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The Sivers asymmetry in Drell–Yan production at the J/Ψ peak at COMPASS

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The abundant production of lepton pairs via J/Ψ creation at COMPASS, $\pi^\pm p^\uparrow \to J/\Psi X \to \ell^+\ell^- X$, allows a measurement of the transverse single spin asymmetry, $A_N^{J/\Psi}$, generated by the Sivers effect. The crucial issue of the sign change of the Sivers function in Drell–Yan lepton pair production, with respect to Semi Inclusive Deep Inelastic Scattering processes, can be addressed in a different context. Assuming that the Sivers asymmetry is related to a universal and intrinsic property of the proton, predictions for the expected magnitude of $A_N^{J/\Psi}$, which turns out to be large, are given. A comparison with the suggested measurement of this single spin asymmetry – an important quantity by itself – should give valuable information.

The distribution, in momentum space, of unpolarized quarks and gluons inside a transversely polarized nucleon, first introduced by Sivers [1,2], is one of the eight leading-twist Transverse Momentum Dependent Partonic Distribution Functions (TMD-PDFs), which can be accessed through experiments and encode our information on the 3-Dimensional nucleon structure. The Sivers distribution for unpolarized quarks (or gluons) with transverse momentum $\boldsymbol{k}_\perp$ inside a proton with 3-momentum $\boldsymbol{p}$ and spin $\boldsymbol{S}$, is defined as

$$\hat{f}_{q/p^\uparrow}(x, \boldsymbol{k}_\perp) = f_{q/p}(x, k_\perp) + \frac{1}{2}\,\Delta^N f_{q/p^\uparrow}(x, k_\perp)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}\times\hat{\boldsymbol{k}}_\perp) = f_{q/p}(x, k_\perp) - \frac{k_\perp}{m_p}\, f_{1T}^{\perp q}(x, k_\perp)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}\times\hat{\boldsymbol{k}}_\perp)\,, \qquad (1)$$

where $f_{q/p}(x, k_\perp)$ is the unpolarized TMD-PDF and $\Delta^N f_{q/p^\uparrow} = (-2k_\perp/m_p) f_{1T}^{\perp q}$ is the Sivers function.

The Sivers function is one of the best known polarized TMD-PDFs and has a clear experimental signature [3–5]. It is of particular interest for several reasons; one expects it to be related to fundamental intrinsic features of the nucleon and to basic QCD properties. In fact, the Sivers distribution relates the motion of unpolarized quarks and gluons to the nucleon spin $\boldsymbol{S}$; then, in order to build a scalar, parity invariant quantity, $\boldsymbol{S}$ must couple to the only other available pseudo-vector, that is the parton orbital angular momentum, $\boldsymbol{L}_q$ or $\boldsymbol{L}_g$. Another peculiar feature of the Sivers distribution is that its origin at partonic level can be traced in QCD interactions between the quarks (or gluons) active in inelastic high energy interactions and the nucleon remnants [6,7]; thus, it is expected to be process dependent and have opposite sign in Semi Inclusive Deep Inelastic Scattering (SIDIS) and Drell–Yan (D–Y) processes [8,9]. This important prediction remains to be tested.

In fact, one might still wonder whether the Sivers effect originates directly from an intrinsic property of the proton, rather than being mediated through initial or final state interactions, which lead to the opposite signs in SIDIS and D–Y processes [6–9]. It is tempting to relate the Sivers effect, at least for valence quarks, to their orbital motion, which, in turn, must be linked to the parent proton spin. In such a case one expects a universality of the Sivers asymmetry. Thus, it is important to find processes in which measurable Single Spin Asymmetries can be generated by the Sivers asymmetric distribution (1) and study them.

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Usually, the Sivers distribution can be accessed through the study of azimuthal asymmetries in polarized SIDIS and D–Y processes. These have been clearly observed in the last years, in SIDIS, by the HERMES [3] and COMPASS [4] Collaborations, allowing extractions of the SIDIS Sivers function [10–12]. However, no information could be obtained on the D–Y Sivers function, as no polarized D–Y process had ever been measured.

