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Effect of parton cascade to medium*

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Abstract Jet quenching has been proposed as a probe of the properties of the strongly interacting quark-gluon-plasma in high energy heavy ion collisions. At the meantime, it is also important to study the excitation of medium by propagating jets. Based on Boltzmann equation, a Monte Carlo was constructed to simulate the elastic collisions with thermal partons by energetic jets. Medium modification due to jet-medium interaction has been studied within this model in a uniform medium.

Key words jet quenching, parton cascade, medium modification

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1 Introduction

In high energy heavy ion collisions, quarks and gluon in nucleon will deconfine and thermalize to form a quark-gluon-plasma(QGP) rapidly. When a jet, a high $\mathrm{p_t}$ parton produced in the initial hard scattering, goes across the medium, it will interact with the plasma and deposit a fraction of its energy in this medium. This phenomena is called as jet quenching [1]. It has been indicated via the measurement of high $\mathrm{p_t}$ hardons suppression [2,3].

The jet-medium interaction not only causes energy loss of jets but also causes a modification of the medium. This modification shows up, for example, as a double-hump structure in ϕ distribution of two particle correlation.

A number of models have been constructed to describe those phenomena. Here, we construct a parton cascade model to simulate the jet-medium interaction. Thus, we can investigate both jet energy loss and medium modification under the same frame. We should claim that only elastic collisions between jets and medium has been considered so far. The medium induced radiations of jets will be considered later. This paper is organized as following: In section 2, we introduce the basic block of our Monte Carlo simulation. Results on jet energy loss and medium modification will be presented in section 3. Section 4 is devote to the conclusion of present study.

2 Basic block of parton cascade

Our parton cascade Monte Carlo simulation is constructed based on Boltzmann equation [4]

$$v_1\cdot\partial f_1(p_1) = -\frac{1}{2E_1}\int\mathrm{d}p_2\int\mathrm{d}p_3\int\mathrm{d}p_4\times (f_1f_2-f_3f_4)|M_{12\to34}|^2\times (2\pi)^4\delta^4(P_1+P_2-P_3-P_4), \quad (1)$$

where

$$\mathrm{d}p_i\equiv\frac{\mathrm{d}^3p_i}{2E_i(2\pi)^3}$$

and $P_i=(|\boldsymbol{p}_i|,\boldsymbol{p}_i)$ are the four momenta of massless partons in the elastic collisions.

The basic block is used to simulate a jet, particle 1, with a given energy and momentum, to collide with particle 2, a thermal parton from the medium (at a given temperature), to produce particle 3 and 4. The elastic collision rate can be calculated as

$$\Gamma_{22} = \frac{1}{2E_1}\int\mathrm{d}p_2\int\mathrm{d}p_3\int\mathrm{d}p_4 f_2|M_{12\to34}|^2\times (2\pi)^4\delta^4(P_1+P_2-P_3-P_4). \quad (2)$$

The energy of particle 2, E_2, satisfies the distribution function $f_2=1/(\mathrm{e}^{E_2/T}\pm1)$, where '+' for quarks and '−' for gluons, and T is the temperature of medium.

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$|M_{12\to 34}|^2=(s^2+u^2)/(t+\hat{q})^2$. $\hat{q}=\mu^2$, and $\mu=gT$ is Debye mass.

For the simplest process–a single scattering between jet and medium, the energy distribution and angle distribution of produced partons can be obtained from numerical integration directly. Therefore we can test our basic block via comparing the results from parton cascade simulation with those from numerical integration. We set particle 1, the jet, move along z-axis in an infinite uniform medium at $T=0.2$ GeV and the squared Debye mass $\hat{q}=1.0$ GeV^2. In Fig. 1 is shown the energy distribution of produced partons. Here different colors correspond to different input jet energies E_1. In Fig. 2, the θ angle distribution of produced partons is shown, where

$$\theta=\arccos\frac{p_z}{E}$$

and $E_1=20$ GeV. Here different colors correspond to different energies of produced partons. In these two figures, solid lines are integration results, and dashed lines are from Monte Carlo simulation.

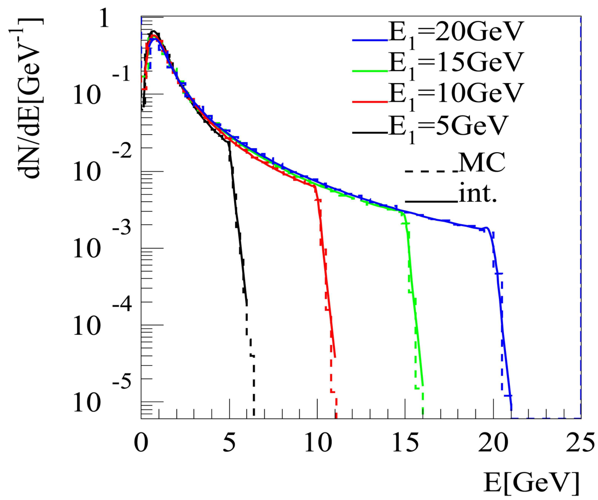

Fig. 1. (Color Online) Energy distribution of produced particles from single scattering. Solid lines are integration results and dashed lines are from Monte Carlo simulation. Different colors correspond to different input jet energies E_1.

