Jet quenching and medium interaction in QGP

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Introduction

Partonic jets produced in ultra-relativistic energy heavy-ion collisions are crucial tools for studying the thermal and transport properties of the expanding Quark-Gluon Plasma (QGP) [1]. These high transverse momenta p_T partons while traversing the QGP, experience energy loss through elastic collisions and medium-induced gluon radiation (inelastic collisions) referred to as *jet quenching*. The radiated gluons subsequently rescatter by interaction with the bulk/medium partons resulting in a wake in the medium. The fully reconstructed jet within a jet cone thus consists of hadrons which are hadronized from the full jet parton shower, as well as hadrons that are produced by bulk-medium excitation within the jet cone [2].

The present study aims to investigate jet quenching and the reconstruction of full jets within a jet cone by developing a coupled (2+1)D relativistic viscous hydrodynamic code [3] to model the baseline hydrodynamic medium evolution, in conjunction with Boltzmann parton transport for simulating full jet shower evolution. The local temperature and flow velocity of the hydrodynamic medium dictate the longitudinal energy loss and transverse momentum broadening experienced during jet shower evolution.

Formalism

The complete jet, comprising both leading and subleading partons, is characterized by a distribution in energy and transverse momentum $f_j(\omega_j, k_{j\perp}^2) = dN_j(\omega_j, k_{j\perp}^2)/d\omega_j dk_{j\perp}^2$. The entire information of the energy and momentum of the leading and subleading partons is contained in this three dimensional distribution. As the jet cluster moves through the medium, it is altered as the original partons lose energy and newly generated partons become incorporated into $f_j(\omega_j, k_{j\perp}^2, t)$. The full evolution of the jet partons within the medium is analyzed using a set of coupled differential transport equations, with the following generic form of equations:

$$\begin{aligned}
&\frac{d}{dt} f_j(\omega_j, k_{j\perp}^2, t) = \left(\hat{e}_j \frac{\partial}{\partial \omega_j} + \frac{1}{4} \hat{q}_j \nabla_{kj\perp}^2 \right) \\
&\times f_j(\omega_j, k_{j\perp}^2, t) \\
&+ \sum_i \int d\omega_i dk_{i\perp}^2 \frac{d\Gamma_{i\to j}(\omega_j, k_{j\perp}^2 | \omega_i, k_{i\perp}^2)}{d\omega_j dk_{j\perp}^2 dt} \\
&\times f_i(\omega_i, k_{i\perp}^2, t) \\
&- \sum_i \int d\omega_i dk_{i\perp}^2 \frac{d\Gamma_{j\to i}(\omega_i, k_{i\perp}^2 | \omega_j, k_{j\perp}^2)}{d\omega_i dk_{i\perp}^2 dt} \\
&\times f_j(\omega_j, k_{j\perp}^2, t). \qquad (1)
\end{aligned}$$

In this phenomenological equation, the first two terms on the right-hand side indicate elastic processes, and the other two terms indicate inelastic processes. The first and second terms are the change in $f_j(\omega_j, k_{j\perp}^2, t)$ due to change of energy and transverse momentum of the partons as it interacts elastically with the medium partons. The third term represents a *gain* term as it incorporates inelastic transfer from i-th parton to j-th parton. Similarly, the fourth term is a *loss* term due to inelastic splitting of j-th to i-th parton. The indices (i, j) refer to different species of partons i.e. quarks as well as gluons.

Results

For Pb + Pb collisons at $5.02A$ TeV at an impact parameter of $b = 4.2$ fm, the initial phase-space configuration of the leading and shower jet partons are simulated using PYTHIA 6.4 encoded in the AMPT transport code [4]. These virtual jets freely propagate in vacuum until $t_0 = 0.4$ fm/c, following which the in-medium evolution is governed by the modified Boltzmann transport equa-

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tion (1). The temperature and velocity profile of the QGP medium that encode the $\hat{q}$ and $\hat{e}$ are obtained from the coupled (2+1) viscous hydrodynamic simulation.
Fig. 1 shows the energy lost $\Delta E(t) = E(t_0) - \sum_j \int \omega f_j(\omega_j, k_{j\perp}^2, t)\, d\omega\, dk_{j\perp}^2$ by the jets with time evolution. The $\Delta E(t)$ increases logarithmically with the initial energy of the jet. Further, the energy loss enhances with viscous damping of the medium as shown for shear viscosity to entropy density ratio of $\eta/s = 3/4\pi$.
The hydrodynamic medium interactions alter the jet substructure by redistributing the transverse momentum among the shower partons, resulting in a net broadening of the jet cone during its evolution. This broadening is described by the jet shape function, $\rho(r) = \frac{1}{\delta r}\frac{1}{N_{jet}}\sum_{N_{jet},j}\frac{p_T^j}{p_T^{jet}}[\Theta[r_j - (r-\frac{1}{2})\delta r]\Theta[r_j + (r+\frac{1}{2})\delta r]$. From Fig. 2 we find that $\rho(r)$ is inversely proportional to the initial energy of the jet parton and directly proportional to the viscosity of the medium.

Conclusion

We have investigated the impact of jet parton transport on the evolution of the QGP and the resulting feedback that modifies jet substructures. The interactions between jet partons and the underlying QGP are sensitive to initial energy of the jet and the viscosity of the medium.

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References

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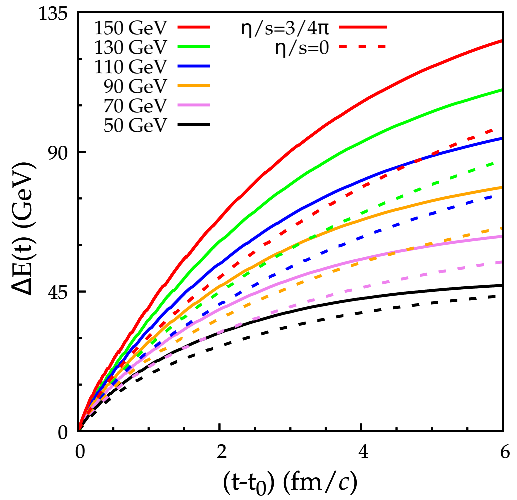

FIG. 1: Time evolution of jet energy loss for different initial energies of jet in viscous and ideal hydrodynamic medium.

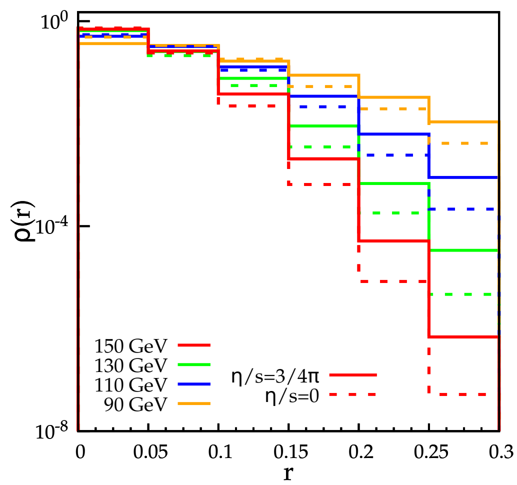

FIG. 2: Jets shape function of full jet at the end of evolution for different initial energies in viscous and ideal hydrodynamic medium.