PROCEEDINGS OF SCIENCE

Radiative energy loss in absorptive medium

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Understanding the energy loss of strongly interacting particles is of utmost importance for studying the quark-gluon plasma (QGP). This very hot and dense state of matter is created during heavy-ion collisions, like the ones performed at the LHC. As the lifetime of the QGP is very brief, special probes are necessary to study it. One of them consists in focusing on the energy loss of energetic quarks or gluons (so-called partons) created in the early stages of the collision. These partons go through the QGP and are sensitive to all its development. One can then compare the energy spectrum of this kind of particles after going through the QGP or after going through usual nuclei and learn features of the QGP by comparison. For this it is important to master theoretically the energy loss of these partons. A particle can loose energy either by collisional processes (diffusion in the medium) or by radiative mechanisms (bremsstrahlung). The emission of a gluon takes a certain amount of time called the formation time. In the medium, this time can be longer than the mean free path of the particle leading to the LPM effect and a modification of the emission spectrum. But what if during its formation the gluon emits other gluons in turn. One phenomenological way to deal with this effect is to associate a damping rate to the first emitted gluon, and then investigate the consequences on its parent parton energy loss. In this presentation, we use the formalism developed in [6] to study the in-medium radiation by energetic quarks or gluons. In this formalism the propagation of a parton and its elastic scatterings with the medium is driven by a two-point correlator of the gluon field in the medium. We examine the modification of the two-point correlator for collisions that are accompanied by bremsstrahlung gluons that are sufficiently soft so as to be formed before the next interaction, and study whether this leads to a damping scenario.

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1. Introduction

The study of the Quark Gluon Plasma (QGP) stands in a central position in the field of Heavy-Ion Physics. An important observable is the nuclear modification factor R_{AA}. This quantity is a normalized ratio for the yield of a given kind of particles between the case of a heavy-ion collision and the case of proton-proton collision. As one does not expect deconfinement in small systems, a difference from unity of such a factor gives indication about the formation of QGP. It appears that the high transverse momentum range analysis of R_{AA} depends on radiative energy loss of particles which produce the one observe in the detectors. So it is very important to have the best understanding of the interaction between such a particle and the medium (i.e. the QGP) possible and by extension the best theoretical evaluation of the radiative energy loss.

2. Radiative energy loss

The most important concept when it comes to radiative energy loss remains the formation time τ_f. Indeed the emission of a quantum by a particle is not an instantaneous process. For gluons in QCD, this time is roughly proportional to the energy ω of the emitted quantum itself: the more energetic the gluon is, the longer the emission process lasts, for a given transverse momentum k_T,

$$\tau_f \approx \frac{\omega}{k_T^2} \tag{2.1}$$

The other time (or length) to take into account is the mean free path λ. The distance between two successive scatterings is of the order of the inverse of g^2T.

Based on these two quantities, one can define two cases for the radiation process during multiple scattering in a medium.

The first one occurs when the mean free path is longer than the formation time ($\lambda \gg \tau_f$). In this situation each radiated quantum is well associated to a scattering centre. One just have the Gunion-Bertsch probability for an emission "attached" to each diffusion centre [1]. It is what one can called the iterate Gunion-Bertsch regime. In short, each successive scattering is independent and each emission is also independent.

In the second case, it is the formation time that is longer than the mean free path ($\lambda \ll \tau_f$). Now the radiation takes place in a region encompassing several scattering centres and could not be associated with a particular one. This gives rise to the Landau-Pomeranchuk-Migdal effect [2]. The latter has been studied in a non-Abelian situation in the 1990's by Baier, Dokshitzer, Mueller, Peigné and Schiff [3] and by Zakharov [4] independently (the so-called BDMPS-Z theory). The radiation is emitted coherently over the different scattering centres met by the emitting parton. As shown by the BDPMS-Z spectrum, this coherent emission induces a decrease in the spectrum emission and in the radiative energy loss.

3. Object of interest

We want to examine a possible additional effect on the radiative energy loss, still in the case of the propagation of a fast parton through dense matter. At some point, this parton may radiate a gluon with enough energy to be emitted according to the BDMPS-Z spectrum, call it the primary gluon. Now we recall that the nascent pair (fast parton and primary gluon) still interact in the medium during the formation time. So one could wonder what happen if during this formation time, the pair radiates again some less energetic gluons (secondary gluons) with a formation time contained in the one of the primary gluon.

