CAN THE COLLINS MECHANISM EXPLAIN
THE LARGE TRANSVERSE SINGLE SPIN ASYMMETRIES
OBSERVED IN $p_\uparrow p \rightarrow \pi X$?*

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We present a calculation of inclusive polarised and unpolarised cross sections within
pQCD and the factorisation scheme, taking into account the parton intrinsic motion,
$k_\perp$, in distribution and fragmentation functions, as well as in the elementary
dynamics. We show, in contradiction with earlier claims, that the Collins
mechanism is suppressed and unable to explain the large asymmetries found in
$p_\uparrow p \rightarrow \pi X$ at moderate to large Feynman $x_F$. The Sivers effect is not suppressed.

In the standard perturbative QCD approach to inclusive particle produc-
tion at high energies, intrinsic transverse motions are integrated out.
Nevertheless, we know how they can help in describing experimental data
for inclusive particle production in hadronic processes at moderately large
$p_T$,1 otherwise heavily underestimated.

When we consider polarised cross sections, $k_\perp$ could become essential:
certain spin and $k$-dependent effects, generated by soft mechanisms, can
be used to understand the large transverse single spin asymmetries (SSA)
found in many reactions like $p_\uparrow p \rightarrow \pi X$.

For polarised processes, $(A, S_A) + (B, S_B) \rightarrow C + X$, by introducing
in the factorisation scheme, in addition to the distribution functions, the

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the pion produced in the XZ plane. The azimuthal dependence of the number of pions created in the fragmentation amplitudes, with definite partonic interpretations. Eq. (3) contains all possible combinations of different distribution and fragmentation amplitudes, with definite partonic interpretations.

Let us now study the processes $A^1(A^4)B \to \pi X$ in the $AB$ center of mass frame, with the polarised beam moving along the positive $Z$-axis and the pion produced in the $XZ$-plane. The $\uparrow (\downarrow)$ is the $+Y (-Y)$ direction. Here we focus only on the contribution of the Collins mechanism, that is the azimuthal dependence of the number of pions created in the fragmentation of a transversely polarised quark.

The helicity amplitudes $\hat{M}$ in Eq. (3), defined in the hadronic c.m. frame, can be related to those given in the canonical partonic c.m. frame, $\hat{M}^0$, with $Z$ in the direction of the colliding partons and the $XZ$-plane as the
scattering plane. By performing a sequence of boost and rotations we get

\[ M_{\lambda_c,\lambda_d;\lambda_a,\lambda_b} = \hat{M}_{\lambda_c,\lambda_d;\lambda_a,\lambda_b}^0 \times e^{-i(\lambda_a - \lambda_b)\hat{\xi}_a - (\lambda_c - \lambda_d)\hat{\xi}_d} e^{-i(\lambda_a - \lambda_b)\hat{\xi}_a - (\lambda_c - \lambda_d)\hat{\xi}_d} e^{i(\lambda_c - \lambda_c)\phi_{\pi}^H}, \]

where \( \hat{\xi}_i \) (\( i = a, b, c, d \)) and \( \phi_{\pi}^H \) depend on parton momenta.²

On summing over \( \{\lambda\} \) [Eq. (3)] we obtain for the Collins contribution to the numerator of SSA \((q\bar{b} \rightarrow q\bar{b}, \; b = q, \bar{q}, g)\):

\[ \left[ \Sigma(\uparrow, 0) - \Sigma(\downarrow, 0) \right] = \left\{ F_{+-}^{T_+}(x, k_\perp) \cos[\phi_a - \phi_{\pi}^H - \xi_a - \xi_c + \hat{\xi}_a + \hat{\xi}_c + \phi_{\pi}^H] \right. \]
\[ \left. - F_{++}(x, k_\perp) \cos[\phi_a - \phi_{\pi}^H + \xi_a + \hat{\xi}_a - \xi_c - \hat{\xi}_c - \phi_{\pi}^H] \right\} \]  
\[ \times \hat{f}_{b/B}(x, k_\perp) \hat{M}_{+,+;+,+}^0 - 2iD_{+-}^n(z, k_\perp) \]  

where ± = ±1/2 (quarks), ±1 (gluons), and \( \phi_{\pi}^H \) is the azimuthal angle of the pion momentum in the fragmenting quark helicity frame. In the notations of Refs. [4] (details will be given in [5], see also [6]), we have

\[ F_{++}^{T_+}(x, k_\perp) = h_1(x, k_\perp) = h_{1T}(x, k_\perp) + \frac{k_{\perp}^2}{2M_p^2} h_{1T}^T(x, k_\perp) \]

\[ F_{++}^{T_+}(x, k_\perp) = \frac{k_{\perp}^2}{2M_p^2} h_{1T}^T(x, k_\perp) \]

\[ -2iD_{+-}^n(z, k_\perp) = \Delta^N D_{\pi/q^T}(z, k_\perp) = \frac{2k_{\perp}}{\sqrt{s}M_\pi} H_{1}^{+/q}(z, k_\perp), \]

where \( M_p \) and \( M_\pi \) are respectively the proton and pion mass.

In all previous studies the large SSA found in the E704 experiment⁷ was explained by either the Sivers⁸ or the Collins mechanisms.⁹ However, only a simplified kinematics was adopted. We now believe that the phases involved, when the kinematics is treated carefully, are crucial, and lead to a large suppression of the asymmetry due to the Collins mechanism. Almost no suppression of \( A_N \) from the Sivers mechanism is found.¹

In order to demonstrate the extent of the suppression we choose for the unmeasured soft functions in Eq. (5) their known upper bounds¹⁰ and adjust their signs so that the contributions from the valence flavours (up and down) reinforce each other. The results are presented in Fig. 1, which shows \( (A_N)_{\text{Collins}} \) as a function of \( x_F \), at \( p_T = 1.5 \text{ GeV/c} \) and \( \sqrt{s} \approx 19.4 \) GeV together with the E704 data.⁷ The only difference between the plots is given by different choices of the polarised distribution functions and/or the unpolarised fragmentation functions. In the upper-right plot the curves for charged pions obtained by setting all phases in Eq. (5) to zero are also given.
(thin lines). We can therefore conclude that the Collins mechanism alone, even maximising all its effects, cannot explain the observed SSA values.

An equally important consequence of keeping proper phases emerges in the calculation of SSA at $x_F < 0$: even maximising all contributions (Sivers mechanism too) one gets much smaller (a few \%) $A_N$ values.\footnote{5}

Once more, the importance and subtleties of spin effects come out; all phases, properly considered, often play crucial and unexpected roles.

![Graph showing maximised values of $A_N$ vs. $x_F$](image.png)

Figure 1. Maximised values of $A_N$ vs. $x_F$, as given by the Collins mechanism alone. Data are from Ref. [7]. See the text for further details.

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