Evolution of full jets in QGP medium

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Introduction

Relativistic heavy ion collisions at RHIC/BNL and LHC/CERN have established the formation of a extremely hot and dense Quark-Gluon-Plasma (QGP) [1–4]. Jets produced form hard nucleon-nucleon collisions serve as an important tool to infer the thermal and transport properties of the expanding QGP [5, 6]. These high-transverse momenta $p_\perp$ partons while traversing the QGP medium experience energy loss by elastic and inelastic (via radiated gluons) collisions and transverse momentum broadening. The jet-medium interactions thus result in quenching of the leading jet energy as well as to transport the lost energy through the recoil of the radiated gluons in the expanding QGP. Consequently, the full jet reconstructed within a jet cone will comprise of leading hadrons that are hadronized from the jet partons and hadrons from the bulk-medium excitation within the jet cone [7, 8].

The present study aims to explore jet quenching and reconstruction of full jets within a jet cone by developing a coupled (2+1)D relativistic viscous hydrodynamic code [9] to treat the baseline hydrodynamic medium evolution that combines with Boltzmann parton transport for jet shower evolution. The local temperature and the flow velocity from the hydrodynamic medium determine the longitudinal energy loss $\hat{e}$ and the transverse momentum broadening $\hat{q}$ for the jet shower evolution. In turn, the local energy-momentum deposited by the jet during evolution in the QGP provides a source term for the hydrodynamic evolution equation.

Formalism

The full jets, consisting of leading and subleading hadrons, is given by a distribution in energy and transverse momentum $f_i(\omega_i, k_{i\perp}^2) = dN_i(\omega_i, k_{i\perp}^2)/d\omega_i dk_{i\perp}^2$. The entire information of the energy and momentum of the leading and subleading partons is contained in this three dimensional distribution. As the jets' cluster traverses through the medium, $f_i(\omega_i, k_{i\perp}^2, t)$ gets modified as the original partons lose energy and newly generated partons become part of $f_i(\omega_i, k_{i\perp}^2, t)$. The complete evolution of the jet partons through the medium is studied through a set of coupled-differential transport equations, with the following generic form of equations:

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

In this phenomenological equation, the first two terms on the right-hand side indicate elastic processes, and the other two terms indicate inelastic losses. 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 traverses elastically in the medium. 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 process of j-th parton to i-th parton. The indices (i, j) refer to different species of partons i.e. quarks as well as gluons. The deposited energy-momentum from jets enter as a source term $J^\mu(x)$ in the (2+1)D viscous hydrodynamic evolution equation for the energy-momentum tensor $\partial_\mu T^{\mu\nu}(x) = J^\nu(x)$.

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Results

The initial jet-shower transverse momenta and their positions are taken from the AMPT transport code [10]. The initial energy and transverse momentum of each parton in the shower is represented a Gaussian profile that enters in the subsequent parton transport with elastic and in-elastic collisions. We solve for $f_j(\omega_j, k_{j\perp}^2, t)$ numerically, using the Iterative-Crank-Nicholson method of 2^{nd}-order iteration.

Fig. 1 shows a representative elastic evolution of $f_j(\omega_j, k_{j\perp}^2, t)$, integrated for a time period of $0.5 - 10$ fm. The peak of $f_j(\omega_j, k_{j\perp}^2, t)$ shifts towards lower energy as partons lose energy. This trend shows the thermalisation of partons present in the jet shower. Fig. 2 displays the elastic evolution of $f_j(\omega_j, k_{j\perp}^2, t)$ with respect to momentum along y-axis. This figure suggest the transverse momentum broadening of jets with time. The peak of the distribution remains stationary at $k_y = 0$, indicating the high directionality of the jet along $x-$axis.

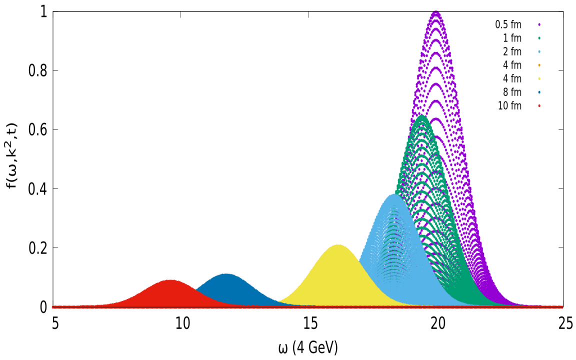

FIG. 1: Time evolution of $f_j(\omega_j, k_{j\perp}^2, t)$ with respect to energy ω_j.

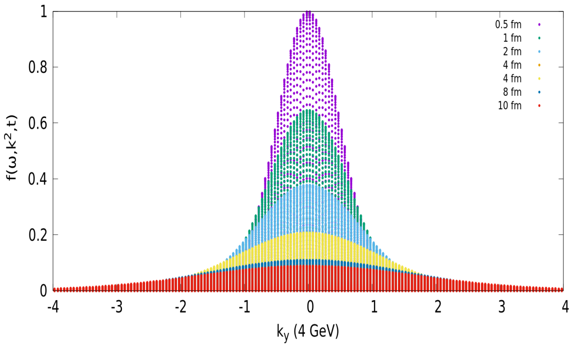

FIG. 2: Time evolution of $f_j(\omega_j, k_{j\perp}^2, t)$ with respect to momenta k_y.

Conclusion

We have developed a coupled relativistic jet shower transport and viscous hydrodynamic description of the jet-induced medium excitation/response. The main goal is to reconstruct the full-jet to study the medium modification of the energy-momentum distribution of light and heavy flavor jets and the jet quenching. This model can also be used to simultaneously characterise the energy density fluctuations present in the medium, as well as generate short wavelength fluctuations that affects higher flow coefficients.

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