

Double-transverse spin asymmetries at NLO¹

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Abstract. We report on a next-to-leading order QCD calculation of the cross section and the spin asymmetry for isolated large- p_T prompt photon production in collisions of transversely polarized protons. Corresponding measurements may be used at RHIC to determine the transversity parton distributions of the proton.

The partonic structure of spin-1/2 targets at the leading-twist level is characterized by the unpolarized, longitudinally polarized, and transversely polarized distribution functions f , Δf , and δf , respectively [1, 2]. These non-perturbative parton densities can be probed universally in a multitude of inelastic scattering processes, for which it is possible to separate (“factorize”) the long-distance physics relating to nucleon structure from a partonic short-distance scattering that is amenable to QCD perturbation theory.

In contrast to the f and Δf , the “transversity” distributions δf are unmeasured thus far. They are presently the focus of much experimental activity. For example, information should soon be gathered from transversely polarized proton-proton collisions at the BNL Relativistic Heavy Ion Collider (RHIC) [3]. The potential of RHIC in accessing transversity in measurements of transverse double-spin asymmetries A_{TT} was examined in [4] for high transverse momentum p_T prompt photon and jet production (for earlier studies, see [5, 6, 7]). All of these calculations were performed only at the lowest order (LO) approximation for the underlying partonic hard-scattering. As is well known, next-to-leading order (NLO) QCD corrections are generally indispensable in order to arrive at a firmer theoretical prediction for hadronic cross sections and spin asymmetries. The NLO calculation for A_{TT}^{γ} for isolated high- p_T prompt photon production, $pp \rightarrow \gamma X$, was recently completed [8]; here we give a brief report on those results.

Interesting new technical questions arise beyond the LO in case of transverse polarization. Unlike for longitudinally polarized cross sections where the spin vectors are aligned with momentum, transverse spin vectors specify extra spatial directions, giving rise to non-trivial dependence of the cross section on the azimuthal angle of the observed photon. As is well-known [2], for A_{TT} this dependence is always of the form $\cos(2\Phi)$, if the z axis is defined by the direction of the initial protons in their center-of-mass system (c.m.s.), and the spin vectors are taken to point in the $\pm x$ direction. Integration over the photon’s azimuthal angle is therefore not appropriate. On the other hand, standard techniques developed in the literature for performing NLO phase-space integrations usually rely on integration over the full azimuthal phase space, and also on the choice of par-

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ticular reference frames that are related in complicated ways to the one just specified. In [8], a new general technique was introduced which facilitates NLO calculations with transverse polarization by conveniently projecting on the azimuthal dependence of the matrix elements in a covariant way. The key point here is to recognize that the factor $\cos(2\Phi)$ in the cross section actually results from the covariant expression

$$\mathcal{F}(p_\gamma, s_a, s_b) = \frac{s}{tu} \left[2(p_\gamma \cdot s_a)(p_\gamma \cdot s_b) + \frac{tu}{s}(s_a \cdot s_b) \right], \quad (1)$$

with s_a, s_b the initial spin vectors and p_γ the photon momentum. \mathcal{F} reduces to $\cos(2\Phi)$ in the hadronic c.m.s. frame. One may thus integrate over all phase space without obtaining a vanishing result if one simply multiplies the squared matrix element by the factor $\mathcal{F}(p_\gamma, s_a, s_b)$. Integration over terms involving the s_a, s_b can be carried out in a covariant way by using standard tensor decompositions. After this step, there are no scalar products involving the s_i left in the squared matrix element. For the ensuing integration over all azimuthal phase space we can now employ techniques familiar from the corresponding calculations in the unpolarized and longitudinally polarized cases.

At NLO, there are two subprocesses that contribute for transverse polarization, $q\bar{q} \rightarrow \gamma X$ and $qq \rightarrow \gamma X$. The first one is already present at LO, where $X = g$. At NLO, one has virtual corrections to the Born cross section ($X = g$), but also $2 \rightarrow 3$ real emission diagrams, with $X = gg + q\bar{q} + q'q'$. For the second subprocess, $X = qq$.

