TRANSVERSITY IN DRELL-YAN PROCESS OF POLARIZED PROTONS AND ANTIPROTONS IN PAX EXPERIMENT

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Estimates are given for the double spin asymmetry in lepton-pair production from collisions of transversely polarized protons and antiprotons for the kinematics of the recently proposed PAX experiment at GSI on the basis of predictions for the transversity distribution from the chiral quark soliton model.

1. Introduction. The leading structures of the nucleon in deeply inelastic scattering processes are described in terms of three twist-2 parton distribution functions (PDF) – the unpolarized $f_1^n(x)$, helicity $g_1^n(x)$, and transversity $h_1^n(x)$. Owing to its chirally odd nature $h_1^n(x)$ escapes measurement in DIS experiments. The transversity was originally introduced in the description of the Drell-Yan process of transversely polarized protons\textsuperscript{1}. Alternative processes have been discussed also, e.g. the Collins effect in semi-inclusive deeply inelastic scattering experiments at HERMES, CLAS and COMPASS could be (partly) understood in terms of transversity\textsuperscript{2}. However, in all these processes $h_1^n(x)$ enters in connection with some badly known\textsuperscript{3} Collins fragmentation function. Moreover these processes involve the introduction of transverse parton momenta, and for none of them a strict factorization theorem could be formulated so far. So, the Drell-Yan process remains up to now the theoretically cleanest and safest way to access $h_1^n(x)$.

The first attempt to study $h_1^n(x)$ by means of the Drell-Yan process is planned at RHIC. Dedicated estimates, however, indicate that at RHIC the access of $h_1^n(x)$ by means of the Drell-Yan process is very difficult. The main reason is that the observable double spin asymmetry $A_{TT}$ is proportional to

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a product of transversity quark and antiquark PDF. The latter are small, even if they were as large as to saturate the Soffer upper limit.

This problem can be circumvented by using an antiproton beam. Then $A_{TT}$ is proportional to a product of transversity quark PDF from the proton and transversity antiquark PDF from the antiproton (which are equal due to charge conjugation). Thus in this case one can expect sizeable counting rates. The challenging program how to polarize an antiproton beam has been recently suggested in the PAX experiment at GSI$^4$. The technically realizable polarization of the antiproton beam more than$^5 (5 − 10)\%$ and the large counting rates make the program rather promising.

In the talk I shortly describe our quantitative estimates for the Drell-Yan double spin asymmetry $A_{TT}$ in the kinematics of the PAX experiment at LO QCD. (For more details and references see$^6$.) We also will estimate the recently suggested analog double spin asymmetry in J/$\Psi$ production$^7$. For the transversity distribution we shall use predictions from the chiral quark soliton model$^8$. This model was derived from the instanton model of the QCD vacuum$^9$ and describes numerous nucleonic properties without adjustable parameters to within $(10 − 30)\%$ accuracy. The field theoretic nature of the model allows to consistently compute quark and antiquark PDF which agree with parameterizations$^10$ to within the same accuracy. This gives us a certain confidence that the model describes $h^a_1(x)$ with a similar accuracy.

2. Lepton pair production in $p \uparrow \bar{p} \downarrow$. The process $p\bar{p} \rightarrow \mu^+\mu^- X$ can be characterized by the invariants: Mandelstam $s = (p_1 + p_2)^2$ and dilepton invariant mass $Q^2 = (k_1 + k_2)^2$, where $p_{1/2}$ and $k_{1/2}$ are the momenta of respectively the incoming proton-antiproton pair and the outgoing lepton pair, and the rapidity $y = \frac{1}{2} \ln \frac{p_{1} (k_1 + k_2)}{p_2 (k_1 + k_2)}$. The double spin asymmetry in Drell-Yan process is given by

$$N^{\uparrow\uparrow} - N^{\uparrow\downarrow} \over N^{\uparrow\uparrow} + N^{\uparrow\downarrow} = D_P \frac{\sin^2 \theta}{1 + \cos^2 \theta} \cos 2\phi A_{TT}(y, Q^2),$$ (1)

where $\theta$ is the emission angle of one lepton in the dilepton rest frame and $\phi$ its azimuth angle around the collision axis counted from the polarization plane of the hadron whose spin is not flipped in Eq. (1). The factor $D_P$ takes into account polarization effects. At LO QCD $A_{TT}$ is given by

$$A_{TT}(y, Q^2) = \frac{\sum_a e_a^2 h^a_1(x_1, Q^2) h^a_1(x_2, Q^2)}{\sum_b e_b^2 f^b_1(x_1, Q^2) f^b_1(x_2, Q^2)},$$ (2)
where the parton momenta $x_{1/2}$ in Eq. (2) are $x_{1/2} = \sqrt{\frac{Q^2}{s}} e^{\pm y}$. In Eq. (2) use was made of the charge conjugation invariance.

