IOP Conf. Series: Journal of Physics: Conf. Series **805** (2017) 012006 doi:10.1088/1742-6596/805/1/012006

Multiple Scattering with fully coherent scattering in pA and AA collisions

Haitham Zaraket

Laboratoire de Physique et d'électronique, Lebanese University, Faculty of Sciences (I), Hadath, Beirut Lebanon

E-mail: hzaraket@ul.edu.lb

Abstract. A new energy loss mechanism model is presented. Medium multiple scattering is modified by the interaction 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 $(1-x)$ and the appropriate sign.

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 carry 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 will modify (quench) the the jet.

Energy loss of a fast parton is currently considered as one of the key characteristics 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) and on the energy (E) of the propagating /parton.

2. Energy loss mechanisms

A simplified model of the propagating medium is a finite sized medium with scattering centers. The main energy loss mechanisms are then collisional and radiation energy losses. However, 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 and it 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 longitudinal. The latter is 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 "steady" comparable values. For gluon radiation with long formation length it is possible that trajectory of the particle is deviated by not only by multiple scattering but also by the the strong magnetic field. In a recent work of Peigné *et al* [3], the authors 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. It was found that the medium-induced radiative energy loss is proportional to E. The main contribution to medium-induced radiation spectrum arises from the interference between initial and final state radiation. In our model the small angle (hard scattering) is replaced by the effect of the passage through a region where a strong background field is present. The method can be applied easily to:

- Zero background field,
- an impulse field, a field that is nonzero in a very small region to mimic the single hard scattering in [3],
- and 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 of momentum p, the parton can radiate a gluon of momentum k 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 multiple soft scatterings as shown in Figure 1. In the region where $x \equiv k^+/p^+ \ll 1$ one recovers the Gunion-Bertsch spectrum [4]. The final

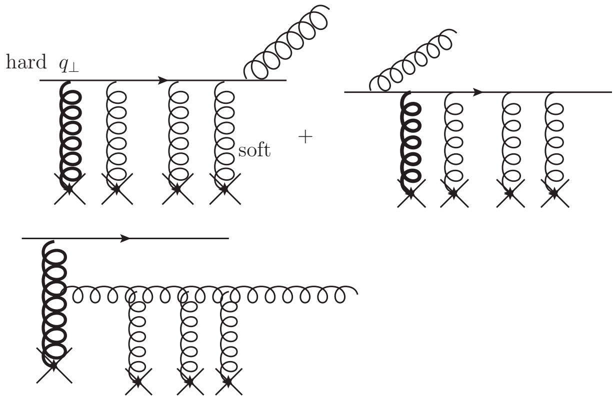

Figure 1. Hard scattering and multiple soft scatterings, three possible diagrams.

spectrum was found [3] to have the linear energy dependence

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

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

4. Energy loss: synchrotron plus collision

The new proposed mechanism is a modification of the parton "trajectory" by the background field while suffering multiple soft scatterings. 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 [5] it is possible to write the gluon emission probability as

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

IOP Conf. Series: Journal of Physics: Conf. Series **805** (2017) 012006 doi:10.1088/1742-6596/805/1/012006

where $n(z)$ is the density of the scattering centers in the medium. 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 $qg\bar{q}$ 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

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

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

where $P(x) = i\sqrt{\alpha_s/2x}[2\lambda_q x + \lambda_g(2 - x)]/2\mu(x)$. 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 allows 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

$$\begin{aligned} x\frac{dP}{dx} &= C_F[1 + (1 - x)^2 - \frac{x^2}{N_c^2}][1 - x + \frac{x^2}{2}]\frac{\alpha_s}{\pi} \\ &\times \frac{L}{\lambda_g} \log \left(1 + \frac{\mu_s^2}{(\mathbf{q}'_\perp)^2(q'x - (1 - x)Q)^2} \right) \end{aligned} \tag{5}$$

where q' and Q are the color charge of the outgoing quark and gluon respectively and the gluon mean free path λ_g is defined as

$$\frac{1}{\lambda_g} = \frac{\alpha_s^2 \pi C_A C_T n}{2\mu_s^2} \ .$$

The present form, which is symmetric in "x", $1 - x$, is expected in a process where the incident parton is a gluon. For a propagating gluon, the radiated gluon and the outgoing gluon are expected to be symmetric in energy repartition.

Eq. (5) should be compared with

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

obtained in [3] for small x. The main concern with eq. (6) is that the color factor $(2C_R - N_c)$ is $-1/N_c$ for a propagating quark, this negative result was interpreted as a phase space artifact. Our result is perfectly positive and hence no potential energy gain mechanism was found. To understand the contracting results it is important to outline the main differences between the two proposed energy "loss" mechanisms:

IOP Conf. Series: Journal of Physics: Conf. Series **805** (2017) 012006 doi:10.1088/1742-6596/805/1/012006

- In this article induced gluon radiation was defined as the radiation spectrum of a parton in a medium plus background minus the radiation of the parton in background field. While in [3] the induced gluon radiation spectrum was defined as that of a parton in a medium minus the vacuum contribution.
- A full x treatment was done in the present article, while small x approximation is done in [3]. However if one considers the small x limit of eq. (5) the result is still positive.

Finally we integrate over x , to get the total energy loss in the two models to obtain

$$\Delta E \equiv E \int dx x \frac{dP}{dx} \approx \mathcal{C} \alpha_s \frac{L}{\lambda_g} \frac{2\mu}{q q'_\perp} E \ . \tag{7}$$

In the background approach the color factor $\mathcal{C}$ contains detailed information about the color charge of the incident quark, final quark and the radiated gluon, while in the hard scattering approach [3] $\mathcal{C}$ is $2C_R - N_c$. Hence in both case energy loss is linear in E.

5. Conclusion

We have proposed a model for the propagation of an asymptotic parton in a medium where besides scattering a remanent non-abelian background field is also present. In the impulse field approximation the effect of the background can be related to the proposed model by Peigné *et al* where multiple soft scatterings are coupled to hard scattering. The two results were found to have opposite signs, which both agree on the final E dependence.

Acknowledgments

The work of H.Z. was supported by the French CNRS through the PICS project ”Parton production and propagation in hot QCD matter” and partially by the Lebanese university. He would also like to thank his colleagues at the LPSC for their hospitality. He also thanks Stephane Peigné for useful discussion.

References

[1] Fries R J, Kapusta J I and Li Yang 2006 From color fields to Quark Gluon Plasma, *Nucl. Phys.* **A 774**, 861
[2] Lappi T, and McLerran L 2006 Some features of the glasma *Nucl. Phys.* **A 772**, 200
[3] Peigné S, Arleo F and Kolevatova R 2014 Medium-induced gluon radiation: an update *Preprint* hep-ph/1402.1671v1
[4] J.F. Gunion and G. Bertsch 1982 Phys. Rev. **D25**, 746
[5] Zakharov B.G. 1997 Radiative energy loss of high-energy quarks in finite-size nuclear matter and quark-gluon plasma, *JETP Lett.* **65**, 615.