This part involves the non-perturbative twist-3 Qiu-Sterman (QS) function $T_F(x,x)$[6,7], which was extracted several years ago[8]. However, a later analysis revealed that this extraction of $T_F(x,x)$ does not satisfy the model-independent relation with the Sivers function extracted from semi-inclusive deep-inelastic scattering (SIDIS) off a transversely polarized proton: the two different extractions disagree in sign[9]. 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 discussion[10]. 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 $p^\uparrow p \to hX$ was given for the first time by the present author and A. Metz[11]:

$$\begin{aligned}\frac{P_h^0 d\sigma(\vec{S}_\perp)}{d^3\vec{P}_h} &= -\frac{2\alpha_s^2 M_h}{S}\epsilon_{\perp,\alpha\beta}\, S_\perp^\alpha P_{h\perp}^\beta \\ &\times \sum_i \sum_{a,b,c}\int_{z_{min}}^1 \frac{dz}{z^3}\int_{x'_{min}}^1 \frac{dx'}{x'}\,\frac{1}{x}\,\frac{1}{x'S+T/z} \\ &\times \frac{1}{-x'\hat{t}-x\hat{u}}\, h_1^a(x)\, f_1^b(x')\left\{\left[\hat{H}^c(z) - z\frac{d\hat{H}^c(z)}{dz}\right]S_{\hat{H}}^i\right. \\ &+\frac{1}{z}H^c(z)\, S_H^i \\ &\left.+ 2z^2\int\frac{dz_1}{z_1^2}PV\frac{1}{\frac{1}{z}-\frac{1}{z_1}}\hat{H}_{FU}^{c,\Im}(z,z_1)\,\frac{1}{\xi}\,S_{\hat{H}_{FU}}^i\right\}. \end{aligned}\tag{2}$$

See the paper[11] 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: $\hat{H}(z)$ and $\hat{H}_{FU}^{\Im}(z,z_1)$. (The function $H(z)$ can be written in terms of the other two.) In principle one has information on $\hat{H}(z)$ through its relation to the Collins function in SIDIS. One must then parameterize the unknown function $\hat{H}_{FU}^{\Im}(z,z_1)$ and see if a fit to the data[1–3] is possible. We propose the following form for this (3-parton) fragmentation correlator that is consistent with its support properties:

$$\begin{aligned}\hat{H}_{FU}^{\Im}(z,z_1) &= N z^\alpha (z/z_1)^\beta (1-z)^\delta (1-z/z_1)^\gamma \\ &\times D_1(z)\, D_1(z/z_1)\,, \end{aligned}\tag{3}$$

where D_1 is the unpolarized fragmentation function. We are in the process of carrying out a numerical study of A_N in $p^\uparrow p \to \pi X$ 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.

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