Multiple Scattering with/versus fully coherent scattering in pA and AA collision

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Abstract. A new energy loss mechanism model is presented. Multiple scattering in the medium is modified by the interaction of the propagating particle with a classical non-abelian background field. It is shown that the obtained gluon radiation spectrum has a symmetric structure in x (the outgoing radiation energy over incident parton energy) and $(1-x)$ A more general result for processes where the incoming quark is "mutated" into an outgoing gluon, or a gluon into a gluon process.

1. Introduction

The medium produced in heavy ion (AA) collision or in pA collision is hard to probe directly. A fast parton produced inside or outside (but passing through) the medium can witness and probe the secrets of the medium and curry it to the outside world (our detectors) in a jet form. Energy loss is among the main processes that the parton will suffer while passing through the medium. This loss will modify the "thumb print" of the observed final jet. Energy loss of a fast parton is currently considered as one of the messengers of the medium. To decode the message sent by the medium we have to model all the loss mechanisms and determine the dependence of energy loss on the size of the medium (length L) or on the energy (E) of the propagating parton.

2. Energy loss mechanisms

A simplified model of the medium is a finite sized medium with scattering centers. The main energy loss mechanisms will be collisional energy loss and radiation energy loss. If one follows the history of the formed medium it is possible to have a remnant background field. It is believed that during and after relativistic heavy ion collisions strong chromomagnetic field will form that can be treated as a classical background. Numerical solutions [1, 2] indicate that "just" after collision transverse color electric and color magnetic fields change suddenly from being transverse in the initial state, in the so-called Color-Glass-Condensate state, to being longitudinal. The latter are called glasma flux tubes. Transverse fields then rise, and at some stage after the collision the transverse and longitudinal components of color electric and color magnetic fields reach a "steady" comparable values. For gluon radiation with long formation length it is possible that the strong field deviates the particle while multiple scattering from random scattering centers are "felt" by the coherent parton-gluon system. This is motivated by a recent work of Peigné *et al* [3]. The authors in [3] considered a scenario where the incoming high energy (E) parton undergoing a hard, small angle, scattering in the medium (a non-abelian possibility) with soft re-scattering has a medium-induced radiative energy loss proportional to E. In our formalism the small angle (hard scattering) is replaced by the effect of the passage through a region where a strong background field is present. Our method is applied to the cases:

- Zero background field,
- an impulse field, a field that is nonzero in a very small region to mimic the single hard scattering in [3],
- a constant field.

In the paper we will focus on the impulse field case.

3. Hard scattering, the linear energy dependence

Considering the propagation of a fast parton in a medium. The parton can radiate a gluon with energy fraction x. If the formation time of the radiated gluon is large compared to the size of the medium, a fully coherent scattering event will occur where hard small angle scattering is possible besides soft multiple scatterings as shown in Figure 1. In the region where $x \equiv k^+/p^+ \ll 1$

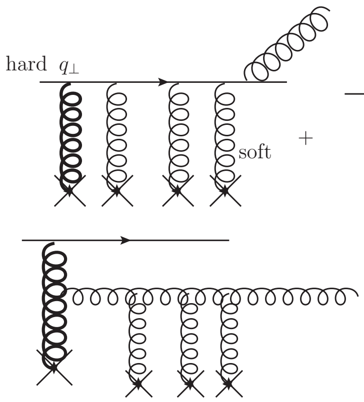

Figure 1. Hard scattering and multiple soft scattering, three possible diagrams.

one recovers the Gunion-Bertsch spectrum. The final spectrum was found [3] to have the linear energy dependence

$$\Delta E \sim (\cdots)E$$

This shows that the energy loss in a finite sized medium is not bounded at high energy. The induced spectrum arises from the interference between diagrams (in a time/path ordered approximation) where the radiated gluon is emitted in the initial state (before the medium) and that from the final state (after the medium).

4. Energy loss: synchrotron plus collision

The proposed mechanism is the deviation of the parton by the background field while suffering multiple soft scattering. By "tuning" the strength and the space-time dependence of the field it is possible to mimic the hard scattering presented in the last section.

