Inclusive Prompt Photon Production in $pp$ and $\bar{p}p$ Interactions

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Abstract. High transverse momentum ($p_T$) production of pions and photons in proton-proton and proton-antiproton interactions are studied within the QCD framework and compared with the presently available experimental data. Scaling violation effects are included, and shown to be important at large $p_T$. Predictions are made for the $\gamma/\pi^0$ ratio at collider energies. The possibility of extricating the gluon distribution function from the invariant cross section data for the process $\bar{p}+p \rightarrow \gamma + X$ is suggested.

1. Introduction

The recently reported results for the ratio for production of prompt photons to $\pi^0$ [1, 2] at large transverse momentum ($p_T$) can be used as a check for the predictions of Quantum Chromodynamics (QCD) [3].

In this note we give a detailed treatment of $\gamma$ and $\pi^0$ production within the QCD framework (in the leading log approximation) where the following effects are included in the calculation:

(i) The point-like coupling of the photon to the electric charge of the quarks (which is known to dominate at large $p_T$ [4]).

(ii) Scale breaking effects.

(iii) Primordial transverse momentum of the partons $k_T$ (using the parametrization suggested by Feynman et al. [5]).

(iv) Direct photon production beyond the leading order (i.e. processes of the type $q+q \rightarrow q+g+\gamma$, $q+g \rightarrow q+g+\gamma$ etc. have been included).

As we expect that both $\bar{p}p$ and higher energy $pp$ colliding beams will soon become a reality we have calculated the productions of $\gamma$ and $\pi^0$ in both $pp$ and $\bar{p}p$ interactions at energies of $\sqrt{s} = 31$, 62, and 200 GeV, and have compared the results with available experimental data at $\sqrt{s} = 31$ and 62 GeV.

In Sect. 2 we discuss the basic formalism of QCD and the parametrization we have adopted. In Sect. 3, we list the subprocesses which yield prompt and bremsstrahlung photons. Section 4 contains a discussion of the various aspects of our parametrization, including the "primordial" transverse momentum $k_T$, the quark to photon fragmentation function, and the magnitude of the bremsstrahlung process. In Sect. 5 we present our results, while their evaluation and our conclusions are given in Sect. 6.

2. Parametrization

The inclusive cross-section for the production of a prompt photon from target particle $B$ and beam particle $A$ is:

$$ E \frac{d\sigma}{d^3p} (AB \rightarrow \gamma X) = \frac{1}{\pi} \sum_{n=1}^{\infty} \int_{x_{n+1}^{min}}^{1} \int_{x_{n}^{min}}^{1} dx_a \int_{x_{b}^{min}}^{1} dx_b G_{a/A}(x_a, Q^2) \cdot G_{b/B}(x_b, Q^2) \cdot \frac{1}{z} \delta(z - 1) \cdot \frac{d\sigma}{dz} (ab \rightarrow \gamma d). \quad (2.1) $$

The summation extends over all partons involved in the process, $G_{a/A}(x_a, Q^2)$ and $G_{b/B}(x_b, Q^2)$ denote the parton momentum distributions within hadrons $A$ and $B$. For comparison we show in Fig. 1 the diagram for the inclusive production of a hadron $C$ (in our case $\pi^0$). $D_{C/a}(z, Q^2)$ denotes the parton fragmentation into hadron $C$.

We adopt a scale breaking form for the parton distribution functions, which fits the experimental data [5, 6] and is consistent with field theoretical studies.
For the $G_i$ distribution functions which appear in (2.1) we use the parametrization suggested by Baier et al. [6], which is based on a Buras-Gaemers type to fit to the CDHS data [8].

3. Subprocesses

The expressions for subprocess cross section $d \sigma / dt$ for the reactions $qq \rightarrow qq, gg \rightarrow gg, qg \rightarrow gq, gg \rightarrow gq$ can be found in [10] (Fig. 2a, b).

An additional process which we include, although suppressed by an order $\alpha_s$, is the quark bremsstrahlung type process as shown in Fig. 2c. Aurenche and Lindfors [11] have given a recipe for calculating $q + q \rightarrow q + q + \gamma$ using dimensional regularization techniques.

This leads to the expression for the quark to photon fragmentation function, which in the leading approximation can be written as

$$D_q(z, Q^2) = \frac{\alpha}{2\pi} \left( \frac{1 + (1 - z)^2}{z} \right) \ln(Q^2/\Lambda^2).$$

(3.2)

The matrix elements for the diagrams shown in Fig. 2c are:

(i) For bremsstrahlung from quark (flavour i) in hadron C

$$\frac{d\sigma}{dq_i} = \frac{4}{9} g_i^2 s \left( 1 + \frac{s^2 + l^2}{\tilde{s}^2} \right) D_q(z, Q^2).$$

(3.3a)

(ii) For bremsstrahlung from quark (flavour j) in hadron D

$$\frac{d\sigma}{dq_j} = \frac{4}{9} g_j^2 s \left( 1 + \frac{s^2 + l^2}{\tilde{s}^2} \right) D_q(z, Q^2).$$

(3.3b)

There is some ambiguity in the choice of the variable $Q^2$ that appears in the running coupling constant $\alpha_s(Q^2)$, the distribution functions $G_i(x, Q^2)$ and the fragmentation function $D_q(z, Q^2)$. In this paper we follow Feynman et al. [5] and take

$$Q^2 = \frac{2\tilde{s} \tilde{t} \tilde{u}}{(s^2 + l^2 + \tilde{l}^2)}. \quad (3.4)$$

4. Discussion

The effect of scaling violations can be anticipated by examining the $Q^2$ dependence of the quark and gluon distributions, where one finds that both decrease with $Q^2$ for most of the $x$ range. If one neglects scaling violation effects, the calculated pion production cross section is much larger than the experimental data.

The expressions used in all our calculations, including that for the running coupling constant (2.6) have been derived within first order QCD perturbation theory. Buras [12] and Politzer [13] have pointed out that at this level the forms obtained are not unique, as they do not include:

(i) Higher order terms in the QCD expansion.
(ii) Higher twist terms [i.e. $O(m_Z/Q^2)$].

Unfortunately, both corrections have the same effective $Q^2$ dependence, and therefore it is difficult experimentally to distinguish between them [14].

Feynman et al. [5] have adopted a pragmatic approach and suggested that since one is unable to estimate the above effects, one may parametrize them using an expression dependent on the "primordial" transverse momentum of the constituents ($k_T$).

For our parametrization we have used the results obtained by Feynman et al. in their fit to high $p_T$ data and taken for $\langle k_T \rangle$, the value of $\sim 850$ MeV/c. Introducing a non-zero $\langle k_T \rangle$, increases the pion and