Asymmetries related to the Sivers effect can also be measured in the so called generalised D–Y processes [13,14], that is the creation of lepton pairs via vector bosons, $p\,p \to W^\pm X \to \ell^\pm \nu\, X$ and $p\,p \to Z^0\, X \to \ell^+\ell^- X$. Also in this case one expects a Sivers function opposite to that observed in SIDIS.

Recently, first few data from D–Y weak boson production at RHIC, $p^\uparrow p \to W^\pm/Z^0\, X$, have become available [15]. They show some azimuthal asymmetry which hints, with large errors and sizeable uncertainties, at a sign change between the Sivers function observed in these generalised D–Y processes and the SIDIS Sivers function, although much caution is still necessary [16]. More data on genuine D–Y processes, $\pi^\pm p^\uparrow \to \gamma^* X \to \ell^+\ell^- X$, are expected soon from the COMPASS Collaboration. However, also in this case, due to the energy of the COMPASS experiment, $\sqrt{s} = 18.9$ GeV, and the accepted safe region for D–Y events, $M \gtrsim 4$ GeV/c^2, where M is the invariant mass of the lepton pair, only a limited number of events, and consequently large statistical errors, are expected, as it is confirmed by first data [17].

Following Refs. [18,19] we propose here to measure the lepton pair production at COMPASS at the peak of the J/Ψ production, where the number of events is greatly enhanced. Notice that the spin-parity quantum numbers of J/Ψ are the same as for a photon.

Let us start from the usual D–Y process. According to the TMD factorisation scheme, the cross section for this process, $h_1\, h_2 \to q\,\bar q\, X \to \ell^+\ell^- X$, in which one measures the four-momentum q of the lepton pair, can be written, at leading order, as [20,21]:

$$\frac{d\sigma^{h_1 h_2\to \ell^+\ell^- X}}{dy\, dM^2\, d^2\boldsymbol{q}_T} = \hat\sigma_0 \sum_q e_q^2 \int d^2\boldsymbol{k}_{\perp 1}\, d^2\boldsymbol{k}_{\perp 2}\, \delta^2(\boldsymbol{k}_{\perp 1} + \boldsymbol{k}_{\perp 2} - \boldsymbol{q}_T)\, f_{\bar q/h_1}(x_1, k_{\perp 1})\, f_{q/h_2}(x_2, k_{\perp 2}) \tag{2}$$

where the $\sum_q$ runs over all relevant quarks and antiquarks and we have adopted the usual variables:

$$q = (q_0, \boldsymbol{q}_T, q_L) \qquad q^2 = M^2 \qquad y = \frac{1}{2}\ln\frac{q_0 + q_L}{q_0 - q_L} \qquad s = (p_1 + p_2)^2\,. \tag{3}$$

The $f_{q/h}(x, k_\perp)$ are the unpolarized TMD-PDFs and $e_q^2\,\hat\sigma_0$ is the cross section for the $q\,\bar q \to \ell^+\ell^-$ process:

$$e_q^2\,\hat\sigma_0 = e_q^2\,\frac{4\pi\alpha^2}{9M^2}\,. \tag{4}$$

$\boldsymbol{k}_{\perp 1}$ and $\boldsymbol{k}_{\perp 1}$ are the parton transverse momenta, while the parton longitudinal momentum fractions are given at $\mathcal{O}(k_\perp/M)$, by

$$x_{1,2} = \frac{M}{\sqrt{s}}\, e^{\pm y} \quad \text{so that} \quad x_F = \frac{2\,q_L}{\sqrt{s}} = x_1 - x_2 = \left(x_1 - \frac{M^2}{s\,x_1}\right) = \left(\frac{M^2}{s\,x_2} - x_2\right),$$
$$y = \frac{1}{2}\ln\frac{x_1}{x_2} = \ln\frac{x_1\sqrt{s}}{M}\,. \tag{5}$$

