TRANSVERSE DOUBLE-SPIN ASYMMETRIES FOR SMALL Q_T DRELL-YAN PAIR PRODUCTION IN PP AND $P\bar{P}$ COLLISIONS

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We discuss transverse double-spin asymmetries for dimuon production at small transverse-momentum Q_T in pp and $p\bar{p}$ collisions. All order resummation of large logarithms relevant in small Q_T region is performed at next-to-leading logarithmic (NLL) accuracy, and asymmetries at RHIC, J-PARC and GSI are calculated.

The transversity $\delta q(x)$, the distribution of transversely polarized quarks inside transversely polarized nucleon, is the last unknown distribution of nucleon at the leading twist.[1] It is not measurable in inclusive DIS due to its chiral-odd structure, and a number of experiments are underway to measure it through semi-inclusive processes. Transversely polarized Drell-Yan process (tDY) is another way to measure it, which could in principle provide us with clean information on the transversity. However, the actual feasibility of extracting $\delta q(x)$ from tDY data depends on the magnitude of transverse double-spin asymmetry: $\frac{\Delta_T d\sigma}{d\sigma} \equiv \frac{d\sigma^{\uparrow\uparrow}-d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow}+d\sigma^{\uparrow\downarrow}}$. At RHIC, the asymmetry is possibly small since (i) pp collision probes products of valence-quark and sea-antiquark distributions where the latter are supposed to be small, and (ii) the small-x rise of unpolarized sea-quark distributions enhance the denominator of the asymmetry at high energy.[2] On the other hand, possibilities of transversly polarized pp ($p\bar{p}$) experiments at J-PARC (GSI) with moderate energies are recently discussed, where larger asymmetries in tDY are expected.[3] In this paper, we explore the asymmetries in Q_T spectrum of Drell-Yan pair, especially in small Q_T region where the bulk of the lepton pair is produced.

In the small Q_T region, fixed-order perturbative calculation does not work well since there appear large logarithmic corrections at each order of perturbation theory as $\alpha_s^n \ln^{2n-1}(Q^2/Q_T^2)/Q_T^2$, $\alpha_s^n \ln^{2n-2}(Q^2/Q_T^2)/Q_T^2$, and so on, corresponding to LL, NLL, and higher contributions, respectively. These "recoil logs" have to be resummed to all orders in α_s to obtain reliable perturbative predictions. The resummation is carried out in the impact parameter b space, conjugate to the Q_T space, to take transverse-momentum conservation into account, and the resummed cross section is expressed as the Fourier transform back to the Q_T space.[4] At the NLL, the resummed cross section of tDY, differential in invariant mass Q, transverse momentum Q_T and rapidity y of the lepton pair, and in azimuthal angle ϕ of one of the outgoing leptons is given by[5] ($\sqrt{S}$ the CM energy of hadrons)

$$\frac{\Delta_T d\sigma^{\rm NLL}}{dQ^2 dQ_T^2 dy d\phi} = \cos(2\phi) \frac{\alpha^2}{3\, N_c\, S\, Q^2} \sum_i e_i^2 \int_0^\infty db \frac{b}{2} J_0(bQ_T) e^{\,S(b,Q)} \times \left[(C_{qq} \otimes \delta q_i) \left(x_1^0, \frac{b_0^2}{b^2} \right) (C_{\bar{q}\bar{q}} \otimes \delta \bar{q}_i) \left(x_2^0, \frac{b_0^2}{b^2} \right) + (x_1^0 \leftrightarrow x_2^0) \right]. \quad (1)$$

Here $J_0(bQ_T)$ is a Bessel function, $b_0 = 2e^{-\gamma_E}$ with γ_E the Euler constant, and the large logarithmic corrections are resummed into the Sudakov factor $e^{S(b,Q)}$ with $S(b,Q) = -\int_{b_0^2/b^2}^{Q^2} (d\kappa^2/\kappa^2) \{ \ln \frac{Q^2}{\kappa^2} A_q(\alpha_s(\kappa)) + B_q(\alpha_s(\kappa)) \}$. A_q, B_q and the coefficient functions $C_{qq}, C_{\bar{q}\bar{q}}$ are perturbatively calculable, and are found in Ref.[5] up to the accuracy necessary for the NLL. $x_{1,2}^0 = (Q/\sqrt{S}) e^{\pm y}$, and $\delta q_i(x, \mu^2)$ is the transversity of i-th flavour quark at the $\overline{\rm MS}$ scale μ. The singularity in b-integration,[4] due to the Landau pole in $\alpha_s(\kappa)$, is taken care of by "contour deformation method" introduced in the joint resummation;[7] correspondingly, [4,6,7] we take non-perturbative effects into account by the replacement $e^{S(b,Q)} \to e^{S(b,Q) - g_{NP} b^2}$ in (1), with a non-perturbative parameter g_{NP}. We combine the resulting NLL cross section with the leading order (LO) cross section, which is of $\mathcal{O}(\alpha_s)$ and is obtained[5] as QCD prediction at large Q_T; the matching of the NLL formula with the corresponding component in the LO cross section is performed at intermediate Q_T following the formulation developed in Ref.[6], to ensure no double counting for all Q_T, and we finally obtain the complete "NLL+LO" cross section $\Delta_T d\sigma/(dQ^2 dQ_T^2 dy d\phi)$, which has a uniform accuracy over the entire range of Q_T.[5] Note that, also for the unpolarized DY, the corresponding "NLL+LO" cross section $d\sigma/(dQ^2 dQ_T^2 dy d\phi)$ can be obtained in the same framework, utilizing the results in the literatures.[10,4].

