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TRANSVERSITY AND ITS CONJUGATE T-ODD DISTRIBUTION FROM UNPOLARIZED AND SINGLE-POLARIZED DRELL-YAN PROCESSES

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Abstract

The Drell-Yan (DY) processes with unpolarized colliding hadrons and with the single transversely polarized hadron are considered. An approach to direct (without any model assumptions) extraction of both transversity and its conjugate T-odd parton distribution functions (PDF) is proposed. The special attention is paid to DY processes with antiproton and pion beams colliding on protons, which are available to PAX and COMPASS experiments, respectively.

The advantage of DY process for extraction of PDFs, is that there is no need in any fragmentation functions. It is well known that the double transversely polarized DY process $H_1^{\uparrow} H_2^{\uparrow} \to l^+ l^- X$ allows to directly extract the transversity distributions (see Ref. [1] for review). In particular, the double polarized DY process with antiproton beam is planned to be studied at PAX [2].

The original expressions for unpolarized and single-polarized DY cross-sections [3] are very inconvenient in application since all k_T-dependent PDFs enter there in the complex convolution. To avoid this problem in Ref. [4] the q_T integration approach [5, 6, 7] was applied. As a result, the procedure proposed in Ref. [4] allows to extract the transversity h_1 and the first moment

$$h_{1q}^{\perp(1)}(x) \equiv \int d^2\mathbf{k}_T \left(\frac{\mathbf{k}_T^2}{2M_p^2}\right) h_{1q}^{\perp}(x, \mathbf{k}_T^2) \tag{1}$$

of T-odd distribution $h_1^{\perp}$ directly, without any model assumptions about k_T-dependence of $h_1^{\perp}(x, k_T^2)$.

The general procedure proposed in Ref. [4] applied to unpolarized DY process $\bar{p}p \to l^+l^-X$ gives[1]

$$\hat{k}\Big|_{\bar{p}p\to l^+l^-X} = 8\frac{\sum_q e_q^2[\bar{h}_{1q}^{\perp(1)}(x_{\bar{p}})\Big|_{\bar{p}} h_{1q}^{\perp(1)}(x_p)\Big|_p + (x_{\bar{p}} \leftrightarrow x_p)]}{\sum_q e_q^2[\bar{f}_{1q}(x_{\bar{p}})\Big|_{\bar{p}} f_{1q}(x_p)\Big|_p + (x_{\bar{p}} \leftrightarrow x_p)]}, \tag{2}$$

where $\hat{k}$ is the coefficient at $\cos 2\phi$ dependent part of the properly integrated over q_T ratio of unpolarized cross-sections:

$$\hat{R} = \frac{\int d^2\mathbf{q}_T[|\mathbf{q}_T|^2/M_p^2][d\sigma^{(0)}/d\Omega]}{\int d^2\mathbf{q}_T\sigma^{(0)}}, \tag{3}$$

$$\hat{R} = \frac{3}{16\pi}(\gamma(1+\cos^2\theta) + \hat{k}\cos 2\phi \sin^2\theta). \tag{4}$$

At the same time in the case of single polarized DY process $\bar{p}p^\uparrow \to l^+l^-X$, operating just as in Ref. [4], one gets

$$\hat{A}_h \;=\; -\frac{1}{2}\frac{\sum_q e_q^2\bar{h}_{1q}^{\perp(1)}(x_{\bar{p}})h_{1q}(x_p) + (x_{\bar{p}} \leftrightarrow x_p)}{\sum_q e_q^2[\bar{f}_{1q}(x_{\bar{p}})f_{1q}(x_p) + (x_{\bar{p}} \leftrightarrow x_p)]}, \tag{5}$$

where the single spin asymmetry (SSA) $\hat{A}_h$ is defined as[2]

$$\hat{A}_h = \frac{\int d\Omega d\phi_{S_2}\int d^2\mathbf{q}_T(|\mathbf{q}_T|/M)\sin(\phi+\phi_{S_2})[d\sigma(\mathbf{S}_{2T}) - d\sigma(-\mathbf{S}_{2T})]}{\int d\Omega d\phi_{S_2}\int d^2\mathbf{q}_T[d\sigma(\mathbf{S}_{2T}) + d\sigma(-\mathbf{S}_{2T})]}. \tag{6}$$

In Eqs. (2-6) the quantity $h_{1q}^{\perp(1)}$ is defined by Eq. (1). All other notations are the same as in Ref. [4] (see Ref. [1] for details on kinematics in the Collins-Soper frame we deal with).