Eq. (2) holds in the kinematical region:

$$q_T^2 \ll M^2 \qquad k_\perp \simeq q_T\,. \tag{6}$$

In the case in which one of the hadrons, say $h_2^\uparrow$, is polarized, Eq. (2) simply modifies by replacing $f_{q/h_2}(x_2, k_{\perp 2})$ with $\hat f_{q/h_2^\uparrow}(x_2, \boldsymbol{k}_{\perp 2})$ as given in Eq. (1). We then have the Sivers single transverse spin asymmetry:

$$A_N = \frac{d\sigma^{h_1 h_2^\uparrow \to \ell^+\ell^- X} - d\sigma^{h_1 h_2^\downarrow \to \ell^+\ell^- X}}{d\sigma^{h_1 h_2^\uparrow \to \ell^+\ell^- X} + d\sigma^{h_1 h_2^\downarrow \to \ell^+\ell^- X}} \equiv \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow} \tag{7}$$

$$= \frac{\sum_q e_q^2 \int d^2\boldsymbol{k}_{\perp 1}\, d^2\boldsymbol{k}_{\perp 2}\, \delta^2(\boldsymbol{k}_{\perp 1} + \boldsymbol{k}_{\perp 2} - \boldsymbol{q}_T)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{k}}_{\perp 2})\, f_{\bar q/h_1}(x_1, k_{\perp 1})\, \Delta^N f_{q/h_2^\uparrow}(x_2, k_{\perp 2})}{2\sum_q e_q^2 \int d^2\boldsymbol{k}_{\perp 1}\, d^2\boldsymbol{k}_{\perp 2}\, \delta^2(\boldsymbol{k}_{\perp 1} + \boldsymbol{k}_{\perp 2} - \boldsymbol{q}_T)\, f_{\bar q/h_1}(x_1, k_{\perp 1})\, f_{q/h_2}(x_2, k_{\perp 2})}. \tag{8}$$

When the lepton pair production occurs via $q\,\bar q$ annihilation into a vector meson V rather than a virtual photon γ^*, Eqs. (2), (4) and (8) still hold, with the replacements [18]:

$$16\pi^2\alpha^2 e_q^2 \to (g_q^V)^2\,(g_\ell^V)^2 \qquad \frac{1}{M^4} \to \frac{1}{(M^2 - M_V^2)^2 + M_V^2\,\Gamma_V^2}\,, \tag{9}$$

where g_q^V and g_ℓ^V are the V vector couplings to $q\,\bar q$ and $\ell^+\ell^-$ respectively. Γ_V is the width of the vector meson and the new propagator is responsible for a large increase in the cross section at $M^2 = M_V^2$.

We then have:

$$A_N^V = \frac{\sum_q (g_q^V)^2 \int d^2\boldsymbol{k}_{\perp 1}\, d^2\boldsymbol{k}_{\perp 2}\, \delta^2(\boldsymbol{k}_{\perp 1} + \boldsymbol{k}_{\perp 2} - \boldsymbol{q}_T)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{k}}_{\perp 2})\, f_{\bar q/h_1}(x_1, k_{\perp 1})\, \Delta^N f_{q/h_2^\uparrow}(x_2, k_{\perp 2})}{2\sum_q (g_q^V)^2 \int d^2\boldsymbol{k}_{\perp 1}\, d^2\boldsymbol{k}_{\perp 2}\, \delta^2(\boldsymbol{k}_{\perp 1} + \boldsymbol{k}_{\perp 2} - \boldsymbol{q}_T)\, f_{\bar q/h_1}(x_1, k_{\perp 1})\, f_{q/h_2}(x_2, k_{\perp 2})}. \tag{10}$$

We propose to use Eq. (10) for lepton pair production at COMPASS, $\pi^\pm p^\uparrow \to \ell^+\ell^- X$, at the J/Ψ peak, $M^2 = M_{J/\Psi}^2$. There are several reasons which make this channel very interesting and promising, as well as some reasons of attention and caution.

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1) At COMPASS energy one has $x_1 x_2 = M^2_{J/\Psi}/s \simeq 0.027$. Due to this relation both x_1 and x_2 must be greater than 0.027 and one of them must be greater than $\sqrt{0.027} \simeq 0.16$. At small values of x_F or y one has approximately $x_1 \simeq x_2 \simeq 0.16$. It is then reasonable to expect that the main channel for the J/Ψ production is indeed $q\bar{q}$ annihilation (rather than gluon fusion).

