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Impact of double TMD effects on transversity measurements at RHIC

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Abstract. A quantitative estimate is presented for the double transverse spin asymmetries *at measured* q_T in both the Drell-Yan process and W-boson production due to Transverse Momentum Dependent (TMD) effects. These spin asymmetries are calculated as a function of the lepton azimuthal angle as measured *in the laboratory frame.* In this frame, in contrast to the Collins-Soper frame, the TMD effects contribute to the spin asymmetry $A_{TT}(q_T)$ in the same way as transversity does, which makes them a background for transversity measurements in the Drell-Yan process and new physics studies in W-boson production. Using the current knowledge of the relevant TMDs we conclude that this background is negligible and, therefore, will not hamper transversity measurements nor new physics studies when performed in the laboratory frame. We also point out a cross-check asymmetry measurement to bound the TMD contributions, which is independent of assumptions on the sizes of the relevant TMDs.

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INTRODUCTION

Transversity was first discussed by Ralston and Soper [1], who suggested its measurement in the Drell-Yan (DY) process through the double transverse spin asymmetry A_{TT} integrated over the transverse momentum q_T of the lepton pair and at measured q_T $A_{TT}(q_T)$, in particular at $q_T = 0$. At measured q_T there will be background contributions from transverse momentum dependence of partons, that have not yet been considered. The $A_{TT}(q_T)$ asymmetry was estimated to be at most 5% [2], based on the upper bound on the transversity distribution. The first extraction [3] indicates the quark transversity to be only half of its maximum value, which, if it also holds for the antiquarks, reduces the asymmetry to 1%, making a background study relevant. We will also study W-boson production, in which one expects zero contribution from transversity within the Standard Model [4, 5]. This allows for new physics studies as proposed in [6], where the maximal asymmetry was estimated to be around 1%, reinforcing the need for a background study.

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The two relevant TMD effects are the double Sivers effect, which describes a transverse momentum distribution of quarks inside a transversely polarized hadron which is asymmetric w.r.t. the spin direction [7] and another effect that was first discussed by Ralston and Soper [1], which describes the distribution of longitudinally polarized quarks inside a transversely polarized hadron. Both effects are described by a transverse momentum dependent parton distribution (TMD): the Sivers effect by a TMD often denoted by $f_{1T}^{\perp}$ [8] and the other by g_{1T} [9] also referred to as Worm-Gear (WG) function.

The expressions for the double Sivers and double WG effect for DY have been given in Ref. [10, 11, 12]. One can consider the so-called Collins-Soper (CS) frame, which allows one to distinguish the double transverse spin asymmetries arising from transversity, the Sivers effect and the WG effect by their lepton azimuthal angular dependence. However, in the laboratory frame, all three effects will contribute to the same angular distribution. The lab frame is thus theoretically not the preferred frame to extract the transversity distribution, but it is experimentally more 'direct' to do so. In fact, in W-boson production with a leptonic decay, it is virtually impossible to transform to the CS frame due to the unobserved neutrino. This makes the lab frame experimentally the most desirable frame to measure spin asymmetries. To study the impact of the Sivers and WG effect on such a measurement, we will present quantitatively the size of the spin asymmetries *in the lab frame* caused by partonic transverse momentum effects in both the DY process and W-boson production.

DISTRIBUTION FUNCTIONS

A factorization between k_T and x dependence and a Gaussian dependence on k_T will be assumed, i.e. we use for the unpolarized parton distribution

$$f_1^q(x,k_T) = f_1^q(x)\,\frac{1}{\pi\langle k_T^2\rangle} e^{-k_T^2/\langle k_T^2\rangle}, \tag{1}$$

with the value of the width $\langle k_T^2\rangle = 0.25\ \mathrm{GeV}^2$, fitted by [13]. For the Sivers function, we will use the extraction obtained by [14]. A determination of the Worm-Gear distribution based on fits of experimental data is not available, so we will employ a model for this WG function. We will use a Gaussian Ansatz in terms of its first transverse moment, i.e.

$$g_{1T}^q(x,k_T) = g_{1T}^{q(1)}(x)\,\frac{2M_p^2}{\pi\langle k_T^2\rangle_{\mathrm{WG}}^2} e^{-k_T^2/\langle k_T^2\rangle_{\mathrm{WG}}}. \tag{2}$$

For the width we will take a value in accordance with the bag model [15] $\langle k_T^2\rangle_{\mathrm{WG}} = 0.71\langle k_T^2\rangle$ and for the first moment, we will use a Wandzura-Wilczek type approximation [16, 17, 18] to express it in terms of the known helicity distribution $g_1(x)$ by

$$g_{1T}^{q(1)}(x) \approx x\int_x^1 dy\,\frac{g_1^q(y)}{y}. \tag{3}$$

The resulting functions agree with model calculations and lattice evaluations, see [19] for details. For numerical estimations the DSSV helicity distribution [20] is used.

