Radiation Spectrum of a Massive Quark-Gluon Antenna in a QCD Medium

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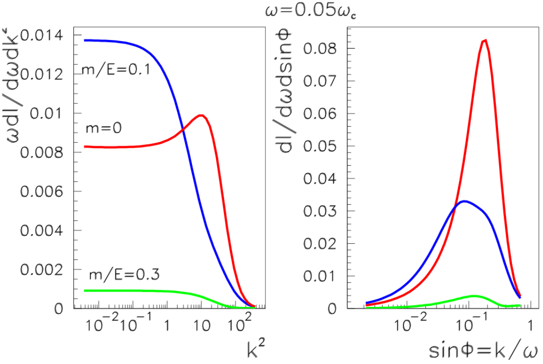
Outline

Motivation

- A state of deconfined coloured particles (QGP) is formed in heavy ion collisions.
- One of the most striking effects of QGP is the energy loss of high energy partons in heavy ion collisions.
- Is the energy loss of heavy quarks the same as for massless quarks?

Massive BDMPS

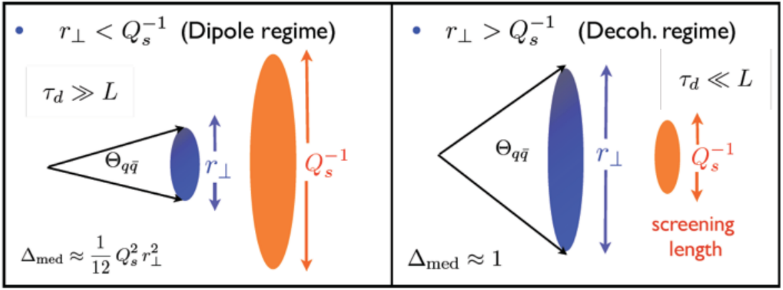
- Single particle spectrum (BDMPS).
- Smaller energy loss in the massive case (dead cone).



(Armesto, Salgado, Wiedemann)

Interferences in the massless case

- Interferences are also important.
- What is the role of the parton mass in the picture below?



(Mehtar-Tani, Tywoniuk, Salgado, Casalderrey, Iancu)

- BDMPS spectrum and interference spectrum calculated by solving CYM equations

$$[D_\mu, F^{\mu\nu}] = J^\nu$$

$$[D_\mu, J^\mu] = 0$$

- The classical currents J^μ represent the high energy partons

$$J^{\mu,a}_{(0)}(x) = g\frac{p^\mu}{E}\delta\left(\vec{x} - \frac{\vec{p}}{E}t\right)\theta(t)Q^a$$

- The classical current gets color rotated because of interactions with the medium.

$$J^\mu(x) = U_p(x^+,0)J^\mu_{(0)}$$

$$U_p(x^+,0) \equiv \mathcal{P}\exp\left\{\int_0^{x^+} \mathrm{d}\xi\, T\cdot A^-_{\mathrm{med}}(\xi,\xi\mathbf{p}_\perp/p^+)\right\}$$

- The propagation in the medium of the emitted gluon is expressed by a Green's function.

$$\mathcal{G}(x^+,\mathbf{x};y^+,\mathbf{y}|k^+) = \int_{\mathbf{r}(y^+)=\mathbf{y}}^{\mathbf{r}(x^+)=\mathbf{x}} \mathcal{D}\mathbf{r}\exp\left\{\frac{ik^+}{2}\int_{y^+}^{x^+}\mathrm{d}\xi\,\dot{\mathbf{r}}^2(\xi)\right\} U(x^+,y^+;\mathbf{r})$$

Applying the usual formulation to compute amplitudes, we get for the massive quark-gluon antenna:

$$\mathcal{M}_\lambda(\vec{k}) = \frac{g}{k^+} \int_{x^+=+\infty} \mathrm{d}^2\mathbf{x}\, e^{ik^-x^+} e^{-i\mathbf{k}\cdot\mathbf{x}} \int_0^{+\infty} \mathrm{d}y^+\, e^{ik^+\frac{p^-}{p^+}y^+}$$

$$\times \epsilon_\lambda(k)\cdot(i\boldsymbol{\partial}_y + k^+\mathbf{n})\,\mathcal{G}(x^+,\mathbf{x};y^+,\mathbf{y}|k^+)\Big|_{\mathbf{y}=\mathbf{n}y^+} U_p(y^+,0)Q$$