The exact elementary mechanism through which the $q\bar{q}$ give origin to the J/Ψ is still not clear (see, for example, Refs. [22,23]). We do not attempt any explanation of such a mechanism: its subtleties and complications are simply hidden in the unknown couplings g_q^V. In the expression of the spin asymmetry, Eq. (10), such couplings cancel: exactly, if they do not depend on the flavour q or, approximately, if one flavour dominates. This will be the case for the J/Ψ production in $\pi\, p$ interactions. Although we do not attempt a prediction for the cross section, we are confident that the expression (10) of the asymmetry is adequate enough to study the Sivers effect in J/Ψ production at COMPASS.

2) The COMPASS data, which have been taken in 2015 and are presently being analysed, refer to the $\pi^- p^\uparrow \to \ell^+\ell^- X$ process at $\sqrt{s} = 18.9$ GeV. Their interesting feature is that the dominant contribution to the asymmetry (10) is given by a $\bar{u}$ quark from the π^- and a u quark from the proton, both of them valence quarks. All other contributions would always involve a sea quark and, in the central rapidity region, are strongly suppressed.

3) Other production mechanisms of J/Ψ might contribute, like gluon fusion. However, while they might enhance the unpolarized cross section, the denominator of A_N^V, it is very unlikely that they significantly affect the numerator of A_N^V; in fact the gluon Sivers function is expected to be small, if not zero [24]. Thus, such contributions might decrease the value of A_N^V, but they cannot alter the conclusion that it mainly originates from the valence quark Sivers functions.

Then we have, for central rapidity $\pi^- p^\uparrow \to J/\Psi\, X \to \ell^+\ell^- X$ processes:

$$A_N^{J/\Psi}(\pi^-; x_1, x_2, \boldsymbol{q}_T) \simeq \frac{\int d^2\boldsymbol{k}_{\perp 1}\, d^2\boldsymbol{k}_{\perp 2}\, \delta^2(\boldsymbol{k}_{\perp 1} + \boldsymbol{k}_{\perp 2} - \boldsymbol{q}_T)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{k}}_{\perp 2})\, f_{\bar{u}/\pi^-}(x_1, k_{\perp 1})\, \Delta^N f_{u/p^\uparrow}(x_2, k_{\perp 2})}{2\int d^2\boldsymbol{k}_{\perp 1}\, d^2\boldsymbol{k}_{\perp 2}\, \delta^2(\boldsymbol{k}_{\perp 1} + \boldsymbol{k}_{\perp 2} - \boldsymbol{q}_T)\, f_{\bar{u}/\pi^-}(x_1, k_{\perp 1})\, f_{u/p}(x_2, k_{\perp 2})} \tag{11}$$

and, for $\pi^+ p^\uparrow \to J/\Psi\, X \to \ell^+\ell^- X$ processes:

$$A_N^{J/\Psi}(\pi^+; x_1, x_2, \boldsymbol{q}_T) \simeq \frac{\int d^2\boldsymbol{k}_{\perp 1}\, d^2\boldsymbol{k}_{\perp 2}\, \delta^2(\boldsymbol{k}_{\perp 1} + \boldsymbol{k}_{\perp 2} - \boldsymbol{q}_T)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{k}}_{\perp 2})\, f_{\bar{d}/\pi^+}(x_1, k_{\perp 1})\, \Delta^N f_{d/p^\uparrow}(x_2, k_{\perp 2})}{2\int d^2\boldsymbol{k}_{\perp 1}\, d^2\boldsymbol{k}_{\perp 2}\, \delta^2(\boldsymbol{k}_{\perp 1} + \boldsymbol{k}_{\perp 2} - \boldsymbol{q}_T)\, f_{\bar{d}/\pi^+}(x_1, k_{\perp 1})\, f_{d/p}(x_2, k_{\perp 2})}\,. \tag{12}$$

Notice that the variables x_1 and x_2 are related to each other and one can use only one of them or the variable x_F or y, see Eq. (5) with $M^2 = M^2_{J/\Psi}$.