SPIN ASYMMETRIES IN THE DRELL-YAN PROCESS

We will define a spin flip symmetric and antisymmetric cross section as a function of the transverse momentum q_T, total momentum Q and rapidity Y of the lepton pair and the lepton azimuthal angle ϕ_l (measured w.r.t. the spin plane) in the laboratory frame by

$$d\sigma^{S,A}(q_T,Q,Y,\phi_l) \equiv \frac{1}{4}\left(d\sigma^{\uparrow\uparrow} \pm d\sigma^{\uparrow\downarrow} \pm d\sigma^{\downarrow\uparrow} + d\sigma^{\downarrow\downarrow}\right). \tag{4}$$

Two double transverse spin asymmetries will be defined,

$$\begin{aligned} A^0_{TT}(q_T,Q,Y) &\equiv \int_0^{2\pi} d\phi_l\, d\sigma^A \Big/ \int_0^{2\pi} d\phi_l\, d\sigma^S, \\ A^C_{TT}(q_T,Q,Y) &\equiv \left(\int_{-\pi/4}^{\pi/4} - \int_{\pi/4}^{3\pi/4} + \int_{3\pi/4}^{5\pi/4} - \int_{5\pi/4}^{7\pi/4}\right) d\phi_l\, d\sigma^A \Big/ \int_0^{2\pi} d\phi_l\, d\sigma^S, \end{aligned} \tag{5}$$

which select out the ϕ_l independent part of the cross section and the part $\propto \cos 2\phi_l$. The double Sivers effect contribution to both these asymmetries is plotted in Fig. 1, the share coming from the WG effect is left out being negligible compared to this. For detailed expressions we refer to [19].

The A^0_{TT} asymmetry reaches up to the percent level, but only for large Q^2 outside the range of interest, whereas the A^C_{TT} asymmetry receives a contribution at the level of 10^{-6} from the double Sivers effect and 10^{-8} from the double WG effect. The maximal value of A^C_{TT} is bounded by the maximal value of A^0_{TT}, irrespective of the parameterization used for TMD distributions. Therefore, as a cross-check of the smallness of the TMD background, one can verify that the A^0_{TT} asymmetry is indeed much smaller.

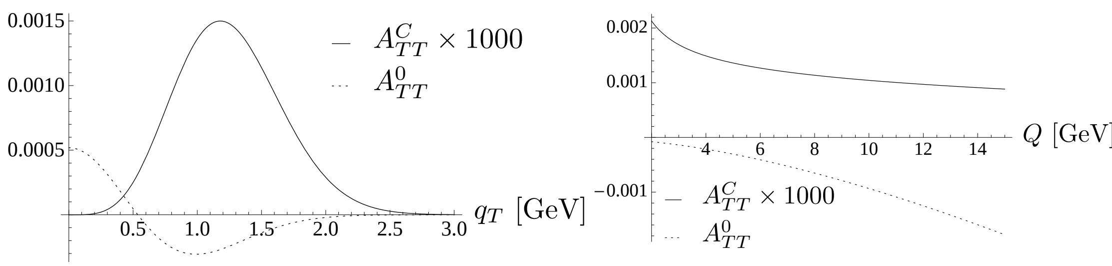

FIGURE 1. Contribution to $A_{TT}(q_T,Q,Y)$ in the Drell-Yan process from the double Sivers effect at $\sqrt{s} = 500$ GeV as a function of q_T at $Q = 5$ GeV (left) and Q at $q_T = 1$ GeV (right) valid for $|Y| \lesssim 2$.

SPIN ASYMMETRIES IN W-BOSON PRODUCTION

In W-boson production we define the same asymmetries as in Eq. 5, but we anticipate on the neutrino being unobserved and express the asymmetries as a function of the lepton transverse momentum l_T and rapidity Y_l only. We show the asymmetries in W^+ production in Fig. 2, because they are largest. The maximal asymmetry is near resonance and reaches up to 0.15%, which is already below the detection limit at RHIC. However, for a bound on a possible W-W' mixing it is the asymmetry in the integrated cross section that is relevant. In those asymmetries the contribution at $l_T < M_W/2$ largely cancels the contribution at $l_T > M_W/2$, resulting in very small asymmetries. We find the asymmetry in the integrated cross section in $W^{\pm}$ production below 10^{-6}, forming a negligible background for the studies proposed in [6].

