Glue emission from heavy quarks in dense nuclear matter

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Abstract: We study the medium-induced glue emission process experienced by a heavy jet parton propagating through the dense nuclear medium in the framework of deep inelastic scattering off a large nucleus. We work beyond the collinear rescattering expansion and the soft-gluon emission limit, and derive a closed formula for the medium-induced single glue emission spectrum from a heavy or light quark jet interacting with the dense nuclear medium via transverse and longitudinal scatterings. Without performing the collinear rescattering expansion, the medium-induced glue emission spectrum is controlled by the full distribution of the differential elastic scattering rates between the propagating quarks and the medium constituents. We further show that if one utilizes heavy flavor colliding centers for the transverse nuclear matter and takes the soft-gluon emission limit, our result can reduce to the first order in opacity Dijljevic-Gyulassy-Leuvi-Vitev formula.

I. Motivation
Jets interact with the medium constituents via elastic and inelastic collisions. The interaction causes the energy loss of hard partons. There exist a few theoretical schemes on radiative parton energy loss based on the pQCD framework, such as BDJMS-Z, GLV, AMY and HT formalisms.

1. Previous pQCD-based jet quenching formalisms have made various approximations in the calculation of medium-induced radiative energy loss:
   - Soft gluon emission approximation (ASWM, GLV),
   - Collinear rescattering expansion (BDJMS-Z, HT).

2. Recent developments:
   - Non-elliptic corrections for medium-induced emission within the path integral formalism [2, 3]
   - Relaxing soft gluon emission approximation for GLV/DGLV formalism [2, 3]
   - Beyond collinear expansion and soft-gluon emission limit in DIS framework [4, 5, 6]

3. The main purpose of our work [5]:
   - Extend our previous study [4] and study the medium-induced glue emission from a massive quark jet within the framework of DIS.
   - Work beyond the collinear rescattering expansion and soft-gluon emission approximation, and derive a closed formula for the medium-induced glue emission spectrum from a heavy quark jet interacting with medium constituents via both transverse and longitudinal scatterings.
   - Without performing the collinear expansion, our medium-induced glue emission spectrum is controlled by the full distribution of the differential elastic scattering rates between the propagating partons and medium constituents.

II. Framework

1. Deep inelastic scattering (DIS)
In the framework of deep inelastic scattering (DIS), a lepton and a nucleus in the medium exchange the V° boson, then get a heavy quark and a neutrino,

\[
\begin{array}{c}
\text{V}^0 + \text{N} \rightarrow \text{q} + \nu \\
\end{array}
\]

Differential cross section for DIS process

\[
\frac{d^2 \sigma}{dy \; d^2 k} = \frac{C^2}{4 \pi} \frac{\lambda^2 (1 + \gamma) (1 - \gamma)}{2 \lambda^2} W_{\text{prop}}^2.
\]

where \( W_{\text{prop}} \) is the semi-inclusive hadronic tensor,

\[
W_{\text{prop}} = \frac{1}{2} \int_0^1 \int_0^1 (2x f_{(2)} + A_P) - \lambda c (|f_{(2)}|^2 X)^{1/2} dA.
\]

2. Vacuum radiation

\[
\frac{d\sigma}{dy} = \frac{C^2}{4 \pi} \lambda^2 \frac{1 + \gamma}{2 \lambda^2} W_{\text{prop}}^2.
\]

3. Medium-induced radiation

There are 21 diagrams contributing to the glue emission process from a heavy quark jet via single rescattering in the DIS framework [4, 5]. Now we present one diagram, and the other 20 diagrams are completely analogous and have been listed in Ref [5].

The medium-induced single glue emission spectrum for the above diagram,

\[
\frac{dN_{\text{glue}}}{dy \; d^2 k} = \frac{C^2}{4 \pi} \frac{\lambda^2 (1 + \gamma) (1 - \gamma)}{2 \lambda^2} \frac{1 + \gamma}{2 \lambda^2} W_{\text{prop}}^2.
\]

4. The final formula

After summing up the contributions from all 21 diagrams, the closed formula for the medium-induced single glue emission spectrum can be written as:

\[
\frac{dN_{\text{glue}}}{dy \; d^2 k} = \frac{C^2}{4 \pi} \frac{\lambda^2 (1 + \gamma) (1 - \gamma)}{2 \lambda^2} \frac{1 + \gamma}{2 \lambda^2} W_{\text{prop}}^2.
\]

References

III. Summary

- We derive a closed formula for medium-induced single glue emission from a heavy jet quark interact with a dense nuclear medium via transverse and longitudinal scatterings.
- Our study is a generalization of both HT and DGLV one-rescattering-one-emission formula, beyond collinear rescattering expansion used in HT, beyond soft gluon emission limit used in static DGLV.
- Outlook: Phenomenological studies of parton energy loss and jet quenching in relativistic heavy ion collisions.