Among variety of DY processes, DY processes with antiproton ($\bar{p}p \to l^+l^-X$, $\bar{p}p^\uparrow \to l^+l^-X$, $\bar{p}^\uparrow p^\uparrow \to l^+l^-X$) have essential advantage because the charge conjugation symmetry can be applied. Indeed, due to charge conjugation, antiquark PDF from the antiproton are equal to the respective quark PDF from the proton. Using the charge conjugation symmetry. neglecting squared antiquark and strange quark PDF contributions to proton and taking into account the quark

[1]Eq. (2) is obtained within the quark parton model. It is of importance that the large values of ν cannot be explained by leading and next-to-leading order perturbative QCD corrections as well as by the high twists effects (see [3] and references therein).

[2]Notice that SSA $\hat{A}_h$ is analogous to asymmetry $A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}}$ (weighted with $\sin(\phi-\phi_S)$ and the same weight q_T/M_N) applied in Ref. [3] with respect to Sivers function extraction from the single-polarized DY processes.

charges and u quark dominance at large[3] x, the equations for $\hat{A}_h$ and $\hat{k}$ are essentially given by

$$\hat{k}(x_{\bar{p}}, x_p)\Big|_{\bar{p}p} \simeq 8\frac{h_{1u}^{\perp(1)}(x_{\bar{p}})h_{1u}^{\perp(1)}(x_p)}{f_{1u}(x_{\bar{p}})f_{1u}(x_p)} \tag{7}$$

$$\hat{A}_h(x_{\bar{p}}, x_p)\Big|_{\bar{p}p\uparrow} \simeq -\frac{1}{2}\frac{h_{1u}^{\perp(1)}(x_{\bar{p}})h_{1u}(x_p)}{f_{1u}(x_{\bar{p}})f_{1u}(x_p)}, \tag{8}$$

where all PDFs are refer to proton.

One can see that the system of Eqs. (7) and (8) has very simple and convenient form in application. Measuring the quantity $\hat{k}$ in unpolarized DY (Eqs. (3), (4)) and using Eq. (7) one can obtain the quantity $h_{1u}^{\perp(1)}$. Then, measuring SSA, Eq. (6), and using the obtained quantity $h_{1u}^{\perp(1)}$, one can eventually extract the transversity distribution h_{1u} using Eq. (8). Let us stress once again that now there is no need in any model assumptions about k_T dependence of $h_1^\perp$ distributions.

To deal with Eqs. (7) and (8) in practice, one should consider them at the points[4] $x_{\bar{p}} = x_p \equiv x$ (i.e., $x_F \equiv x_{\bar{p}} - x_p = 0$), so that

$$h_{1u}^{\perp(1)}(x) = f_{1u}(x)\sqrt{\frac{\hat{k}(x,x)\Big|_{\bar{p}p}}{8}}, \tag{9}$$

and

$$h_{1u}(x) = -4\sqrt{2}\frac{\hat{A}_h(x,x)\Big|_{\bar{p}p\uparrow}}{\sqrt{\hat{k}(x,x)\Big|_{\bar{p}p}}}f_{1u}(x). \tag{10}$$

To estimate the possibility of $h_{1u}^{\perp(1)}$ and h_{1u} measurement, the special simulation of DY events with the PAX kinematics [2] are performed. The proton-antiproton collisions are simulated with PYTHIA event generator [9]. Two samples are prepared: for the collider mode (15 GeV antiproton beam colliding on the 3.5 GeV proton beam) and for fixed target mode (22 GeV antiproton beam colliding on an internal hydrogen target). Each sample contains about 100 K pure Drell-Yan events. Notice, that this is just the statistics planned to be achieved by PAX. Indeed (see ref. [2]), the sample for collider mode corresponds to about one year of data-taking with a cross-section of 40 mb and a luminosity

[3]The large x values is the peculiarity of the $\bar{p}p$ experiments planned at GSI – see ref. [2].
[4]The different points $x_F = 0$ can be reached changing Q^2 value at fixed $s \equiv Q^2/x_{\bar{p}}x_p \equiv Q^2/\tau$.

