PROCEEDINGS OF SCIENCE

On the role of the Sivers effect in A_N for inclusive particle production in pp collisions

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Single spin asymmetries, A_N, for inclusive particle production in pp collisions are considered within a generalized parton model with inclusion of spin and tranverse momentum effects. We consider the potential role of the Sivers effect in A_N, as extracted from a careful analysis of azimuthal asymmetries in SIDIS, and discuss its phenomenological consequences in connection with a recently updated study of the Collins effect.

XXI International Workshop on Deep-Inelastic Scattering and Related Subjects
22-26 April, 2013
Marseilles, France

PoS(DIS 2013)239

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[*] Speaker.

1. Sivers effect and A_N in the Generalised Parton Model formalism

Large values of Single Spin Asymmetries (SSA) A_N

$$A_N = \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow} \qquad \text{with} \qquad d\sigma^{\uparrow,\downarrow} \equiv \frac{E_h\, d\sigma^{p^{\uparrow,\downarrow} p \to hX}}{d^3\mathbf{p}_h}\,, \tag{1.1}$$

have been measured over the years in many different experiments in a broad range of energies [1 – 12]. Collinear, leading twist, perturbative QCD predicts negligible asymmetries, contrary to the observed data. Several approaches have been proposed to explain the SSA. Here we will make use of the so called Generalized Parton Model (GPM) [13 – 16]. The GPM can be considered as a natural phenomenological extension of the usual collinear factorization scheme, with the inclusion of spin and $k_\perp$ effects. In Refs. [13, 16] it was shown that the only non negligible contributions to A_N are given by the Sivers and the Collins effects,

$$[d\sigma^\uparrow - d\sigma^\downarrow] \simeq \Delta^N f_{q/p^\uparrow} \otimes f_{b/p} \otimes d\hat\sigma \otimes D_{h/c} \tag{1.2}$$
$$+\ \Delta_T q \otimes f_{b/p} \otimes d\Delta\hat\sigma \otimes \Delta^N D_{h/q^\uparrow} \tag{1.3}$$

where $\Delta^N f_{a/p^\uparrow}(x_a, k_{\perp a})$ is the Sivers function, $\Delta_T q$ is the transversity function and $\Delta^N D_{h/q^\uparrow}$ is the Collins function. The Collins contribution, Eq. (1.3), was studied in Ref. [16]. Here, we present the results of Ref. [17] devoted to the Sivers effect, Eq. (1.2).

The Sivers function has been studied extensively in Semi Inclusive Deep Inelastic Scattering (SIDIS) processes. Here we want to investigate the impact of the available information on the Sivers function from SIDIS processes in the calculation of A_N in pp inclusive scattering.

The main limitation of the present SIDIS data is that they cover only a limited region of x_B, $x_B \lesssim 0.3$. This is reflected in a large uncertainty of the Sivers function at large x.

The Sivers functions, $\Delta^N f_{q/p^\uparrow}(x, k_\perp)$, have been parameterised as follows:

$$\Delta^N f_{q/p^\uparrow}(x, k_\perp) = 2\,\mathcal{N}_q^S(x)\, f_{q/p}(x)\, \sqrt{2e}\, \frac{k_\perp}{M}\, e^{-k_\perp^2/M^2}\, \frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}\,, \tag{1.4}$$

where

$$\mathcal{N}_q^S(x) = N_q^S x^{\alpha_q}(1-x)^{\beta_q}\, \frac{(\alpha_q+\beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\beta_q^{\beta_q}}\,, \tag{1.5}$$

with $|N_q^S| \leq 1$. The large uncertainty at large x is thus reflected in a large uncertainty in the β parameter of this parameterization. To fully take into account this uncertainty we decide to adopt the following procedure (β scan):

- We refit SIDIS data [18, 19] taking 7 free parameter: $N_u, N_d, \alpha_d, \alpha_u, \beta_u, \beta_d, M$. In this way we obtain, from the best fit of the data, our reference χ_0^2. Notice that the recently introduced TMD-evolution [20] is not taken into account here, while we considered the DGLAP QCD evolution of the collinear factorised part.

- We then consider several (β_u, β_d) pairs, with $0 \leq \beta_{u,d} \leq 4$ at steps of 0.5 and for each pairs we perform a new fit getting a new χ^2 and, correspondingly, a new set of Sivers functions.