Using the light cone formalism proposed by Zakharov [4] it is possible to write the gluon emission probability as

$$\frac{dP}{dx} = \int_0^L dz n(z) \frac{d\sigma_{eff}(x,z)}{dx} \tag{1}$$

where $n(z)$ is the density of the scattering centers in the medium and the effective cross section, with transverse variable $\boldsymbol{\rho}$, is approximated in the light cone approximation by

$$\frac{d\sigma_{eff}}{dx} = \mathrm{Re} \int d\boldsymbol{\rho} \psi_m^*(\boldsymbol{\rho}, x) \sigma_3(\boldsymbol{\rho}, x) \psi_f(\boldsymbol{\rho}, x, z) \tag{2}$$

σ_3 is the cross section of interaction of the fictive $qg\bar{q}$ system, the analogue of the three diagrams in the Gunion-Bertsch approximation (Figure 1), ψ_f is the light-cone wave function in the background field, ψ_m is the light-cone medium modified wave function, given by

$$\psi_f(\boldsymbol{\rho}, x) = P(x) \left(\frac{\partial}{\partial \rho'_x} - i\lambda_g \frac{\partial}{\partial \rho'_y} \right) \int_0^\infty d\xi \mathcal{K}_f(\boldsymbol{\rho}, z | \boldsymbol{\rho}', z - \xi) \Bigg|_{\rho'=0} \tag{3}$$

$$\begin{aligned} \psi_m^*(\boldsymbol{\rho}, x, z) &= -P(x) \left(\frac{\partial}{\partial \rho'_x} - i\lambda_g \frac{\partial}{\partial \rho'_y} \right) \\ & \quad \int_0^\infty d\xi \mathcal{K}_m(\boldsymbol{\rho}, z + \xi | \boldsymbol{\rho}', z) \Bigg|_{\rho'=0} \end{aligned} \tag{4}$$

where $P(x) = i\sqrt{\alpha_s/2x}[2\lambda_q x + \lambda_g(2 - x)]/2\mu(x)$, with the effective mass $\mu(x) = Ex(1 - x)$. The light-cone propagators K_f and K_m are obtained by solving the problem of a fast parton in a background field and in medium respectively. Hence the emission probability is the interference between medium modified and background modified wave functions.

To mimic the hard scattering we consider a background field of the form

$$H = H_o \delta(z - z_s)$$

which allow us to model the hard scattering event. The propagator K_f is evaluated exactly while the propagator K_m is approximated by the $N = 1$ term. The approximated spectrum is then written as

$$x\frac{dP}{dx} = (2C_R - N_c)\frac{\alpha_s}{\pi}\frac{L}{\lambda_g} \log\left(1 + \frac{\mu_s^2}{(\mathbf{q}'_\perp)^2 (q'x - (1-x)Q)^2}\right) \tag{5}$$

where q' and Q are the color charge of the outgoing quark and gluon respectively. The obtained result should be compared with

$$x\frac{dP}{dx} = (2C_R - N_c)\frac{\alpha_s}{\pi}\frac{L}{\lambda_g} \log\left(1 + \frac{\mu_s^2}{(\mathbf{q}_\perp)^2 x^2}\right) \tag{6}$$

in the small x limit [3] . The new mechanism could be seen as a model for small x or small $(1 - x)$ regimes in the long formation time limit. It should be noted that the obtained form is more likely to be expected in a process where the incident parton is a gluon. The radiated gluon and the outgoing gluon are expected to be symmetric in energy repartition, an x, $(1 - x)$ symmetry in the radiation spectrum.

However if one integrates over x the two models give

$$\Delta E \equiv E \int dx x \frac{dP}{dx} \approx (2C_R - N_c)\alpha_s \frac{L}{\lambda_g}\frac{2\mu}{qq'_\perp} E \tag{7}$$

a linear dependence is thus obtained in the background field.

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