Owing to the presence of ultraviolet, infrared, and collinear singularities at intermediate stages of the calculation, it is necessary to introduce a regularization. Our choice is dimensional regularization, that is, the calculation is performed in $d = 4 - 2\epsilon$ space-time dimensions. Ultraviolet poles in the virtual diagrams are removed by the renormalization of the strong coupling constant. Infrared singularities cancel in the sum between virtual and real-emission diagrams. After this cancelation, only collinear poles are left. These result for example from a parton in the initial state splitting collinearly into a pair of partons, corresponding to a long-distance contribution in the partonic cross section. From the factorization theorem it follows that such contributions need to be factored into the parton distribution functions. In our calculations [8], we have imposed on the photon the isolation cut proposed in [9]. All *final-state* collinear singularities then cancel. The isolation constraint was implemented analytically by assuming a narrow isolation cone.

For our numerical predictions we model the δf by assuming that the Soffer inequality [10] is saturated at some low input scale $\mu_0 \simeq 0.6 \text{ GeV}$. For $\mu > \mu_0$ the transversity densities $\delta f(x, \mu)$ are then obtained by solving the appropriate QCD evolution equations. Our numerical predictions apply for prompt photon measurements with the PHENIX detector at RHIC. Figure 1 shows our results for the transversely polarized prompt photon production cross sections at NLO and LO for two different c.m.s. energies. The lower part of the figure displays the so called “ K -factor”, $K = d\delta\sigma^{\text{NLO}}/d\delta\sigma^{\text{LO}}$. One can see that the NLO corrections are somewhat smaller for $\sqrt{s} = 500 \text{ GeV}$ and increase with p_T . The shaded bands in the upper panel of Fig. 1 indicate the uncertainties from varying the factorization and renormalization scales in the range $p_T/2 \leq \mu_R = \mu_F \leq 2p_T$. The solid and dashed lines are always for the choice where all scales are set to p_T , and so is the K factor underneath. One can see that the scale dependence becomes much weaker at NLO, as expected. The corresponding spin asymmetries $A_{\text{TT}}^Y = d\delta\sigma/d\sigma$ may be found in Fig. 2 of Ref. [8]; they are generally smaller at NLO than at LO.

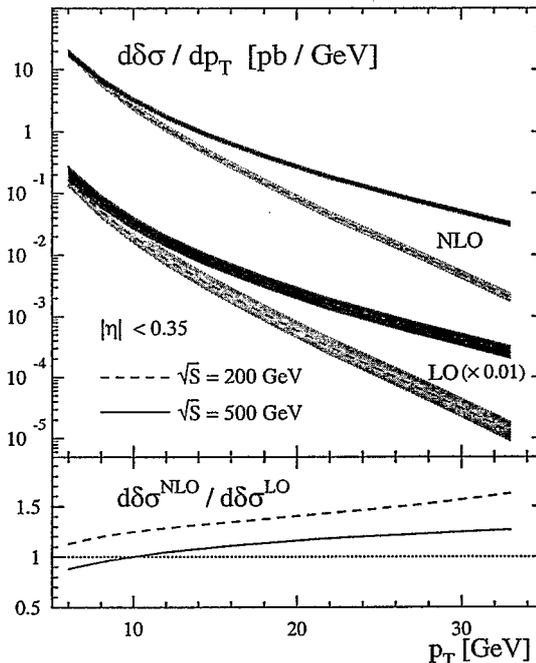


FIGURE 1. Predictions for the transversely polarized prompt photon production cross sections at LO and NLO, for $\sqrt{s} = 200$ and 500 GeV. The LO results have been scaled by a factor of 0.01. The shaded bands represent the theoretical uncertainty if $\mu_F (= \mu_R)$ is varied in the range $p_T/2 \leq \mu_F \leq 2p_T$. The lower panel shows the ratios of the NLO and LO results for both c.m.s. energies.

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