Eqs. (11) and (12) can be further evaluated adopting, as usual, a Gaussian factorized form both for the unpolarized distribution and the Sivers functions, as in Ref. [10]:

$$f_{q/p}(x, k_\perp) = f_q(x)\, \frac{1}{\pi \langle k_\perp^2\rangle}\, e^{-k_\perp^2/\langle k_\perp^2\rangle} \tag{13}$$

$$\Delta^N f_{q/p^\uparrow}(x, k_\perp) = 2\,\mathcal{N}_q(x)\, h(k_\perp)\, f_{q/p}(x, k_\perp) \tag{14}$$

$$h(k_\perp) = \sqrt{2e}\,\frac{k_\perp}{M_1}\, e^{-k_\perp^2/M_1^2}\,, \tag{15}$$

where the $f_q(x)$ are the unpolarized PDFs, M_1 is a parameter which allows the $k_\perp$ Gaussian dependence of the Sivers function to be different from that of the unpolarized TMDs and $\mathcal{N}_q(x)$ is a function which parameterises the factorized x dependence of the Sivers function. The same functional form as in Eq. (13), with the same value of $\langle k_\perp^2\rangle$, is assumed for the unpolarized quark distribution inside a pion.

In such a case the $\boldsymbol{k}_\perp$ integrations can be performed analytically in Eqs. (11) and (12), obtaining:

$$\begin{aligned} A_N^{J/\Psi}(\pi^-; x_2, \boldsymbol{q}_T) &= \frac{\langle k_S^2\rangle^2}{[\langle k_S^2\rangle + \langle k_\perp^2\rangle]^2}\, \exp\left[-\frac{q_T^2}{2\,\langle k_\perp^2\rangle}\left(\frac{\langle k_\perp^2\rangle - \langle k_S^2\rangle}{\langle k_\perp^2\rangle + \langle k_S^2\rangle}\right)\right] \times \frac{\sqrt{2\,e}\, q_T}{M_1} \times 2\,\mathcal{N}_u(x_2)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{q}}_T) && (16)\\ &\equiv A_N^{J/\Psi}(\pi^-; x_2, q_T)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{q}}_T) && (17) \end{aligned}$$

and

$$\begin{aligned} A_N^{J/\Psi}(\pi^+; x_2, \boldsymbol{q}_T) &= \frac{\langle k_S^2\rangle^2}{[\langle k_S^2\rangle + \langle k_\perp^2\rangle]^2}\, \exp\left[-\frac{q_T^2}{2\,\langle k_\perp^2\rangle}\left(\frac{\langle k_\perp^2\rangle - \langle k_S^2\rangle}{\langle k_\perp^2\rangle + \langle k_S^2\rangle}\right)\right] \times \frac{\sqrt{2\,e}\, q_T}{M_1} \times 2\,\mathcal{N}_d(x_2)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{q}}_T) && (18)\\ &\equiv A_N^{J/\Psi}(\pi^+; x_2, q_T)\, \boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{q}}_T) && (19) \end{aligned}$$

where

$$\langle k_S^2\rangle = \frac{M_1^2\,\langle k_\perp^2\rangle}{M_1^2 + \langle k_\perp^2\rangle}\,. \tag{20}$$

Notice that the unpolarized PDFs cancel out.

$A_N^{J/\Psi}(\pi^\pm; x_2, q_T)$ is the amplitude of the azimuthal modulation in the angle defined by $\boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{q}}_T)$. For example, taking the proton moving in the $-\hat{\boldsymbol{z}}$ direction and $\boldsymbol{S} \equiv\, \uparrow$ along $+\hat{\boldsymbol{y}}$, in the $\pi - p$ c.m. frame, one has $\boldsymbol{S}\cdot(\hat{\boldsymbol{p}}_2 \times \hat{\boldsymbol{q}}_T) = -\cos\phi$, where ϕ is the azimuthal angle