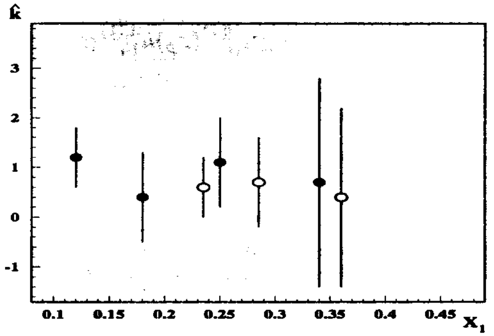

Figure 1: $\hat{k}$ versus $x_{\bar{p}}$ at $x_F \simeq 0$. Data is obtained with MC simulations for collider (closed circles) and for fixed target mode (open circles). For better visibility (to avoid overlapping) the points for collider (fixed target) mode are shifted 0.01 to the left (right) along the x-axis.

of $2 \times 10^{30} cm^{-2}s^{-1}$. For fixed target mode it can takes about three months with a cross-section of 30 mb and a luminosity of about $10^{31} cm^{-2}s^{-1}$.

The events are weighted (see Ref. [4] for detail) with the ratio of DY cross-sections given by (see Refs. [3, 10])

$$R \equiv \frac{d\sigma^{(0)}/d\Omega}{\sigma^{(0)}}, \quad (11)$$

$$R = \frac{3}{16\pi}(1 + \cos^2\theta + (\nu/2)\cos 2\phi \sin^2\theta) \quad (\nu \equiv 2\kappa), \quad (12)$$

where ν dependencies of q_T and x are taken from Refs. [10, 11]. The angular distributions of $\hat{R}$ (Eqs. (3) and (4)) for both samples are studied just as it was done in Ref. [10] with respect to R (Eqs. (11), (12)). The results are shown in Fig. 1. The value of $\hat{k}$ at averaged Q^2 for both energies are found to be 1.2 ± 0.2 for collider mode and 1.0 ± 0.2 for the fixed target mode. The quantity $h_{1u}^{\perp(1)}$ is reconstructed from the obtained values of $\hat{k}$ using Eq. (9) with $x_F = 0 \pm 0.04$. The results are shown in Fig. 2.

Using the obtained magnitudes of $h_{1u}^{\perp(1)}$ we estimate the expected SSA given by Eq. (8). The results are shown in Fig. 3. For estimation of h_{1u} entering SSA together with $h_{1u}^{\perp(1)}$ (see Eq. (8)) we follow the procedure of Ref. [12] and use (rather crude) "evolution model" [1, 12] , where there is no any estimations of uncertainties. That is why in (purely qualitative) Fig. 3 we present the solid curves instead of points with error bars. To obtain these curves we reproduce

x-dependence of $h_{1u}^{\perp(1)}$ in the considered region, using the Boer's model (Eq. (50) in Ref. [3]), properly numerically corrected in accordance with the simulation results.

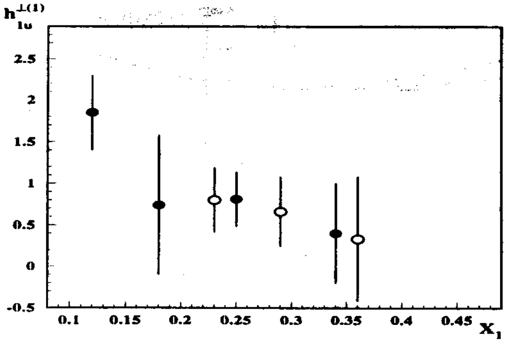

Figure 2: $h_{1u}^{\perp(1)}$ versus $x_{\bar{p}}$ at $x_F \simeq 0$. Data is obtained with MC simulations for collider (closed circles) and for fixed target mode (open circles). For better visibility (to avoid overlapping) the points for collider (fixed target) mode are shifted 0.01 to the left (right) along the x-axis.

