Linear Boltzmann Transport for Jet Propagation in the Quark-Gluon Plasma: Medium-Induced Gluon Radiation and Medium Recoil

Yayun He, Tan Luo, Xin-Nian Wang and Yan Zhu

Institute of Particle Physics, Central China Normal University, Wuhan 430079

2015 KOBE JAPAN

Abstract: A Linear Boltzmann Transport model within perturbative QCD is developed for the study of parton propagation inside a static and homogeneous quark-gluon plasma. Our previous work has shown that recoil partons have significant influences on the jet shape, fragmentation functions and angular distribution of reconstruct jets. In this study, we implement the medium-induced gluon radiation processes derived from a higher-twist approach and find the contribution from radiations dominates over the elastic one. For both situations, we investigate parton energy loss, transverse momentum broadening and their nontrivial energy and length dependence. All partons, including leading partons, recoil partons and the radiated gluons, are tracked so that one can also study jet-induced medium excitations. We further investigate the jet shape and fragmentation functions of reconstructed jets.

Motivation

- The energy loss and transverse momentum broadening of an energetic parton traveling in the quark-gluon plasma(QGP) have been a powerful probe for the study of the medium properties.
- The Linear Boltzmann Transport (LBT) model has been manifested as a valid tool to investigate the jet propagation and jet-induced medium excitation.
- The radiation processes in the LBT model should be supplemented with all elastic processes.

Model introduction

The $2 \to 2$ *Boltzmann equation*:

$$p_1 \cdot \partial f_a(p_1) = -\int \frac{d^3p_2}{(2\pi)^3 2E_2} \int \frac{d^3p_3}{(2\pi)^3 2E_3} \int \frac{d^3p_4}{(2\pi)^3 2E_4} \sum_{b(c,d)} [f_a(p_1)f_b(p_2) - f_c(p_3)f_d(p_4)]|M_{ab\to cd}|^2 \times S_2(s,t,u)(2\pi)^4\delta^4(p_1+p_2-p_3-p4)$$

For an elastic process, the scattering rate is

$$\Gamma_{ab\to cd} = \frac{1}{2E_1}\int \frac{d^3p_2}{(2\pi)^3 2E_2} \int \frac{d^3p_3}{(2\pi)^3 2E_3} \int \frac{d^3p_4}{(2\pi)^3 2E_4} f_b(p_2) \times |M_{ab\to cd}|^2 S_2(s,t,u)(2\pi)^4\delta^4(p_1+p_2-p_3-p4)$$

where the regularization to avoid divergence is

$$S_2(s,t,u) = \theta(s \geq 2\mu_D^2)\theta(-s+\mu_D^2 \leq t \leq -\mu_D^2)$$

and the Debye screening mass is given as $\mu_D^2 = (\frac{3}{2})4\pi\alpha_s T^2$.

One can then approximate the probability for at least one parton-medium scattering, $P_a(\Delta t) = 1 - e^{-\Gamma_a \cdot \Delta t}$, during the time interval Δt.

The elastic processes are linear for the reason that the interactions between the jet partons and the recoil partons are neglected. It's a good approximation when the jet-induced medium excitation $\delta f \ll f$.

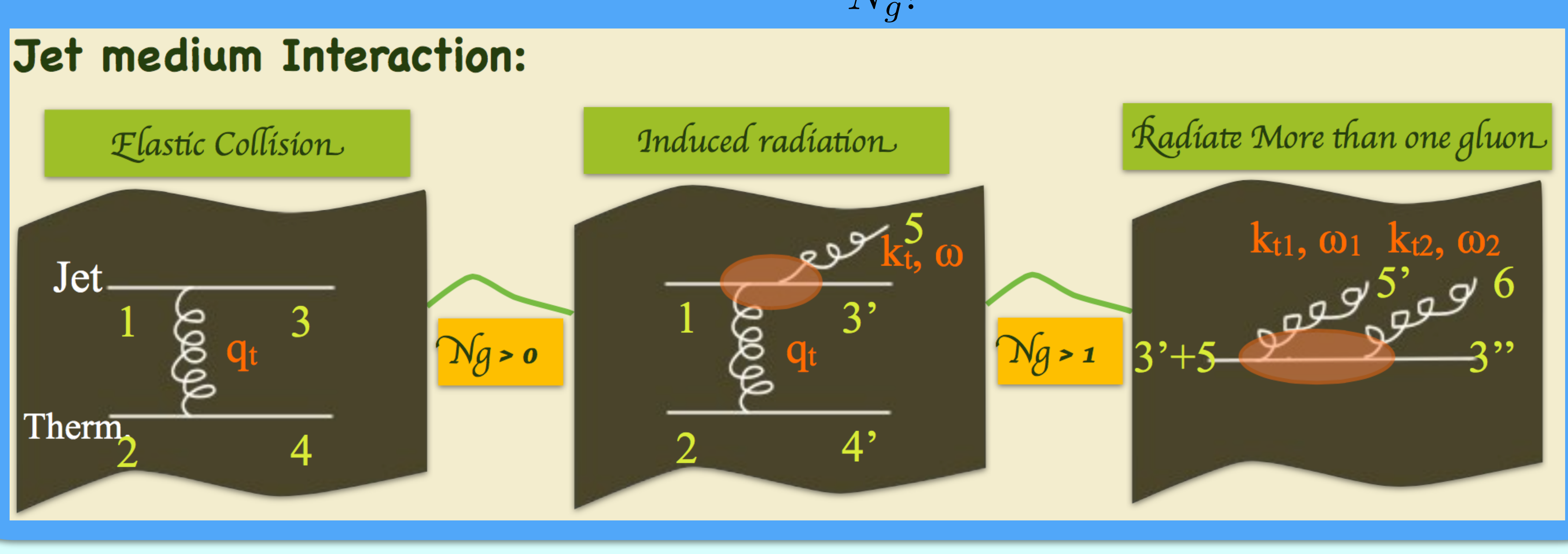
Moreover, the medium-induced gluon radiation processes are implemented in this work. The radiated gluon distribution is

