Next-to-leading order corrections to processes with longitudinally and transversely polarized particles*

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Higher (next-to-leading) order corrections (HOC) to certain processes with longitudinally and transversely polarized particles are determined. K -factors well exceeding 1 are found. General features in common between the above processes as well as between polarized and the corresponding unpolarized processes are noted. The question of dominance of HOC by soft, collinear and virtual gluons is considered.

1. INTRODUCTION

At high energy the state of a quark q in a nucleon h is determined by three distributions: (i) The unpolarized $F_{q/h}(x, Q)$, related with the well known structure function $f_1(x, Q)$, (ii) The longitudinally polarized $\Delta_L F_{q/h}(x, Q)$ connected with $g_1(x, Q)$ of the EMC, SMC and SLC experiments, and (iii) The transversity distribution $\Delta_T F_{q/h}(x, Q)$, related with $h_1(x, Q)$. All three are very important in revealing the structure of the nucleon.

Here we consider (ii) and (iii) and study the following 4 processes: (A) Deep inelastic Compton scattering (DIC) by longitudinally polarized γ and p , (B) Large- p_T direct photon production in longitudinally polarized pp collisions, (C) Lepton pair production in transversely polarized hadron collisions (transverse Drell-Yan), and (D) Inclusive production of transversely polarized baryon-antibaryon pairs in e^-e^+ collisions.

2. PROCESSES WITH LONGITUDINALLY POLARIZED PARTICLES

Here an essential question is the size of the polarized gluon distribution. One of the most appropriate reactions to determine it is (B), i.e. $\bar{p}p \rightarrow \gamma(\text{large } p_T) + X$, dominated by $\bar{g}q \rightarrow \gamma q$, and an experiment is planned at RHIC ($\sqrt{s} =$

100 – 500 GeV) [1].

HOC to this reaction are now determined [2]. In all cases, i.e. varying $\sqrt{s}$ and rapidity, K -factors ($K = (\sigma_{\text{Born}} + \sigma_{\text{HOC}})/\sigma_{\text{Born}}$) well exceeding unity were found, leading, in general, to sizeable cross sections [2].

Reaction (A), i.e. $\bar{\gamma}p \rightarrow \gamma(\text{large } p_T) + X$, is dominated by $\bar{\gamma}q \rightarrow \gamma q$, which gives the abelian part of $\bar{g}q \rightarrow \gamma q$. Here the K -factors are not particularly large [3], but again $K > 1$. For both (A) and (B) the structure and relative size of HOC is much the same as for the corresponding unpolarized reactions [2, 3].

3. PROCESSES WITH TRANSVERSELY POLARIZED PARTICLES

The structure function $h_1(x, Q)$ is chiral-odd (contrary to the chiral-even g_1), and to get information on $\Delta_T F_{q/h}$ one needs processes that break chiral symmetry spontaneously [1]. The best example is Drell-Yan lepton-pair production, mediated via

$$q(p_1, s_1) + \bar{q}(p_2, s_2) \rightarrow V^* \rightarrow l^-(p_3) + l^+(p_4) \quad (1)$$

where $V = \gamma$ or Z , p_i ($i = 1, \dots, 4$) are 4-momenta and s_1, s_2 are transverse spin 4-vectors. With $M^2 \equiv (p_3 + p_4)^2$ and $\hat{\Omega}_3$ the solid angle of p_3 in the c.m. of q and $\bar{q}$, we consider

$$\Delta_T \frac{d\hat{\sigma}}{dM^2 d\hat{\Omega}_3} \equiv \frac{1}{2} \left\{ \frac{d\hat{\sigma}(s_1, s_2)}{dM^2 d\hat{\Omega}_3} - \frac{d\hat{\sigma}(s_1, -s_2)}{dM^2 d\hat{\Omega}_3} \right\} \quad (2)$$

From this, we obtain the observables

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Figure 1.

$d\sigma/dM^2 d\phi_3 d\eta_3$ and $d\sigma/dM^2 d\phi_3$, where η_3 and ϕ_3 denote rapidity and azimuthal angle of l^- .

To determine HOC we work in Dimensional Reduction (DRED) [4], where momenta are in $n = 4 - 2\epsilon$ dimensions and everything else in $n = 4$. We find that in order to satisfy the QED Ward identity we must add a vertex counterterm $\sim \frac{1}{\epsilon} \gamma_\mu^{(\epsilon)}$; this eliminates a term $\sim s_1 \cdot s_2 \delta(1 - \hat{\tau})$, where $\hat{\tau} = M^2/\hat{s}$. Similar counterterms are discussed in [5]. We use the Feynman gauge and the universal definition of HOC [4].

