Medium-induced jet evolution for an expanding QGP

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Introduction

A comprehensive understanding of the signatures of the intermediate states of strongly expanding medium formed in heavy ion collisions like in RHIC and LHC have been sought for quite a long time now. An interplay of the soft and hard processes inside medium at the partonic level can significantly modify observables at the hadronic regime. The hard partons undergo radiative energy loss in presence of medium before hadronisation. These modifications to the gluon spectrum can be collectively used to study the phenomena of jet quenching in heavy ion collisions [1–3]. In this work, we aim at computing the distribution of medium-induced gluons in an expanding medium. This ultimately leads to the energy loss of energetic quarks and gluons propagating in the medium based on Baier-Dokshitzer-Mueller-Peigne-Schiff-Zakharov (BDMPSZ) formalism [4]. We assume that the fast quark is produced by hard processes outside the medium. In this work, we highlight the steps for the formulation of the medium induced splitting functions through the kinematic rate equations leading to the study of quenching of jets in an expanding medium.

Formalism

In the multiple soft scattering process, the one gluon radiation spectrum is given by [1, 2],

$$\omega\frac{dI}{d\omega} = \frac{\alpha_s\, C_R}{(2\pi)^2\,\omega^2}\, 2\mathrm{Re}\int_{\xi_0}^{\infty} dy_l \int_{y_l}^{\infty} d\bar{y}_l \times \int d\mathbf{u} \int_0^{\chi\omega} d\mathbf{k}_\perp\, e^{-i\mathbf{k}_\perp\cdot\mathbf{u}}\, e^{-\frac{1}{2}\int_{\bar{y}_l}^{\infty} d\xi\, n(\xi)\sigma(\mathbf{u})} \times\frac{\partial}{\partial\mathbf{y}}\cdot\frac{\partial}{\partial\mathbf{u}}\,\mathcal{K}(\mathbf{r}_1, y_1; \mathbf{r}_2, y_2|\omega) \quad (1)$$

which is valid at small transverse distances $r = |r|$ and under the dipole approximation $\sigma(\mathbf{r}) = C\mathbf{r^2}$. Now, the path integral in the dipole approximation for an expanding medium can be written as [1, 5],

$$\mathcal{K}(\mathbf{r}_1, y_1; \mathbf{r}_2, y_2|\omega) = \int_{\mathbf{y}=0}^{\mathbf{u}} \mathcal{D}\mathbf{r}\exp\left[i\frac{\omega}{2}\int_{y_1}^{y_2} d\xi\left(\dot{\mathbf{r}}^2 - \frac{\Omega_\alpha^2(\xi_0)}{\xi^\alpha}\,\mathbf{r}^2\right)\right] \quad (2)$$

which is identical to the path integral of a 2-dimensional harmonic oscillator with time-dependent imaginary frequency. The time dependence of the transport co-efficient $\hat{q}(\xi)$ can be expressed by the following power law [1],

$$\frac{\Omega_\alpha^2(\xi_0)}{\xi^\alpha} = \frac{\hat{q}(\xi)}{i\,2\,\omega} = -i\frac{\hat{q}_0}{2\omega}\left(\frac{\xi_0}{\xi}\right)^\alpha . \quad (3)$$

Here, $\alpha = 0$ characterizes the static medium and $\alpha = 1$ is attributed for a one-dimensional boost invariant longitudinal expanding partonic medium. The solution of (2) can be expressed as [1, 2],

$$\mathcal{K}(\mathbf{r}_1, y_1; \mathbf{r}_2, y_2|\omega) = \frac{i\,\omega}{2\pi D(y_1, y_2)} \times\exp\left[-\frac{-i\omega}{2\,D(y_1, y_2)}\left(c_1\mathbf{r}_1^2 + c_2\mathbf{r}2^2 - 2\mathbf{r}_1\cdot\mathbf{r}_2\right)\right] \quad (4)$$