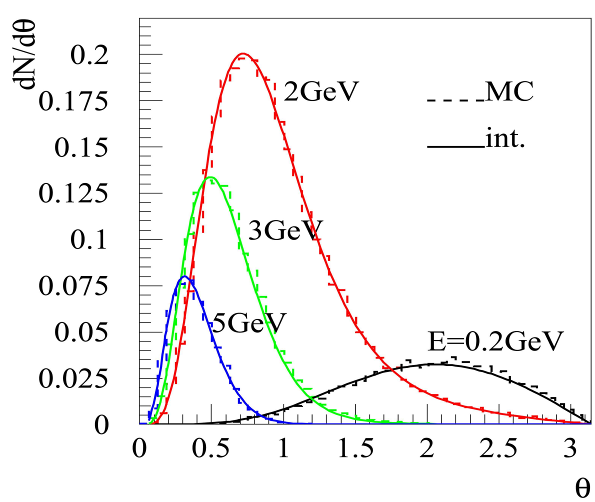

Fig. 2. (Color Online) $\theta=\arccos\frac{p_z}{E}$ distribution of produced particles with $E_1=20$ GeV. Solid lines are integration results and dashed lines are from Monte Carlo simulation. Different colors correspond to different energies of produced partons.

A complete coincidence between the results from the two methods convinces us the basic Monte Carlo block is reliable. In the following we may use this simulation procedure for sequential multiple scattering when the medium is big and the propagation time is long enough.

3 Results and discussion

First, we use our parton cascade model to investigate parton energy loss. Since only elastic collisions are considered by now, we only can get the elastic energy loss.

From previous work [5] by X.N. Wang et al, the elastic energy loss per unit distance in a uniform plasma consisted of 3-flavour quarks is

$$\frac{\mathrm{d}E_{\mathrm{el}}^{\mathrm{qq}}}{\mathrm{d}z}=\frac{2}{3}\pi\alpha_{\mathrm{s}}^2T^2\left(\ln\left(1+\frac{s}{4\mu_{\mathrm{D}}^2}\right)+\frac{1}{\frac{s}{4\mu_{\mathrm{D}}^2}+1}-1\right). \quad (3)$$

To obtain this result, small angle approximation has been used in the differential cross section.

$$\frac{\mathrm{d}\sigma_i}{\mathrm{d}q_\perp^2}=\frac{4}{9}\frac{2\pi\alpha_{\mathrm{s}}^2}{(q_\perp^2+\mu_{\mathrm{D}}^2)^2}. \quad (4)$$

In Fig. 3, energy loss from parton cascade simulation with the same small angle approximation is plotted as triangles, which is very close to previous work [3], shown as solid line. In the previous analytical calculation, the squared center of mass energy s in Eq. (3) can only be estimated. Here s is set to be 8.2ET. While in our simulation this value can be calculated in each collision. The different treatment on s may be responsible for the difference at low energy region.

Elastic energy loss can hardly derived without small angle approximation. However, in parton cascade simulation, this can be obtained strictly without any approximation. In Fig. 3 the result without small angle approximation is shown as stars, evidently lower than that with small angle approximation. This can be understood, since $q_\perp = E\sin\theta \sim 2E\sin(\theta/2)$ has been taken in small angle approximation.

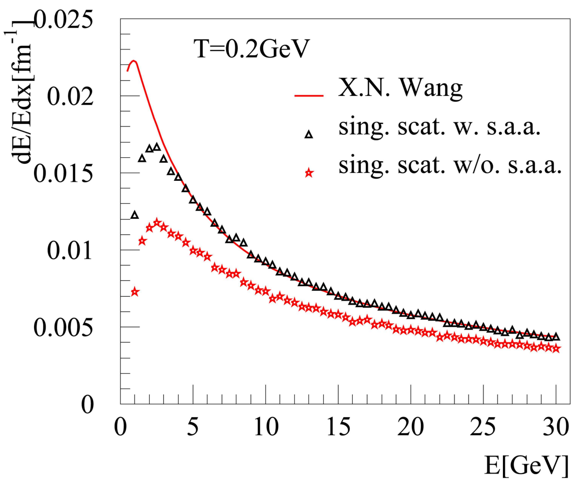

Fig. 3. (Color Online) Energy loss per unit length as a function of jet energy. Line is analytic result in Eq. (3) with $s = 8.2ET$. Triangles and stars are results from MC simulation with and without small angle approximation(s.a.a.).