$$\frac{dN_g}{dx dk_\perp^2 dt} = \frac{2C_A\alpha_s P(x)\hat{q}}{\pi k_\perp^4}\sin^2\frac{t-t_i}{2\tau_f}, \quad \tau_f = \frac{2Ex(1-x)}{k_\perp^2}.$$

Induced radiations are accompanied by elastic collisions.

The probability for the number of radiated gluons also follows:

$$P(N_g, <N_g>) = \frac{<N_g>^{N_g} e^{-<N_g>}}{N_g!}$$



Summary

I. For the leading jet parton, the contribution with radiation interaction to the energy loss is dominant with respect to the elastic only collisions, and it will weaken the p_T broadening.

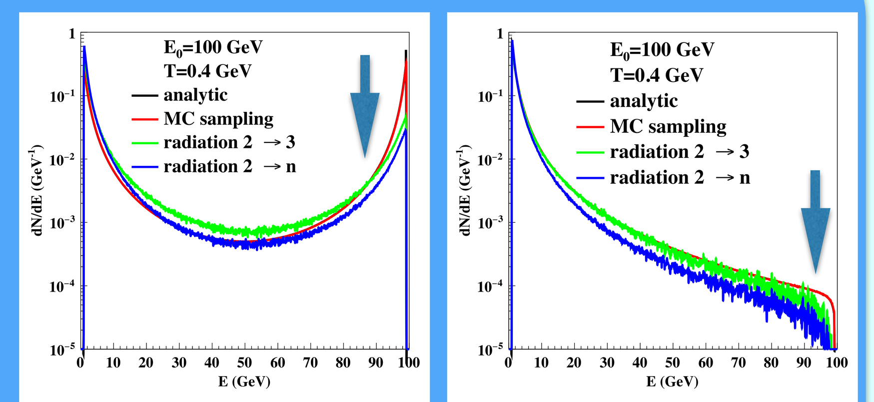
II. Both the recoil partons and the radiated gluons distort the shape of the reconstructed leading jet, and make it different from the leading jet parton.

References

[1] X. N. Wang and M. Gyulassy, Phys. Rev. Lett. **68**, 1480 (1992).
[2] H. Li, F. Liu, G. L. Ma, X. N. Wang and Y. Zhu, Phys. Rev. Lett. **106**, 012301 (2011).
[3] X. N. Wang and Y. Zhu, Phys. Rev. Lett. **111**, 062301 (2013).
[4] Y. He, Tan Luo, X. N. Wang and Yan Zhu, Phys. Rev. C **91**, 054908 (2015)
[5] M. Cacciari, G. P. Salam and G. Soyez, Eur. Phys. J. C **72**, 1896 (2012).

Test of the radiated gluon distribution

The decrease at the tail of the spectrum within the LBT model originates from the energy-momentum conservation of a real scattering, and it enhances when more gluons are induced.



