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Radiative energy loss of neighboring subjets

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Abstract

We compute the in-medium energy loss probability distribution of two neighboring subjets at leading order, in the large-N_c approximation. Our result exhibits a gradual onset of color decoherence of the system and accounts for two expected limiting cases. When the angular separation is smaller than the characteristic angle for medium-induced radiation, the two-pronged substructure lose energy coherently as a single color charge, namely that of the parent parton. At large angular separation the two subjets lose energy independently. Our result is a first step towards quantifying effects of energy loss as a result of the fluctuation of the multi-parton jet substructure and therefore goes beyond the standard approach to jet quenching based on single parton energy loss. We briefly discuss applications to jet observables in heavy-ion collisions.

Keywords: Perturbative QCD; Jet physics; Jet quenching

1. Introduction

First observed at RHIC [1,2], then at LHC [3–5], the large suppression of high-p_T particle spectra in nucleus–nucleus collisions, referred to as “jet quenching”, is commonly regarded as a signature of the formation of the quark–gluon plasma (QGP). This striking phenomenon is attributed to medium-induced radiative energy loss of high momentum partons as they propagate through a hot and spatially extended medium [6–8]. Measurements of fully reconstructed jets

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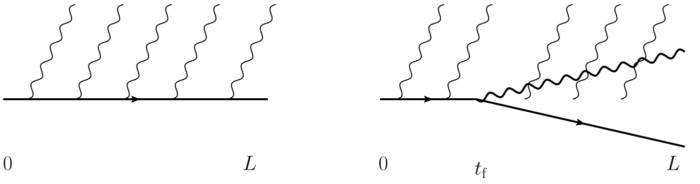

Fig. 1. Radiative energy loss for a single particle (left) and a two-pronged color object (right).

allowed the investigation of new jet quenching observables covering not only measurements of the suppression of inclusive jet spectra [9–12] and photon-jet correlations [13], but also including information about the redistribution of jet energy [14] within and outside the jet cone [15–17]. In consequence, jet observables, and jet substructure measurements in particular, have shed new light on the mechanism of jet-medium interactions and the details of energy loss while posing new challenges to the theoretical description of in-medium fragmentation at the same time.

In-medium jet quenching have so far been treated at the level of single parton energy loss whose radiation pattern is affected by multiple scattering. This dynamical process gives rise to the Landau–Pomeranchuk–Migdal (LPM) interference [18–24], that causes the suppression of the radiation spectrum at large frequencies. The dominant soft emissions take place at time-scales parametrically smaller than the medium size and can therefore be treated as quasi-instantaneous [25,26]. This permits a probabilistic treatment of multiple emissions [27]. For soft gluon emission, the resulting cascade is governed by turbulence [28] which efficiently transports energy to large angles [29–32].

The probability of emitting a total energy ϵ off the leading parton passing through a medium, $P_1(\epsilon)$, was first discussed in [33]. In the absence of any angular constraints, this probability distribution is governed by the energy scale $\omega_s \sim \alpha_s^2\, \hat{q}\, L^2$, in a medium of size L and characterized by the jet quenching parameter $\hat{q}$, which is a diffusion coefficient in transverse momentum space. It follows that the related fluctuations of energy loss are also of the same order [34,35]. The resultant single-parton spectrum is shifted towards decreasing energies as compared to the primordial one leading to an overall suppression (see also [36–38]). See also [39–42] for related work on medium-induced multi-gluon emissions.

Extending the calculations of radiative energy loss from single partons to jets proved to be a difficult problem. In point of fact, there is a large probability for nascent partons to branch due to the infrared and mass singularities of QCD splittings, and many jet properties, such as the effect of the cone size, jet substructure and jet mass, appear only on the level of at least one splitting. Moreover, it is difficult to argue that all splittings take place outside of the medium, typically extending over several fm's, which would justify a treatment where only the parent parton suffers energy loss. This implies that jets propagate through the medium as multi-parton quantum states whose energy loss pattern is expected to differ from that of independent partons. Moreover, it is well known that color coherence plays an important role and leads to angular ordering of subsequent emissions [43,44]. These probabilistic features arise due to the active role of interferences. The treatment of jet fragmentation vertices inside the medium remains therefore an open question. Nevertheless, several Monte-Carlo prescriptions that are based on heuristic arguments exist in the literature, see e.g. [45,46].

The purpose of this paper is to address this problem from first principles. The key point of our formalism is the resummation of multiple soft primary radiation off a color dipole with proper treatment of interferences. The processes under consideration are depicted in Fig. 1. In contrast to single-particle energy loss (left), having two participants (right) begs the question of how energy