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It can be shown that [1],

$$D(\xi,\xi') = \frac{2\nu}{(2\nu\Omega_\alpha(\xi_0))^{2\nu}}(zz')^\nu \times [I_\nu(z)K_\nu(z') - K_\nu(z)I_\nu(z')] \,, \tag{5}$$

$$c_1 = z\left(\frac{z'}{z}\right)^\nu [I_{\nu-1}(z)K_\nu(z') + K_{\nu-1}(z)I_\nu(z')] \tag{6}$$

$$c_2 = z'\left(\frac{z}{z'}\right)^\nu [K_\nu(z)I_{\nu-1}(z') + I_\nu(z)K_{\nu-1}(z')] \tag{7}$$

where, $\nu = (2-\alpha)^{-1}$, $z \equiv z(\xi) = 2\nu\Omega_\alpha(\xi_0)\xi^{(1/2\nu)}$ and corresponding $z' \equiv z(\xi')$. In the realistic scenario of the expanding medium, the Modified Bessel's function (for $\nu \neq 0, 1/2$) can be approximated as,

$$I_\nu(z) \sim \frac{e^z}{\sqrt{2\pi z}}\Big(1 - \frac{4\nu^2-1}{8z}\Big)$$
$$K_\nu(z) \sim \sqrt{\frac{\pi}{2z}}e^{-z}\Big(1 + \frac{4\nu^2-1}{8z}\Big) \tag{8}$$

Thus, we can obtain for the case $\nu = 1$ or $\alpha = 1$, *i.e.* expanding medium, analytical expressions for $D(\xi,\xi'), c_1$ and c_2 [7]. We can write the total radiation spectrum in an elementary collision as [2],

$$\frac{dI^{(\mathrm{tot})}}{d\omega} = \frac{dI^{(\mathrm{med})}}{d\omega} + \frac{dI^{(\mathrm{vac})}}{d\omega} \,. \tag{9}$$

Here, the vacuum contribution to the gluon energy spectrum is proportional to $(1/k_\perp^2)$ and can be associated with the hard radiation off a nascent quark jet propagating in vacuum. The explicit expressions of the medium dependent contributions for $\alpha \neq 0$ have been given in Ref.([1]). In the case $\alpha = 0, \nu = (1/2)$, we recover the known form of the BDMPSZ gluon distribution function in the limit $R \to \infty$ [1, 3, 4],

$$\lim_{R\to\infty} \omega\frac{dI}{d\omega}^{(med)} = \frac{2\alpha_s C_R}{\pi}\ln\left|\cos\left[(1+i)\sqrt{\frac{\omega_c}{2\omega}}\right]\right| \,. \tag{10}$$

Finally, we will use the kinematic rate equation to quantify energy loss distribution of the jet $\mathcal{D}^{(med)} = xdN/dx$ [3],

$$\frac{\partial\mathcal{D}^{(med)}(x,\tau)}{\partial\tau} = \int dz\kappa(z) \times\Big[\sqrt{\frac{z}{x}}\mathcal{D}^{(med)}(\frac{x}{z},\tau) - \frac{z}{\sqrt{x}}\mathcal{D}^{(med)}(x,\tau)\Big] \tag{11}$$

where $\kappa = dI/dxdt$ is the splitting function, N is number of gluons and τ is related to the light cone time t as $\tau = (\alpha_s N_c t/\pi L)\sqrt{2\omega_c/E}$ [6]. We will incorporate the analogue of single gluon emission spectrum (Eq.(10)) for expanding medium to find a full expression of medium induced resummed multi-gluon emissions using the kinematic rate Eq.(11). Thereby, we can derive the medium modified splitting rate κ for an evolving medium. The complete calculation will soon be reported in an upcoming work [7].

Summary and discussions

We will analyse the modification to the gluon distribution function for an expanding medium for Eq.(10). In addition, we will incorporate this modified gluon distribution function to study the kinematic rate equation to arrive at analytical expressions of the modified splitting function [3, 6]. The corresponding numerical estimations for the gluon distribution functions in medium can be greater or lesser than the vacuum counterpart; according to which it can be inferred that the jet will be quenched or enhanced in evolving medium.

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References

[1] C.A.Salgado and U.A.Wiedemann, Phys. Rev. D **68** (2003) 014008.
[2] U.A.Wiedemann, Nucl. Phys. B **588** (2000) 303; Nucl. Phys. A **690** (2001) 731.
[3] Y. Mehtar-Tani and K. Tywoniuk, Phys. Lett. B **744** (2015) 284.
[4] R. Baier *et. al.* Nucl. Phys. B **484** (1997) 265.
[5] R. Baier *et. al.* Phys. Rev. C **58** (1998) 1706.
[6] J.-P. Blaizot, E. Iancu, and Y. Mehtar-Tani, Phys.Rev.Lett.111 (2013) 052001
[7] S. P. Adhya, C. A. Salgado and K. Tywoniuk (*in preparation*)