Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B 824 (2010) 154–167
NUCLEAR PHYSICS B
www.elsevier.com/locate/nuclphysb

# High-energy resummation in direct photon production

Giovanni Diana [a,b,*]

[a] *Dipartimento di Fisica, Università di Milano, via Celoria 16, I-20133 Milan, Italy*
[b] *INFN, sezione di Milano, via Celoria 16, I-20133 Milan, Italy*

Received 25 June 2009; accepted 1 September 2009
Available online 4 September 2009

**Abstract**

We present the computation of the direct photon production cross-section in perturbative QCD to all orders in the limit of high partonic center-of-mass energy. We show how the high-energy resummation can be performed consistently in the presence of a collinear singularity in the final state, we compare our results to the fixed order NLO cross-section in the $\overline{\text{MS}}$ scheme, and we provide predictions at NNLO and beyond.


## 1. Introduction

Perturbative QCD provides accurate theoretical predictions for hard processes at high-energy colliders. Logarithmic corrections to the lowest-order cross-sections can be systematically computed in the region of large hard scale $Q^2$, $\Lambda^2 \ll Q^2 \sim S$, by a renormalization group approach which leads to the factorization theorem of mass singularities [1]. However, the TeV energy range opens up the two scale region $\Lambda^2 \ll Q^2 \ll S$, where the usual perturbative expansion receives large contributions characterized by logarithms of the ratio $x = Q^2/S$. In order to recover the accuracy of the perturbative results, logarithmically enhanced small-$x$ contributions to the hard cross-sections, associated to multiple gluon emission, must be resummed to all orders.

Prompt photon production [2] is a relevant process for the study of hard interactions in high-energy collisions. For example, it is the most important reducible background for the $H \to \gamma\gamma$ signal in the light Higgs scenario [4]. A thorough understanding of this process in the small-$x$ limit is thus relevant to make predictions for the LHC.

* Address for correspondence: INFN, sezione di Milano, via Celoria 16, I-20133 Milan, Italy.
*E-mail address:* giovanni.diana@mi.infn.it.

0550-3213/$ – see front matter 
doi:10.1016/j.nuclphysb.2009.09.001

Currently the direct photon cross-section is known up to $\mathcal{O}(\alpha\alpha_s^2)$ [5] and Sudakov resummation effects have been computed up to NLL accuracy [6]. Prompt photon production is especially useful to probe the gluon parton density over a wide range of $x$ [7], since the initial state gluon appears already at leading order, and in particular the small-$x$ ($x \gtrsim 10^{-5}$) region. For this reason we expect that, in prompt photon production, high-energy resummation affects significantly the fixed-order results.

The general procedure for the small-$x$ leading-log (LL$x$) resummation of hard coefficient functions is well established in perturbative QCD within the framework of the $k_t$-factorization theorem [8,9], and involves the computation of the leading amplitude of the process with off-shell incoming gluons. This technique has been used to obtain resummed cross-sections for heavy quarks photo- and hadro-production [8,10–12], deep inelastic scattering [9,13], Higgs production [14–16] and recently for the Drell–Yan process [17]. Other applications of the $k_t$-factorization theorem can be found in Refs. [18,19] for the NLO corrections to the jet vertex and the DIS impact factor.

Prompt photon cross-section contains two different contributions: the direct component, where the photon participates at leading order to the hard process, and a fragmentation component, which is needed to take account of the hadronic component of the photon. From a phenomenological point of view, at high-energy both terms are important [20]; in this work we will consider the direct contribution, leaving the fragmentation component to a future work.

All the processes for which small-$x$ resummation has been performed so far are free of collinear singularities in the final state since the corresponding cross-sections are totally inclusive; on the contrary such a divergence does appear in direct photon production because the process is exclusive with respect to the final state photon, which from this point of view must be viewed as another hadronic state [21]. In this work we perform the high-energy resummation of the direct photon coefficient function consistently with the $\overline{\text{MS}}$ scheme of subtraction of the final state singularity to all orders in perturbation theory.

## 2. Prompt photon production

### 2.1. Collinear factorization

The prompt photon process is characterized by a hard event involving the production of a single photon. Let us consider the hadronic process

$$H_1(P_1) + H_2(P_2) \to \gamma(q) + X. \tag{1}$$

According to perturbative QCD, the direct and the fragmentation component of the inclusive cross-section at fixed transverse momentum $\mathbf{q}$ of the photon can be written as [6]

$$\mathbf{q}^3 \frac{d\sigma_\gamma(x_\perp, \mathbf{q}^2)}{d\mathbf{q}}$$
$$= \sum_{a,b} \int_{x_\perp}^{1} dx_1\, f_{a/H_1}\big(x_1, \mu_F^2\big) \int_{x_\perp/x_1}^{1} dx_2\, f_{b/H_2}\big(x_2, \mu_F^2\big)$$
$$\times \int_0^1 dx \bigg\{ \delta\bigg(x - \frac{x_\perp}{x_1 x_2}\bigg) \mathcal{C}_{ab}^{\gamma}\big(x, \alpha_s\big(\mu^2\big); \mathbf{q}^2, \mu_F^2, \mu_f^2\big)$$