It should be noticed that the estimations of $\hat{k}$ and $\hat{A}_h$ magnitudes obtained it this paper are very preliminary and show just the order of values of these quantities. For more precise estimations one needs the Monte-Carlo generator more suitable for DY processes studies (see, for example. Ref. [4]) than PYTHIA generator which we used (with the proper weighting of events) here.

Looking at the (preliminary) estimations presented by Fig. 1 and 2, one can conclude that the quantities $\hat{k}$ and $h_{1u}^{\perp(1)}$ are presumably measurable in most of the considered x-region. At the same time, looking at Fig. 3 one can see that for both modes SSA $\hat{A}_h$ is estimated to be about 6-8%. On the other hand, as it was argued in Ref. [2] (see section "Single Spin asymmetries and Sivers Function", p. 25), the studied in ref. [3] SSA $A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}}$ of order 5-10% can be measured by PAX. It is obvious that studied in this paper SSA $\hat{A}_h$, weighted with $\sin(\phi+\phi_S)$ and the same weight q_T/M_N, is absolutely analogous to SSA $A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}}$, so that it is clear that if $A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}}$ of 5-10% is measurable, then $\hat{A}_h$ of 6-8% is measurable too.

Thus, it is shown that it is possible to directly extract the transversity and its accompanying T-odd PDF from the unpolarized and single polarized DY processes with antiproton participation. It is of importance that there is no need in any model assumptions about k_T dependence of $h_1^\perp$. One can directly extract

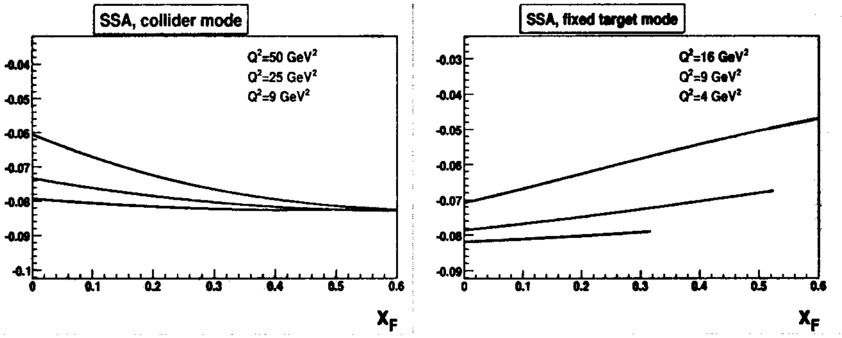

Figure 3: Left part: SSA given by Eq. (8) versus x_F for collider mode for three values of Q^2: 50 GeV^2 (lower curve), 25 GeV^2 (middle curve) and 9 GeV^2 (upper curve). Right part: SSA given by Eq. (8) versus x_F for fixed target mode for three values of Q^2: 16 GeV^2 (lower curve), 9 GeV^2 (middle curve) and 4 GeV^2 (upper curve).

both h_1 and first moment of $h_1^\perp$ from the single-polarized and unpolarized DY processes, since these quantities enter the measured $\hat{k}$ and SSA $\hat{A}_h$ in the form of simple product instead of complex convolution. The preliminary estimations for PAX kinematics show the possibility to measure both $\hat{k}$ and SSA $\hat{A}_h$ and then to extract the quantities $h_1^{\perp(1)}$ and h_1. Certainly, the estimations of $\hat{k}$ and $\hat{A}_h$ magnitudes obtained in this paper are very preliminary and show just the order of values of these quantities. For more precise estimations one needs the Monte-Carlo generator more suitable for DY processes studies (see, for example. ref. [4]) than PYTHIA generator which we used (with the proper weighting of events) here.

Notice, that it is straightforward to properly modify the procedure discussed in this paper to DY processes: $\pi^- p \to \mu^+\mu^- X$ and $\pi^- p^\uparrow \to \mu^+\mu^- X$, which could be study in the COMPASS experiment at CERN.

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Discussion

Q. (O. Teryaev, JINR, Dubna, Russia): Did you estimate numerically the contributions of other mechanisms to $\gamma(k)$?

A. According to Boer, they cannot explain the data, although this work should be done in future.