For the valence quark distributions we take $\Delta_T F_{q_v/p}(x, Q_0) = \Delta_L F_{q_v/p}(x, Q_0)$, with $\Delta_L F_{q_v/p}$ the solution 1 used in Refs [2(a)] and [3] ($Q_0 = 2$ GeV). The transverse sea is rather arbitrary; using $|\Delta_L F_{\bar{q}/p}| \leq F_{\bar{q}/p}$, Regge behaviour at small x etc. [4] we take

$$\Delta_T F_{\bar{q}/p}(x, Q_0) = -0.24x^{-1}(1-x)^{9.5} \quad (3)$$

Fig. 1(a) presents K -factors for $p_1 p_1 \rightarrow l^- l^+ + X$; the peaks and dips are due to γ - Z interference. The important point is that the K will exceed 1.

An other example of spontaneous breaking of chiral symmetry is presented by the pro-

cess $e^+ e^- \rightarrow B_1 \bar{B}_1$ (back-to-back) + X involving transversity fragmentation functions $\Delta_T \mathcal{D}_{B/q}$. For $\sqrt{s} \simeq M_Z$ this proceeds via

$$e^- e^+ \rightarrow Z^*(Q) \rightarrow q(p_3, s_3) + \bar{q}(p_4, s_4) \quad (4)$$

where Q, p_3, p_4 are 4-momenta and s_3, s_4 transverse spins. Here the proper kinematic variables are $z \equiv 2p_3 \cdot Q/s$ and $\xi \equiv p_3 \cdot p_4/p_3 \cdot Q$; in the rest frame of Z , they correspond to momentum fractions of q and $\bar{q}$. To determine HOC, we again work in DRED [6].

We particularly consider $B = \Lambda$ (polarization self-analyzer) [7]. Taking into account $|\Delta_T \mathcal{D}_{\Lambda/q}(z)| \leq \mathcal{D}_{\Lambda/q}(z)$ and estimating $\mathcal{D}_{\Lambda/q}(z)$ from data on the hadronic decays of Z , we use

$$\begin{aligned} \Delta_T \mathcal{D}_{\Lambda/s}(z) &= 0.2(1-z)^3/z, \\ \Delta_T \mathcal{D}_{\Lambda/u}(z) &\simeq \Delta_T \mathcal{D}_{\Lambda/d}(z) \simeq 0 \end{aligned} \quad (5)$$

to obtain the cross section $\Delta_T d\sigma/dz d\xi d\phi_3 \equiv \sigma_T$.

We find the following interesting feature: Consider the two cases where the spin vectors of $\Lambda, \bar{\Lambda}$ (or $B, \bar{B}$) are: (a) on the production plane and (b) perpendicular to it. Then σ_T has opposite

sign (i.e. between the two orientations, σ_T has a zero). This holds both at the Born and one-loop level, and is independent of the magnitude and shape of all $\Delta_T \mathcal{D}_{\Lambda/q}$. Thus it can be tested even with a small number of events.

Fig. 2 presents our K -factors at $\sqrt{s} = M_Z$ for case (a); for case (b) the K -factors are almost identical [6]. Again K well exceed 1.

4. DOMINANCE OF HOC BY SOFT, COLLINEAR AND VIRTUAL GLUONS

Returning to transverse Drell-Yan, the general structure of HOC is ($\hat{\tau} = M^2/\hat{s}$):

$$\Delta_T f = a\delta(1-\hat{\tau}) + b \frac{1}{(1-\hat{\tau})_+} + c \left(\frac{\ln(1-\hat{\tau})}{1-\hat{\tau}} \right)_+ + d + e \ln(1-\hat{\tau}) + \dots + h \frac{\ln^2(\hat{\tau})}{1-\hat{\tau}} \quad (6)$$

where the terms after the third contain no distributions. The first 3 terms arise from soft, collinear and virtual gluons. Denoting by σ_S the contribution of the 3 terms to the physical cross section and by $\sigma_H (= \sigma_{\text{HOC}} - \sigma_S)$ that of the rest, in Fig. 1(b) we present the ratio $L \equiv \sigma_H/\sigma_S$. Clearly, as $\tau \equiv M^2/s \rightarrow 1$ (kinematic endpoint), L decreases.

For processes (A) and (B), instead of τ , the proper is variable $x_T = 2p_T/\sqrt{s}$. Again, as $x_T \rightarrow 1$, $|L|$ have been found to decrease fast for all s and η [2,3]. Finally, for process (D), the ratios L are shown in Fig. 2; clearly as z and/or ξ increase ($\rightarrow$ kinem. endpoint) L decrease fast.

In conclusion, in all cases considered, as we approach the kinematic endpoints, HOC are dominated by soft, collinear and virtual gluons. This is in common with unpolarized processes and is discussed in the second of [2].

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Figure 2.

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