We calculate the following transverse double-spin asymmetries:

$$A_{TT} = \left[\Delta_T d\sigma/dQ^2 dQ_T^2 dy d\phi\right] / \left[d\sigma/dQ^2 dQ_T^2 dy d\phi\right] \ . \qquad (2)$$

As non-perturbative inputs, we use the same parton distributions as those used in Ref.[2]; in particular, for the numerator, we use a model of the transversity $\delta q(x,\mu^2)$ which saturates the Soffer bound as $\delta q(x,\mu_0^2) = [q(x,\mu_0^2) + \Delta q(x,\mu_0^2)]/2$ at low input scale $\mu_0 \sim 0.6$ GeV and is evolved to higher μ^2 with NLO DGLAP kernel.[8] The non-perturbative parameter g_{NP} is taken to be the same value for both numerator and denominator of (2), and we use $g_{NP} \simeq 0.5$ GeV^2 as suggested by the result of Ref.[9].

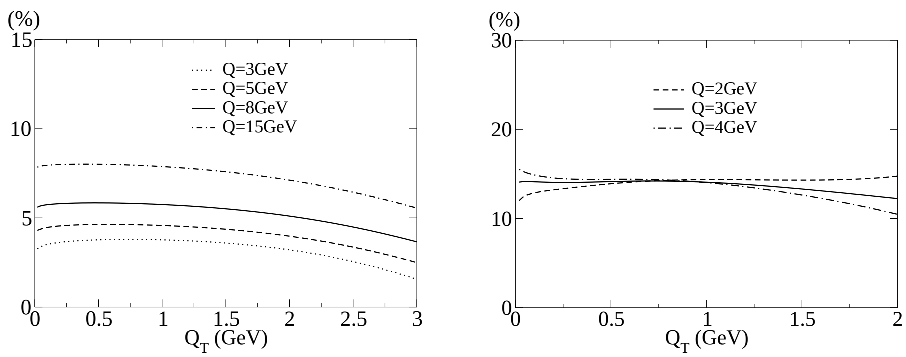

Figure 1. A_{TT} in pp collision. Left: $\sqrt{S} = 200$ GeV, $y = 2$, $\phi = 0$ and $Q = 3, 5, 8, 15$ GeV, corresponding to RHIC kinematics. Right: $\sqrt{S} = 10$ GeV, $y = \phi = 0$ and $Q = 2, 3, 4$ GeV, corresponding to J-PARC kinematics. $g_{NP} = 0.5$ GeV^2 in both cases.

A_{TT} in pp collision are shown as functions of Q_T in Fig. 1, where the left (right) panel is for RHIC (J-PARC) kinematics. $A_{TT} \gtrsim 10\%$ are obtained for J-PARC, where the parton distributions are probed at medium $x_{1,2}^0$ (see (1)). For the RHIC case, A_{TT} are less than 10%, and becomes smaller for smaller Q due to the small-x rise of unpolarized sea-distributions in the denominator of (2). The largest A_{TT} of 15-30% are obtained in $p\bar{p}$ collision at GSI kinematics as shown in Fig. 2, where A_{TT} are dominated by valence distributions at medium x. Integrating the numerator and denominator of (2) over Q_T^2, our results for GSI kinematics reproduce the corresponding NLO asymmetries given by Barone et al.[3].

In all cases of Figs. 1 and 2, A_{TT} have flat behavior in small Q_T region, although the numerator and denominator of (2) have strong Q_T depen-

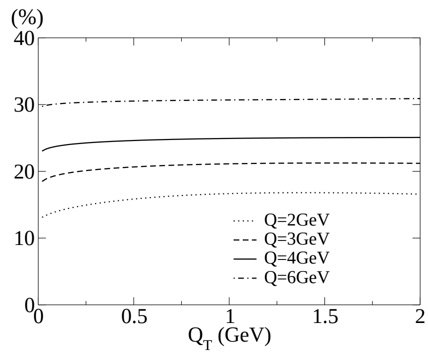

Figure 2. A_{TT} in $p\bar{p}$ collision at $\sqrt{S} = 14.5$ GeV, $y = \phi = 0$, and $Q = 2, 3, 4, 6$ GeV, corresponding to GSI kinematics, and with $g_{NP} = 0.5\text{GeV}^2$.

dence, respectively.[5] We also note that A_{TT} are almost unaffected when the parameter g_{NP} is varied in the range $g_{NP} = 0.3$-0.8 GeV^2. These common features in Figs. 1 and 2 come from the dominance of soft gluon effects in small Q_T region, whose main part, i.e. the Sudakov factor of (1), is universal[5] at the NLL level in both polarized and unpolarized channels.

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