$P_{g\to gg}(x) = 2N_C\frac{(1-x+x^2)^3}{x(1-x)}$ $\quad P_{q\to gq}(x) = C_A\frac{(1-x)(1+(1-x)^2)}{x}$

Results of the leading jet parton

a. For the energy loss with radiation processes:

i. radiation dominates over elastic

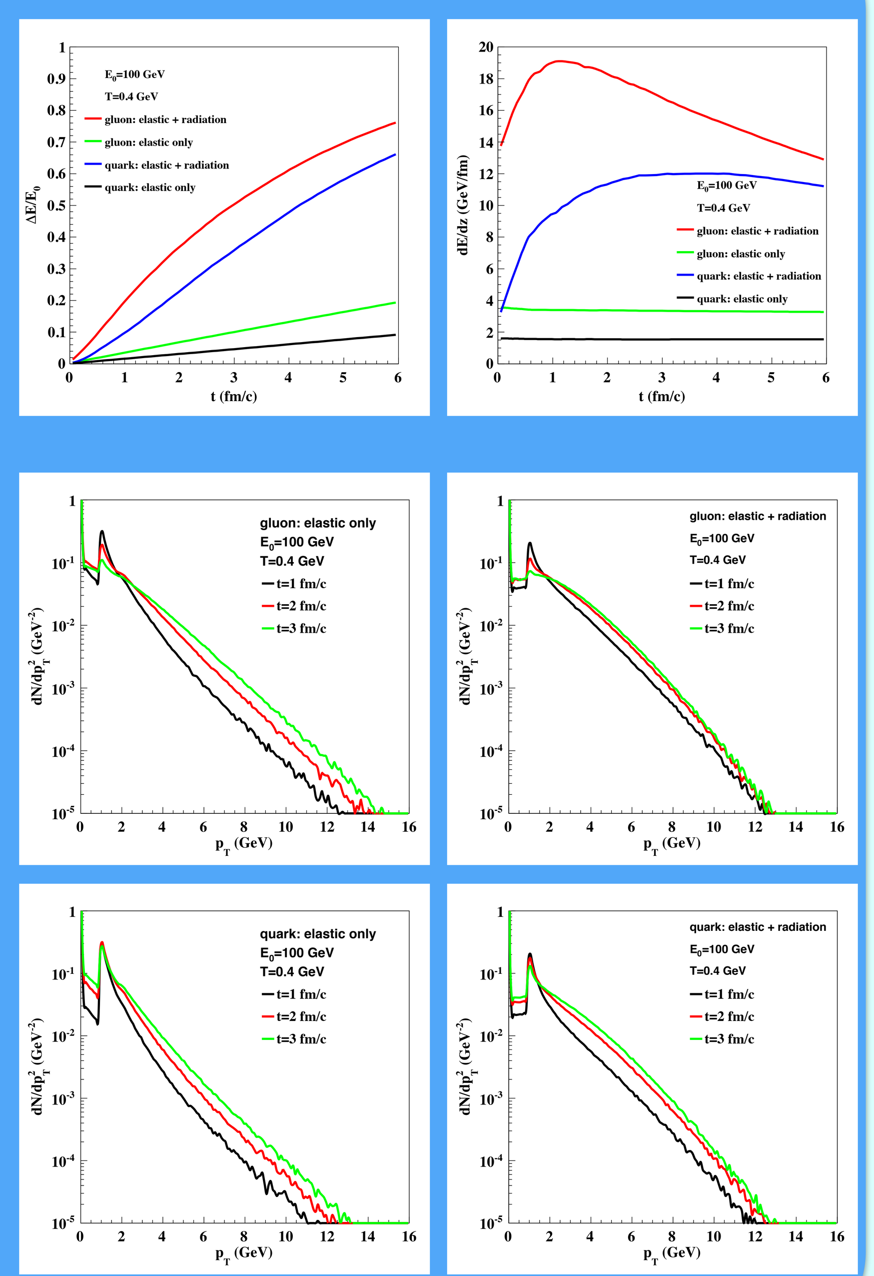
ii. gluon as the initial jet parton is no longer much greater than quark, because more gluons are induced in radiations

iii. Nontrivial energy loss of length dependence at the early stage

b. For the transverse momentum spectra with radiation processes:

i. The broadening effects fade because of the significant energy loss

ii. The curvature becomes positive at the mid-range, and a Gaussian fit may be adopted.



Results of the reconstructed leading jet

a. For the energy loss with radiation processes:

i. Results are similar with that of the leading jet parton.

ii. The energy loss is less than that of the leading jet parton, because the jet cone reserves many recoil partons and radiated gluons that gain energy lost by the leading jet parton.

b. For the transverse momentum spectra with radiation processes:

The broadening effects reinforce, different from the results of the leading jet parton due to the massive recoil partons and the radiated gluons with large transverse momentum contained in the jet cone.

c. For the fragmentation functions with radiation processes:

The transfer of the energy at the beam direction to the transverse plane also reflects the importance of the recoil partons and the radiated gluons.