In the PAX experiment an antiproton beam with energies in the range (15 – 25) GeV could be available, which yields $s = (30 – 50)$ GeV$^2$ for a fixed proton target. The region $1.5$ GeV $< Q < 3$ GeV, i.e. below the $J/\Psi$ threshold but well above $\Phi(1020)$-decays (and with sufficiently large $Q^2$) would allow to explore the region $x > 0.2$. However, in principle one can also address the resonance region itself and benefit from large counting rates since the unknown $q\bar{q}J/\Psi$ and $J/\Psi\mu^+\mu^-$-couplings cancel in the ratio in Eq. (1) as argued in Ref. 7. Keeping this in mind we shall present below estimates for $s = 45$ GeV$^2$, and $Q^2 = 5$ GeV$^2$, $9$ GeV$^2$ and $16$ GeV$^2$.

3. Double spin asymmetry $A_{TT}$ at PAX. The estimates for the double spin asymmetry $A_{TT}$ as defined in Eq. (2) for the PAX kinematics on the basis of the ingredients discussed above is shown in Fig. 1a. The exploitable rapidity range shrinks with increasing dilepton mass $Q^2$. Since $s = x_1 x_2 Q^2$, for $s = 45$ GeV$^2$ and $Q^2 = 5$ GeV$^2$ ($9$ GeV$^2$ $16$ GeV$^2$) one probes parton momenta $x > 0.3$ ($x > 0.5$). The asymmetry $A_{TT}$ grows with increasing $Q^2$ where larger parton momenta $x$ are involved, since $h_1^u(x)$ is larger with respect to $f_1^u(x)$ in the large $x$-region.

![Figure 1](image-url)

**Figure 1.** a) The asymmetry $A_{TT}(y, M^2)$, cf. Eq. (2), as function of the rapidity $y$ for $Q^2 = 5$ GeV$^2$ (solid) and $9$ GeV$^2$ (dashed) and $16$ GeV$^2$ (dotted line) for $s = 45$ GeV$^2$. b) Comparison of $A_{TT}(y, M^2)$ from proton-antiproton (solid) and proton-proton (dotted line) collisions at PAX for $Q^2 = 5$ GeV$^2$ and $s = 45$ GeV$^2$.

The advantage of using antiprotons is evident from Fig. 1b. The corresponding asymmetry from proton-proton collisions is an order of magnitude smaller (this observation holds also in the kinematics of RHIC). At first
glance this advantage seems to be compensated by the polarization factor in Eq. (1). For the antiproton beam polarization of $(5 - 10)\%$ and the proton target polarization of $90\%$, i.e. at PAX $D_P \approx 0.05$. However, thanks to the use of antiprotons the counting rates are more sizeable. A precise measurement of $A_{TT}$ in the region $Q > 4 \text{ GeV}$ is very difficult, however, in the dilepton mass region below the $J/\Psi$ threshold\textsuperscript{7} $A_{TT}$ could be measured with sufficient accuracy in the PAX experiment.

A precise measurement would allow to discriminate between different models for $h_1^a(x)$. E.g., on the basis of the non-relativistic quark model motivated popular guess $h_1^a(x) \approx g_1^a(x)$ (at some unspecified low scale) one would expect\textsuperscript{7} an $A_{TT}$ of about $30\%$ to be contrasted with the chiral quark soliton model estimate of about $50\%$.

At next-to-leading order in QCD one can expect corrections to this result which reduce somehow the asymmetry\textsuperscript{11}. Similarly large asymmetries can be also expected in the recently suggested process of lepton pair production via $J/\Psi$ production\textsuperscript{7}.

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