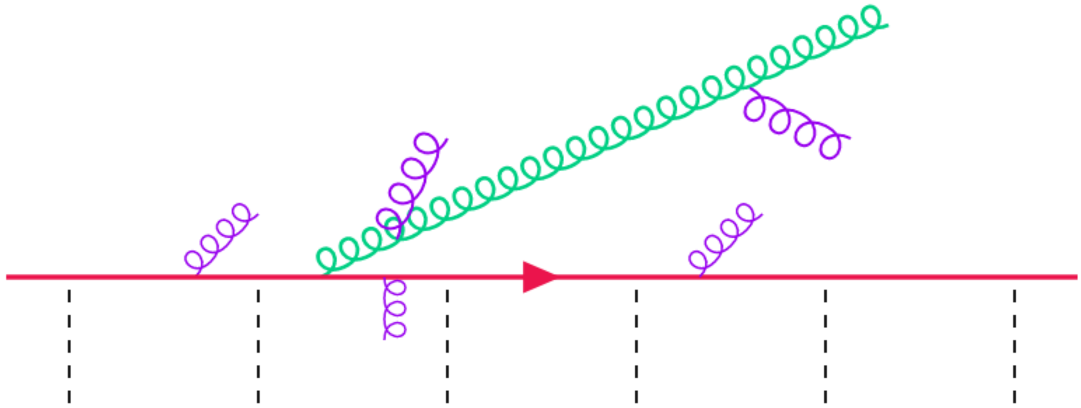

Figure 1: Typical process we want to consider : the red parton is the hard parton going through the medium, the green gluon is the primary gluon and purple gluons are the secondary gluons

Physically, we associate these microscopic processes to a macroscopic feature of the medium that is absorption. The fact that the primary gluon seems to disappear during its formation itself can be interpreted as an absorption effect and lead to a damping rate. A semi-classical study try to show that when one adds such a damping rate as an imaginary part of the refractive index, one can find a decrease in the energy loss [5].

4. The BDIM formalism

In a Feynman diagram approach these secondary gluon emissions give rise to an infinity of diagrams, so we propose to use an effective formalism which avoid the calculation of these diagrams.

For doing that we use a formalism developed by Blaizot, Dominguez, Iancu and Mehtar-Tani a few years ago [6]. In the latter work, they study the propagation of a fast parton through dense matter such as the QGP. They describe the medium as a random color field interacting with the hard parton by a correlation function or correlator. The latter is a function of a difference in space-time coordinates: the difference between the position of the interaction medium-parton in the amplitude and in the complex conjugate amplitude (Fig. 2). Basically, the further away these points are, the less interaction one can expect. This object is at the heart of their formalism. Thanks to it they are able to define an effective propagator and an effective vertex which take into account multiple scattering in the medium.

Besides they can express the broadening probability and the BDMPS-Z spectrum as functional of their correlator. Our proposal is to use these functional but with a modified correlator which will

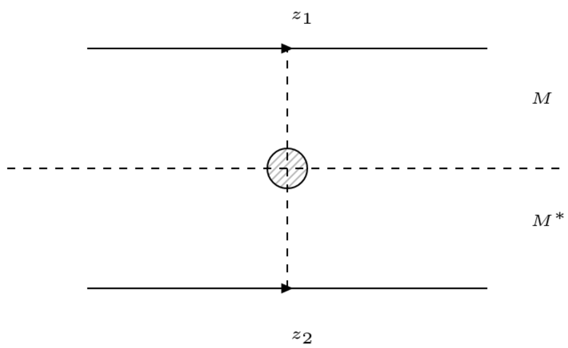

Figure 2: The correlator is a function of $\Delta z = z_1 - z_2$ and the blob represents the medium particles

take into account the possibility to radiate the secondary gluons. So we have to find the modification of the correlator by the addition of radiative effects.

5. Our version of broadening

Even if our main goal is to study radiative effects we need to familiarise ourselves with the elastic case. We do this by expressing the broadening probability in a way that could be easily extended later on. We remember that the broadening probability is the probability for a gluon to change of a given amount of transverse momentum during a given amount of time passing through the medium.