The difference between the massive and massless cases comes from the dispersion relation:

$$2p^+p^- - \mathbf{p}^2 = M^2$$

This leads to the appearence of a new phase:

$$\exp\left(ik^+\frac{p^-}{p^+}y^+\right) = \exp\left(i\frac{k^+}{2}\theta_{DC}^2 y^+\right)\exp\left(i\frac{k^+}{2}\mathbf{n}^2 y^+\right)$$

where

$$\boxed{\theta_{DC} \equiv \frac{M}{p^+}}$$

The radiation spectrum can be written now as

$$dN = \frac{\alpha_s}{(2\pi)^2}\left[C_F\mathcal{R}_q + C_A\mathcal{R}_g - \frac{C_A}{2}\mathcal{J}\right]\frac{d^3k}{(k^+)^3}$$

where we have defined:

$$C_F\mathcal{R}_q = (k^+)^2\langle|\mathcal{M}_q|^2\rangle$$

$$C_A\mathcal{R}_g = (k^+)^2\langle|\mathcal{M}_g|^2\rangle$$

$$\frac{-C_A}{2}\mathcal{J} = (k^+)^2\,\mathrm{Re}\langle\mathcal{M}_q\mathcal{M}_g^\dagger\rangle$$

BDMPS of massive quarks.

Recovery of the BDMPS spectrum for heavy quarks.

$$\mathcal{R}_q = 2\mathrm{Re} \int_0^\infty \mathrm{d}y'^+ \int_0^{y'^+} \mathrm{d}y^+ \exp\left[i\frac{k^+}{2}\theta_{DC}^2(y^+ - y'^+)\right] \times$$
$$\times \int \mathrm{d}^2\mathbf{z} \exp\left[-i\mathbf{k}\cdot\mathbf{z} - \frac{1}{2}\int_{y'^+}^\infty \mathrm{d}\xi\, n(\xi)\sigma(\mathbf{z})\right] \boldsymbol{\partial}_y \cdot \boldsymbol{\partial}_z \mathcal{K}(y'^+, \mathbf{z}; y^+, \mathbf{y})\big|_{\mathbf{y}=\mathbf{0}}$$

(Armesto, Salgado, Wiedemann)

Interference spectrum

The main result (interference for heavy quark-gluon antenna):

$$\mathcal{J} = \mathrm{Re}\left\{ \int_0^\infty \mathrm{d}y'^+ \int_0^{y'^+} \mathrm{d}y^+ \; (1 - \Delta_{\mathrm{med}}(y^+, 0)) \; e^{i\frac{k^+}{2}y^+(\theta_{DC}^2 + \delta\mathbf{n}^2)} \right.$$
$$\times \int \mathrm{d}^2\mathbf{z} \exp\left[-i\bar{\boldsymbol{\kappa}} \cdot \mathbf{z} - \frac{1}{2}\int_{y'^+}^\infty \mathrm{d}\xi \, n(\xi)\sigma(\mathbf{z}) \right]$$
$$\left. \times \left(\boldsymbol{\partial}_y - ik^+\delta\mathbf{n} \right) \cdot \boldsymbol{\partial}_z \, \mathcal{K}(y'^+, \mathbf{z}; y^+, \mathbf{y})\Big|_{\mathbf{y}=\delta\mathbf{n}y^+} \right\} + \mathrm{sym.}$$

Discussion

- $\exp\left(i\frac{k^+}{2}\theta_{DC}^2 y^+\right)$ is a quickly oscillating exponencial if the mass is big enough:

$$\theta_{DC}^2 \gg \frac{2}{k^+ L}$$

- The effect of the mass will suppress the interferences, thus losing coherence more easily than in the massless antenna.
- The loss of coherence implies a larger energy loss.
- Phenomenological relevance to be investigated.

Summary

- Energy loss of heavy quarks one of the remaining puzzles.
- Dead cone makes the energy loss smaller.
- Role of interferences in in-medium jets investigated in the last years.
- Here we compute the interferences for a heavy quark-gluon antenna.
- Coherence more easily lost for heavy quarks implies enhanced energy loss.