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Next-to-leading Order QCD Corrections to A_{TT} for Single-Inclusive Hadron Production

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Abstract. We report on a calculation of the next-to-leading order QCD corrections to the partonic cross sections contributing to single-inclusive high-p_T hadron production in collisions of transversely polarized hadrons. We give some predictions for the double spin asymmetry A_{TT}^{π} for the proposed experiments at RHIC and at the GSI.

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INTRODUCTION

The leading-twist partonic structure of a spin-$\frac{1}{2}$ hadron is given in terms of the unpolarized parton distribution functions $f(x,Q^2)$, the helicity distributions $\Delta f(x,Q^2)$, and the transversity distributions $\delta f(x,Q^2)$. Transversity describes the number density of a parton with the same transverse polarization as the nucleon, minus the number density for opposite polarization. Among the various parton distributions, the $\delta f(x,Q^2)$ are the ones about which we have the least knowledge. They are at present the focus of much experimental activity. Transversity will be probed by double-transverse spin asymmetries in transversely polarized pp collisions at the BNL Relativistic Heavy Ion Collider (RHIC) [1]. The most promising reaction is the Drell-Yan process, which offers the largest spin asymmetries, but whose main drawback is the rather moderate event rate [2]. Other relevant processes include high p_T prompt photon [3, 4] and jet production [3]. However, for these the asymmetry is expected to be much smaller because of the absence of gluon-initiated subprocesses in the transversely polarized cross section. Recently, it has also been investigated whether one could extract transversity from measurements of A_{TT} for the Drell-Yan process in transversely polarized $\bar{p}p$ collisions at the planned GSI-FAIR facility [5, 6, 7, 8, 9, 10]. In this note (for details, see Ref. [11]), we consider the spin asymmetry in single-inclusive production of pions at large transverse momentum p_T as a possible means for determining transversity at RHIC or the GSI. We report on the calculation of the next-to-leading order (NLO) corrections for this reaction, and also present some phenomenological results.

PROJECTION TECHNIQUE

It is known that the NLO QCD corrections are required in order to have firm theoretical predictions for hadronic scattering. Only with their knowledge can one reliably extract information on the partonic (spin) structure of nucleons. Apart from this motivation, also interesting new technical questions arise beyond leading order (LO) in the calculations of cross sections with transverse polarization. Unlike the longitudinally polarized case, where the spin vectors are aligned with the momenta, the transverse spin vectors specify extra spatial directions and, as a result, the cross section has non-trivial dependence on the azimuthal angle of the observed particle. For A_{TT} this dependence is of the form [4]

$$\frac{d^3\delta\sigma}{dp_T d\eta d\Phi} \equiv \cos(2\Phi) \left\langle \frac{d^2\delta\sigma}{dp_T d\eta} \right\rangle , \tag{1}$$

for a parity conserving theory with vector coupling. Here, the spin vectors are taken to point in the $\pm x$ direction. We furthermore consider the scattering in the center-of-mass frame of the initial hadrons and use their momenta to define the z axis. Because of the $\cos(2\Phi)$ dependence, integration over all azimuthal angles is not appropriate. This makes it difficult to use the standard techniques developed for NLO calculations of unpolarized and longitudinally polarized processes, because these techniques usually rely on the integration over the full azimuthal phase space and also on the choice of particular reference frames that are related in complicated ways to the center-of-mass frame of the initial hadrons. In [4] a general technique was introduced that facilitates NLO calculations for transverse polarization by conveniently projecting on the azimuthal dependence of the cross section in a covariant way. The projector

$$F(p, s_a, s_b) = \frac{s}{\pi t u} \left[2\,(p\cdot s_a)\,(p\cdot s_b) \, + \, \frac{tu}{s}\,(s_a\cdot s_b) \right] \tag{2}$$

reduces to $\cos(2\Phi)/\pi$ in the center-of-mass frame of the initial hadrons. Here p is the momentum of the observed particle in the final state and the s_i are the initial transverse spin vectors. The squared matrix element for the partonic process is multiplied with this projector and integrated over the full azimuthal phase space. Integrations of terms involving the product of the transverse spin vectors with the final-state momenta can be performed using a tensor decomposition. After this step, no scalar products involving the s_i are left in the squared matrix element. For the remainder of the phase space integrations, one can now use techniques familiar from the unpolarized and longitudinally polarized cases. This method is particularly convenient at NLO, where one uses dimensional regularization and the phase space integrations are performed in $n \neq 4$ dimensions.