For calculating this quantity we begin with the diffusion probability for a hard parton to scatter over a medium particle. This probability is proportional to the Fourier transform of the same correlator as the one introduced in the BDIM formalism,

$$\frac{dW}{d^4 Z d^3 \tilde{P}'} = \rho_1(Z) g^2 \frac{\sqrt{s}}{2} \int d^4 \Delta z e^{i(P'-P)\cdot\Delta z} \gamma(\Delta z) \tag{5.1}$$

Equation (5.1) shows the link between the correlator and the elastic matrix element from the first principles. Let take the following lagrangian:

$$\mathscr{L} = g(\bar{\Psi}_1(x)\gamma^\mu \Psi_1(x) + \bar{\Psi}_2(x)\gamma^\mu \Psi_2(x))A_\mu(x) \tag{5.2}$$

where Ψ_1 corresponds to the hard parton and Ψ_2 to the medium particle. We can write

$$\gamma(\Delta z) = \frac{\rho_2(Z)}{2g^2(\sqrt{s})^3} \int d^4 P' d^3 \tilde{p}' e^{i(P'-P)\cdot\Delta z} \delta^{(4)}(P' + p' - P - p)|\mathscr{M}|^2 \tag{5.3}$$

In order to get the broadening probability we have to sum the probabilities over one, two, three and so on, scattering centres. For doing this an important assumption is to consider the successive scatterings centres as independent. In other words the mean free path λ should be much longer than the range of the interaction given by μ^{-1}. When it is the case, the sum exponentiates which gives back the expression of the BDIM formalism.

$$W(\Delta\vec{P}_T, \Delta t) = \int d^2 \Delta\vec{z}_T e^{-i\Delta\vec{P}_T\cdot\Delta\vec{z}_T} exp[-g^2 N_c \Delta t(\gamma(\vec{0}) - \gamma(\Delta\vec{z}_T))] \tag{5.4}$$

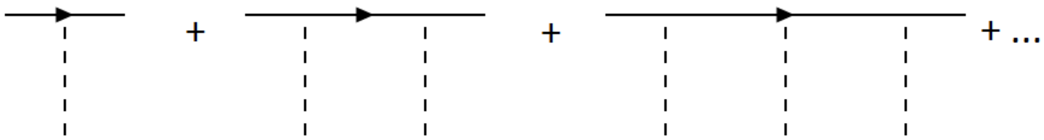

Figure 3: Resummation for multiple scattering

6. Include radiative process

So now we want to construct a new correlator to take into account the secondary gluons. The idea is to see if these gluons can destroy the coherence of the emission and have an effect on the energy loss.

The implementation relies on the fact that we only consider gluons with a small formation time. We expect that these gluons will act as a small perturbation to the multiple scattering situation and that the instantaneous character of the interaction remains. The same construction as previously, putting just the Gunion-Bertsch matrix element instead of the elastic one in (5.3) gives

$$\gamma_{rad}(\Delta z) = \frac{\rho_2(Z)}{2g^2(\sqrt{s})^3}\int d^4P' d^3\tilde{p}' e^{i(P'-P)\cdot\Delta z}\delta^{(4)}(P'+p'-P-p)|\mathscr{M}|^2_{GB} \tag{6.1}$$

In order to get the new BDMPS-Z spectrum, we have to take into account the superposition of both correlators.

7. Conclusion and Outlooks

An attempt to include radiative effects in the propagation of a fast parton through dense matter has been done by using a formalism developed by Blaizot, Dominguez, Iancu and Mehtar-Tani. In this formalism, only collisional interactions with the medium were studied. We made an ansatz for the correlator incorporating low-energy radiative processes.

We now have to determine the emission spectrum coming from this new correlator thanks to the BDIM formalism, and possibly to associate a damping rate to the primary gluon. Indeed as soon as it is created this quantum begins to disappear in a certain way. So it could be viewed as a damping process. Finally, we probably have to investigate the contribution of more energetic secondary gluons as well. Preliminary results indicate that Gunion-Bertsch-like gluons do not change significantly the physics from that of the elastic case so we do not expect a sizable modification for the energy loss with just them. Maybe BDPMS-Z-like gluons could make more noticeable modification in the spectrum.

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