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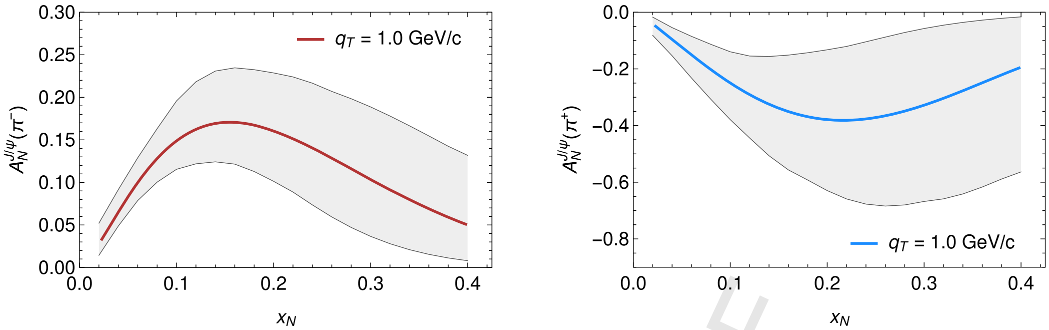

Fig. 1. Plots of $A_N^{J/\Psi}(\pi^-; x_N, q_T)$ (left) and $A_N^{J/\Psi}(\pi^+; x_N, q_T)$ (right) versus x_N, at $q_T = 1$ GeV/c. These estimates are obtained according to Eqs. (16)–(19) of the text ($x_2 \equiv x_N$), using the parameters of the Sivers function given in Ref. [12]. The uncertainty of these parameters generates the shaded areas.

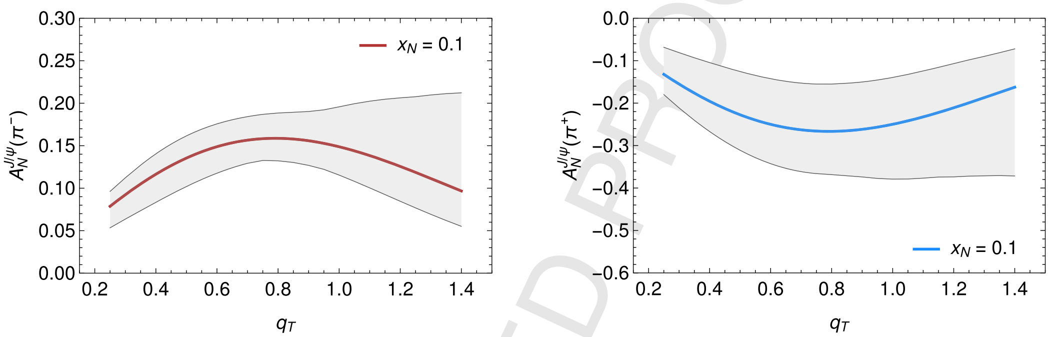

Fig. 2. Plots of $A_N^{J/\Psi}(\pi^-; x_N, q_T)$ (left) and $A_N^{J/\Psi}(\pi^+; x_N, q_T)$ (right) versus q_T, at $x_N = 0.1$. These estimates are obtained according to Eqs. (16)–(19) of the text ($x_2 \equiv x_N$), using the parameters of the Sivers function given in Ref. [12]. The uncertainty of these parameters generates the shaded areas.

of the J/Ψ. Measurements of $A_N^{J/\Psi}(\pi^-; x_2, q_T)$ and $A_N^{J/\Psi}(\pi^+; x_2, q_T)$ give a direct access, respectively, to $\mathcal{N}_u(x_2)$ and $\mathcal{N}_d(x_2)$, and the corresponding Sivers functions, Eq. (14).

As a possible test of the (non)universality of the Sivers function we give an estimate of $A_N^{J/\Psi}(\pi^-; x_2, q_T)$ and $A_N^{J/\Psi}(\pi^+; x_2, q_T)$, based on the Sivers functions extracted from SIDIS data. All quantities necessary to compute the two asymmetries can be found in Ref. [12] (Eq. (40) and third column of Table III), taking into account only the valence quark contributions.

