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Soft-gluon resummation for single-particle inclusive hadroproduction at high transverse momentum

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Abstract

We consider the cross section for one-particle inclusive production at high transverse momentum in hadronic collisions. We present the all-order resummation formula that controls the logarithmically-enhanced perturbative QCD contributions to the partonic cross section in the threshold region, at fixed rapidity of the observed parton (hadron). The explicit resummation up to next-to-leading logarithmic accuracy is supplemented with the computation of the general structure of the near-threshold contributions to the next-to-leading order cross section. This next-to-leading order computation allows us to extract the one-loop hard-virtual amplitude that enters into the resummation formula. This is a necessary ingredient to explicitly extend the soft-gluon resummation beyond the next-to-leading logarithmic accuracy. These results equally apply to both spin-unpolarized and spin-polarized scattering processes.

1. Introduction

A well-known feature of QCD is that perturbative computations for hard-scattering processes are sensitive to soft-gluon effects. These effects manifest themselves when the considered observable is computed close to its corresponding boundary of the phase-space. In these kinematical regions, real radiation is strongly inhibited and the cancellation of infrared singular terms between virtual and real emission contributions is unbalanced. This leads to large logarithmic

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terms that can invalidate the (quantitative) reliability of the order-by-order perturbative expansion in powers of the QCD coupling α_S. These large logarithmic terms have to be evaluated at sufficiently-high perturbative orders and, whenever it is possible, they should be resummed to all orders in QCD perturbation theory.

In the context of hadron–hadron collisions, a class of soft-gluon sensitive observables is represented by inclusive hard-scattering cross sections in kinematical configurations that are close to (partonic) threshold. Typical examples are the cross sections for the production of Drell–Yan lepton pairs and Higgs bosons. In these cases, where only two QCD partons enter the hard-scattering subprocess at the Born-level, the soft-gluon resummation formalism was established long ago [1–3], and explicit resummed results have been obtained up to next-to-next-to-leading logarithmic (NNLL) accuracy [4–6], and including still higher-order logarithmic terms that have been explicitly computed [7,8]. The case of cross sections that are produced by Born-level hard-scattering of three and four (or more) coloured partons is very important from the phenomenological viewpoint, and it is much more complex on the theoretical side. Soft-gluon dynamics leads to non-trivial colour correlations and colour coherence effects that depend on the colour flow of the underlying partonic subprocess. The general soft-gluon resummation formalism for inclusive cross sections in these complex multiparton processes was developed in a series of papers [9–14]. In recent years, techniques and methods of Soft Collinear Effective Theory (SCET) have also been developed and applied to resummation for inclusive cross sections near (partonic) threshold [15–21].

Some examples of relevant processes with three or four partons at the Born-level are the direct production of prompt photons [12,13,22,23,21], vector boson [24,25] and Higgs boson [26] production at high transverse momentum, production of heavy quarks [9,10,12,27,20,28–30] and coloured supersymmetric particles (Ref. [31] and references therein) at hadron colliders, single top-quark production [32,33], jet [34–36] and dihadron [37,38] production, and single-hadron inclusive production in hadronic collisions [39]. Soft-gluon resummation for single-hadron inclusive production in collisions of spin-polarized hadrons has been considered in Ref. [40].

In this paper we consider the single-hadron inclusive cross section. At sufficiently-large values of the hadron transverse momentum, the cross section for this process factorizes into the convolution of the parton distribution functions of the colliding hadrons with the (short-distance) partonic cross section and with the fragmentation function of the triggered parton into the observed hadron. Since the single-inclusive cross section can be easily measured by experiments in hadron collisions, the process offers a relevant test of the QCD factorization picture. Conversely, measurements of the corresponding cross section as function of the transverse momentum and at different collision energies permit to extract quantitative information about the parton fragmentation (especially, the gluon fragmentation) function into the observed hadron, thus complementing the information obtained from hadron production in e^+e^- and lepton–hadron collisions.

The next-to-leading order (NLO) QCD calculation of the cross section for single-hadron inclusive production was completed long ago [41–43]. Soft-gluon resummation of the logarithmically-enhanced contributions to the partonic cross section was performed in Ref. [39]. The study of Ref. [39] considers resummation for the transverse-momentum dependence of the cross section integrated over the rapidity of the observed final-state hadron, and it explicitly resums the leading logarithmic (LL) and next-to-leading logarithmic (NLL) terms. The results of the phenomenological studies (which combine NLL resummation with the complete NLO calculation) in Ref. [39] indicate that the quantitative effect of resummation is rather large, especially in the kinematical configurations that are encountered in experiments at the typical energies of fixed-target collisions.