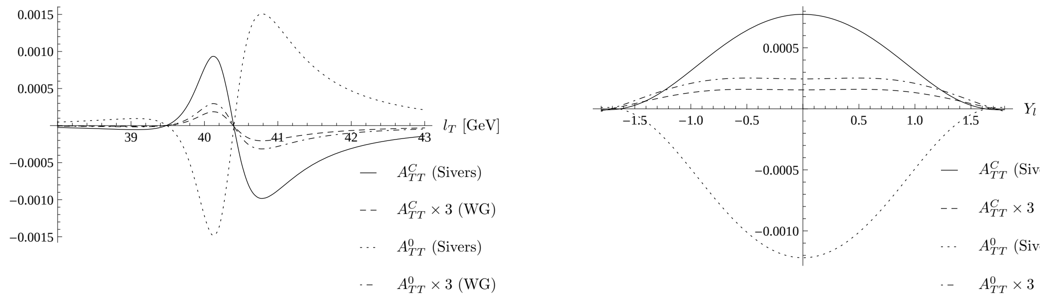

FIGURE 2. Contributions to $A_{TT}(l_T, Y_l)$ in W^+ boson production from the double Sivers and Worm-Gear effect at $\sqrt{s} = 500$ GeV as a function of l_T at $Y_l = 0$ (left) and Y_l at $l_T = 40$ GeV (right).

CONCLUSIONS

We estimated the contribution from the Sivers and Worm-Gear effect to the double spin asymmetries at measured q_T in the DY process and in W-boson production. Our conclusion is that, in the laboratory frame, these TMD effects contribute to the lepton azimuthal angle dependent A^C_{TT} asymmetry, but only at the level of 10^{-6} in the DY process and 10^{-3} in W-boson production. At that level, the TMD effects do not form a relevant background for transversity measurements nor for new physics studies based on A^C_{TT} in the DY process and W-boson production respectively. As a cross-check one can use the azimuthal angle independent A^0_{TT} asymmetry to bound the TMD contributions.

REFERENCES

1. J. P. Ralston, D. E. Soper, Nucl. Phys. **B152**, 109 (1979).
2. H. Kawamura, J. Kodaira and K. Tanaka, Nucl. Phys. B **777**, 203 (2007).
3. M. Anselmino *et al.*, Phys. Rev. D **75**, 054032 (2007).
4. C. Bourrely and J. Soffer, Nucl. Phys. B **423**, 329 (1994).
5. V. L. Rykov, arXiv:hep-ex/9908050.
6. D. Boer and W. J. den Dunnen, Phys. Rev. Lett. **105**, 071801 (2010).
7. D. W. Sivers, Phys. Rev. D **41**, 83 (1990).
8. D. Boer and P. J. Mulders, Phys. Rev. D **57**, 5780 (1998).
9. R. D. Tangerman and P. J. Mulders, Phys. Rev. D **51**, 3357 (1995).
10. D. Boer, Phys. Rev. D **60**, 014012 (1999).
11. Z. Lu, B. Q. Ma and I. Schmidt, Phys. Rev. D **75**, 094012 (2007).
12. S. Arnold, A. Metz and M. Schlegel, Phys. Rev. D **79**, 034005 (2009).
13. M. Anselmino *et al.*, Phys. Rev. D **71**, 074006 (2005) [arXiv:hep-ph/0501196].
14. M. Anselmino *et al.*, Eur. Phys. J. A **39**, 89 (2009).
15. H. Avakian, A. V. Efremov, P. Schweitzer and F. Yuan, Phys. Rev. D **81**, 074035 (2010).
16. S. Wandzura and F. Wilczek, Phys. Lett. B **72**, 195 (1977).
17. R. D. Tangerman and P. J. Mulders, arXiv:hep-ph/9408305.
18. A. M. Kotzinian and P. J. Mulders, Phys. Rev. D **54**, 1229 (1996).
19. D. Boer, W. J. den Dunnen and A. Kotzinian, Phys. Rev. D **83**, 114032 (2011).
20. D. de Florian, R. Sassot, M. Stratmann and W. Vogelsang, Phys. Rev. Lett. **101**, 072001 (2008).