Now we investigate the modification of the medium due to jet propagation with this Monte Carlo simulation. At $t = 0$, particle 1, the jet with $E_1 =$ 20 GeV, starts from the origin to move along z-axis in an infinite uniform medium at $T = 0.2$ GeV. After a certain time, we can check the parton distribution in the medium after colliding with jets.

In Fig. 4 is shown the modified $\phi = \arccos(p_z/\sqrt{p_z^2+p_x^2})$ distribution of thermal partons after a single scattering. This distribution depends strongly on the energy of partons selected in the medium. When this energy $E = 0.5$ GeV, there is no double-peak, while double-peaks appears when this energy is higher, for example, $E = 1.0$ or 2.0 GeV, and the distance between two peaks gets smaller for larger energy E.

When medium has a big size and the propagation time is long, jets usually scatter with the medium several times. For multiple scattering, the interval between two successive collisions λ_i satisfy distribution $f(\lambda_i) = \mathrm{e}^{-\lambda_i/\lambda}/\lambda$, where λ is mean free path. We set the mean free path of jet medium interaction to be $\lambda_{\rm jet} = 3$ fm, and that for thermal partons interaction to be $\lambda_{\rm th} = 1.5$ fm. In Fig. 5 is shown the ϕ modification of medium at different moments, i.e., t=1, 4, 15 fm/c. One can see that the angle distribution changes gradually with time elapses. At t=1 fm/c, it shows a similar behavior as after a single scattering in Fig. 4. Later on, double-peak disappears and finally a uniform distribution appears.

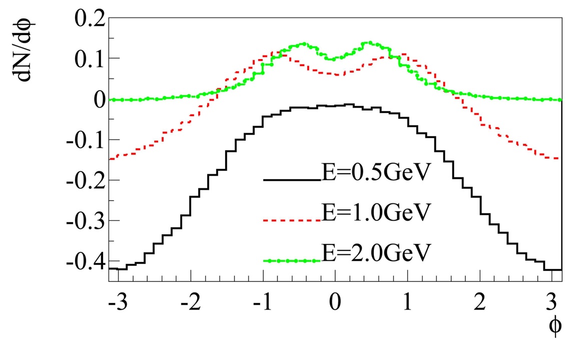

Fig. 4. (Color Online) The modified ϕ distribution of thermal partons after a single scattering with jet.

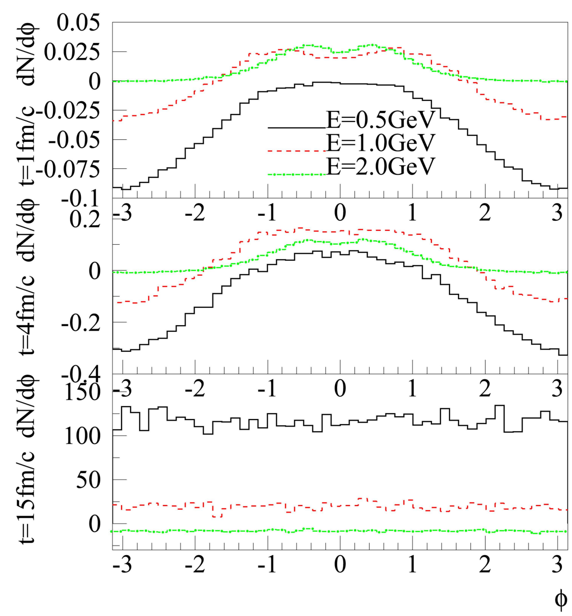

Fig. 5. (Color Online) The modified ϕ distribution in the medium at $t = 1, 4, 15$ fm/c with $\lambda_{\rm jet} = 3$ fm and $\lambda_{\rm th} = 1.5$ fm.

4 Conclusions

Based on Boltzmann equation, a Monte Carlo has been constructed to simulate the elastic collisions between jet and medium. Elastic energy loss has been investigated with this parton cascade simulation. Lower energy loss has been obtained when small angle approximation is removed. Medium modification due to jet propagation has also been investigated. The angle distribution of partons in the medium depends strongly on selected energy windows and the propagation time. Double-peak may appear at the early propagation time for partons with some relative higher energy, $E = 1.0$ or 2.0 GeV. When a jet propagates in a relatively big medium, ϕ distribution of thermal partons will finally tend to uniform after much enough of multiple scatterings. So final hadronic correlation may be a signal of the plasma size, if only parton cascade is responsible for those angle distribution.

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