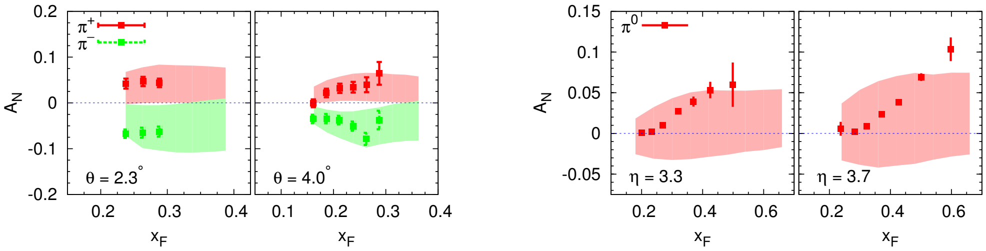

Figure 1: Scan band (*i.e.* the envelope of the 81 curves obtained with the scanning procedure) for the Sivers contribution to the charged pion single spin asymmetries A_N, at $\sqrt{s} = 200$ GeV, as a function of x_F at two different scattering angles, compared with the corresponding BRAHMS experimental data [8] (left panel) and to the neutral pion single spin asymmetry A_N, at $\sqrt{s} = 200$ GeV, as a function of x_F at two different pseudo-rapidity values, compared with the corresponding STAR experimental data [9] (right panel). The shaded scan band is generated adopting the GRV98 set of collinear PDFs and the Kretzer FFs.

- The next step is to select only those fits leading to a χ^2 such that $\chi^2 \leq \chi_0^2 + \Delta\chi^2$. This means to choose only Sivers functions describing the SIDIS data with the statistical criteria established by our $\Delta\chi^2$. We find (for 217 data points) $\chi_0^2 = 270.51$ and we adopt $\Delta\chi^2 = 14.34$, see Ref. [17] for details.

- Finally, we compute, for each set which fulfilled the above selection criteria, the contribution of the Sivers effect to A_N.

2. Results from the scan procedure

Some of our results for RHIC experiments are shown in Fig. 1: the scan band for A_N, as a function of x_F at fixed scattering angles, is shown in the left panel for charged pions and BRAHMS kinematics, while in the right panel the same result is given, at fixed pseudo-rapidity values, for neutral pions and STAR kinematics. In Ref. [17] we also give the scan band, as a function of P_T at several fixed x_F values, for STAR kinematics. All these results are given at $\sqrt{s} = 200$ GeV. Moreover in Ref. [17] we reported our estimates for kaon production at $\sqrt{s} = 200$ GeV and BRAHMS kinematics, and those for neutral pion production at $\sqrt{s} = 500$ GeV and STAR kinematics at very large P_T [11].

From these results we can conclude that the Sivers effect alone might in principle be able to explain the BRAHMS charged pion results on A_N in the full kinematical range so far explored, as well as almost the full amount of STAR π^0 data on A_N. This is to be contrasted with the analogous study of the Collins effect [16], where we concluded that such effect alone cannot explain the observed values of A_N in the medium-large x_F region.

At this point we wonder whether, among the Sivers functions resulting from the scan, we can find some sets which give a good description of all the data. Thus, among the full set of curves produced by the scan procedure, we have isolated the set leading to the best description of A_N (actually one could find more than a single set); we have then evaluated, as in Appendix A of Ref. [21], the corresponding statistical error band. Our results for STAR and BRAHMS are presented in Fig. 2. More results for STAR, inclusive jet [12, 24] and photon production can be found in Ref. [17]. Again we can see that for most pion data there is a Sivers function that

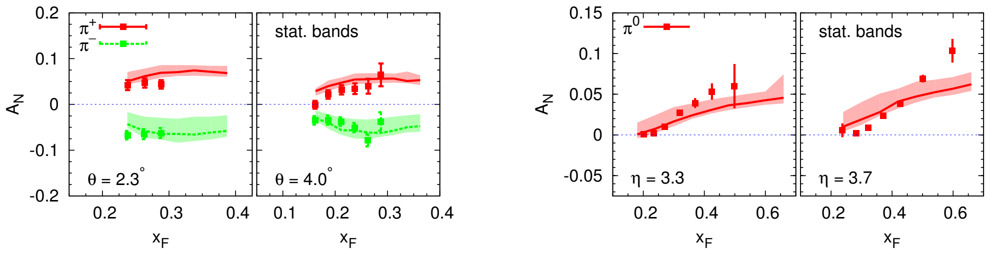

Figure 2: The Sivers contribution to the charged pion single spin asymmetry A_N, compared with the corresponding BRAHMS experimental data at two fixed scattering angles and $\sqrt{s} = 200$ GeV [8] (left panel) and the Sivers contribution to the neutral pion single spin asymmetry A_N, compared with the corresponding STAR experimental data at two fixed pion rapidities and $\sqrt{s} = 200$ GeV [9] (right panel). The central lines are obtained adopting the GRV98 set [26] of collinear PDFs and the Kretzer FFs [25], with the Sivers functions given in Table 1 of Ref. [17]. The shaded statistical error bands are generated applying the error estimate procedure described in Appendix A of Ref. [21] .

alone could explain the observed values of A_N in magnitude and, in particular, in sign. This is in contrast to other approaches, also related to the Sivers effect, which seem to have problems [22, 23] in explaining the sign of the observed A_N. Nevertheless it is important to stress here that a full understanding of the SSAs in inclusive $p^{\uparrow}p \to hX$ processes should also take into account the contribution of the Collins effect, which might be small, but not entirely negligible.

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