APPLICATION TO SINGLE-INCLUSIVE HADROPRODUCTION : PHENOMENOLOGICAL RESULTS

Next, we give some phenomenological results for transversely polarized pp collisions at RHIC ($\sqrt{S} = 200$ and 500 GeV) and $\bar{p}p$ collisions at the GSI-FAIR facility in an

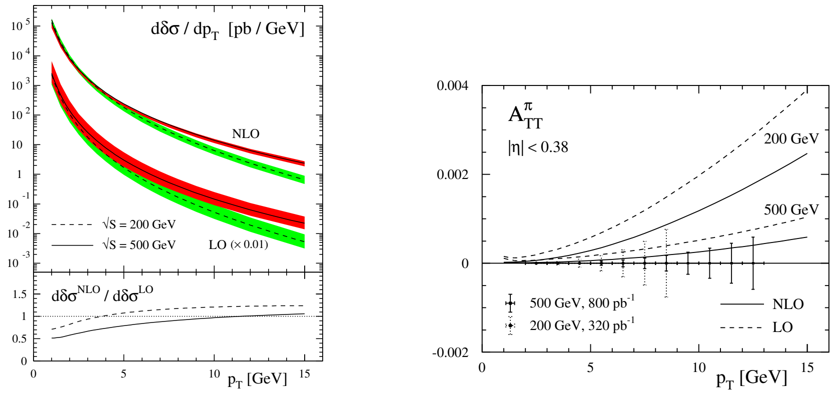

FIGURE 1. Predictions for the transversely polarized single-inclusive pion production cross sections at LO and NLO at RHIC (left), and for the transverse double-spin asymmetry $A_{\mathrm{TT}}^{\pi^0}$ (right). The shaded bands represent the range of predictions when the scale μ is varied in the range $p_T \leq \mu \leq 4p_T$. The lower panel on the left shows the ratios of the NLO and LO results (the "K-factors").

asymmetric collider mode with proton and antiproton energies of 3.5 GeV and 15 GeV, respectively [11]. For our numerical predictions, we model the transversity distributions by saturating the Soffer inequality [12] at some low input scale $\mu_0 \approx 0.6$ GeV, using the NLO (LO) GRV [13] and GRSV ("standard scenario") [14] densities $q(x,\mu_0)$ and $\Delta q(x,\mu_0)$, respectively.

Figure 1 (left) shows our predictions for the transversely polarized single-inclusive pion production cross sections at LO and NLO for the two different c.m.s. energies at RHIC. We also display the scale uncertainty. For the K-factor shown in the lower panel the scale choice is $\mu = 2p_T$. A significant decrease of scale dependence is observed when going from LO to NLO. Figure 1 (right) shows the asymmetry $A_{\mathrm{TT}}^{\pi^0}$ defined as the ratio of the polarized and unpolarized cross sections. Here, the scale is set to $\mu = p_T$. We also display the statistical errors that may be achievable in experiment. We have calculated these using

$$\delta A_{\mathrm{TT}} \simeq \frac{1}{P_1 P_2 \sqrt{\mathscr{L}\,\sigma_{\mathrm{bin}}}}\,, \tag{3}$$

where $P_1 = P_2 = 0.7$ are the transverse polarizations of the proton beams, $\mathscr{L}$ the integrated luminosity of the collisions indicated in the figure, and σ_{bin} the unpolarized cross section integrated over the p_T-bin for which the error is to be determined. The asymmetry is very small.

Figure 2 (left) shows the corresponding cross sections in transversely polarized $\bar{p}p$ collisions at $\sqrt{S} = 14.5$ GeV in an asymmetric collider mode at the GSI-FAIR facility. We have assumed beam polarizations of 30% and 50% for the antiprotons and protons, respectively. At GSI energies, the scale dependence does not really improve from LO to NLO. A resummation of the double-logarithmic corrections to the partonic cross sections [15] would be very desirable for the future, along with a study of power corrections. Figure 2 (right) shows the predicted transverse double-spin asymmetry at the GSI, which is much larger than at RHIC.

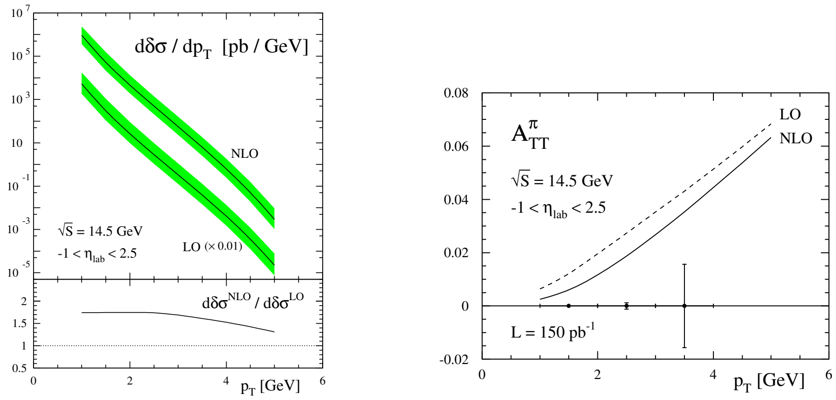

FIGURE 2. LO and NLO predictions for the cross section (left) and the transverse spin asymmetry $A_{\mathrm{TT}}^{\pi^0}$ (right) for single-inclusive pion production in $\bar{p}p$ collisions at the GSI. The shaded bands represent the range of predictions if the scale μ is varied in the range $p_T \le \mu \le 4p_T$. The lower panel (left) shows the ratios of the NLO and LO results (the "K-factors").

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