The process we are considering is, at the partonic level, more complicated than the usual continuum D–Y lepton pair production via a $q\bar{q} \to \gamma^*$ annihilation. The arguments based on initial versus final state interactions in SIDIS and D–Y processes [6–9] might not hold in this case. Thus, we do not change the sign of the SIDIS Sivers functions. Our estimates are actually made assuming the universality of the Sivers effect, thinking of it as generated by intrinsic properties of the nucleons; one might think, for example, of the Sivers asymmetric distribution (1) as a typical feature of quarks orbiting inside the nucleon. Comparison with data will confirm or not this assumption.

In Fig. 1 we plot $A_N^{J/\Psi}(\pi^-; x_N, q_T)$ (left plot) and $A_N^{J/\Psi}(\pi^+; x_N, q_T)$ (right plot), at $q_T = 1$ GeV/c, as functions of x_N in the expected kinematical region of the COMPASS experiment. For a better reading we denote by x_N the longitudinal momentum fraction of the nucleon carried by the quark, defined as x_2 in the text. The uncertainty bands correspond to the uncertainty in the knowledge of the Sivers functions from Ref. [12]. Similarly, in Fig. 2 we plot the asymmetries, for $x_N = 0.1$ (corresponding to $x_1 \equiv x_\pi = 0.3$ and $x_F = 0.2$), versus q_T.

In both cases the Sivers asymmetries can be large, with a well defined sign, driven by the sign of the Sivers functions of the proton valence quarks, u quark for $A_N^{J/\Psi}(\pi^-)$ and d quark for $A_N^{J/\Psi}(\pi^+)$. Notice that within the uncertainty bands the expected magnitudes of $A_N^{J/\Psi}(\pi^-)$ and $A_N^{J/\Psi}(\pi^+)$ might sizeably vary, keeping however a definite sign.

In order to obtain a better statistics, one could gather data over the full range of q_T for which Eq. (6) holds; then the asymmetries are given by Eqs. (11) and (12) with numerator and denominator integrated over q_T from 0 up to, say, 2 GeV/c.

In conclusion, we propose a simple measurement of the single transverse spin asymmetry A_N in the channel $\pi^\pm p^\uparrow \to J/\Psi X \to \ell^+\ell^- X$, for which abundant data have been already collected by the COMPASS Collaboration. If, as we expect at the kinematics of the experiment, the asymmetry is mainly generated by the Sivers distribution of unpolarized valence quarks inside the polarized proton, its sign reveals the sign of the corresponding Sivers function.

We give some estimates for the asymmetry in a simplified factorized scheme which avoids the complications of the actual knowledge of the partonic interactions which couple a $q\bar{q}$ pair to the J/Ψ. We do not attempt, and cannot give, any prediction for the cross section of the process, but the expression of the asymmetry is much simpler and well defined, due to cancellations of unknown quantities. Our main assumption is indeed the dominance of the $q\bar{q}$ channel. Admittedly, our results for the asymmetry might be too optimistic as other production mechanism might increase the denominator of Eq. (7): however, we do believe that any measured asymmetry should be related to the quark Sivers effect.

Our estimates are given assuming the same Sivers functions as those extracted from SIDIS, without any sign change. We do not take into account their possible TMD evolution: the Q^2 region of the SIDIS data, a few GeV^2, is not far from the $M^2_{J/\Psi}$ value relevant here. Moreover, we expect that, while TMD evolution might be relevant for cross sections, it does not affect much the value of their ratios, which appear in the asymmetries. A detailed study of the issues related to the phenomenological implementation of TMD evolution in

SIDIS processes at COMPASS kinematics, strongly dominated by non-perturbative effects, can be found in Ref. [25], where estimates of their impact is given.

An experimental confirmation of our estimated signs would favour the universality of the Sivers functions. An opposite sign might indicate that the argument according to which the Sivers functions in SIDIS and D–Y processes must be opposite holds also for this process, $\pi^\pm p^\uparrow \to J/\Psi\, X \to \ell^+\ell^- X$. In any case the measurement of $A_N^{J/\Psi}$ at COMPASS is interesting and worth being performed.

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