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Effects of initial state fluctuations on jet energy loss

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The effect of initial state fluctuations on jet energy loss in relativistic heavy-ion collisions is studied in a 2+1 dimensional ideal hydrodynamic model. Within the next-to-leading order perturbative QCD description of hard scatterings, we find that a jet loses slightly more energy in the expanding quark-gluon plasma if the latter is described by the hydrodynamic evolution with fluctuating initial conditions compared to the case with smooth initial conditions. A detailed analysis indicates that this is mainly due to the positive correlation between the fluctuation in the production probability of parton jets from initial nucleon-nucleon hard collisions and the fluctuation in the medium density along the path traversed by the jet. This effect is larger in non-central than in central relativistic heavy ion collisions and also for jet energy loss that has a linear than a quadratic dependence on its path length in the medium.

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I. INTRODUCTION

Jet quenching is a measure of the energy loss of an initially produced leading jet parton as it traverses through the dense matter formed in relativistic heavy ion collisions via multiple scatterings [1]. Its observation through the suppression of large transverse momentum single hadron, dihadron, and γ-hadron spectra in relativistic heavy ion collisions [2, 3] is one of the most important evidence for the formation of a strongly coupled quark-gluon plasma (QGP) in these collisions. Theoretical studies on parton jet energy loss have concentrated on both gluon radiation induced by multiple scattering and elastic collision energy loss. Due to the non-Abelian Landau-Pomeranchuk-Migdal (LPM) interference effect [4], the radiative energy loss shows a quadratic path-length dependence [5–9], which is in contrast to the linear path-length dependence of the elastic collision energy loss [10–12]. Also, a cubic path-length dependence of the jet energy loss has been found in the strongly coupled limit of the QCD medium using the AdS/CFT correspondence [13, 14].

The study of jet quenching in heavy ion collisions has been carried out in the 1-dimensional Bjorken hydrodynamics [15–19] as well as the 2+1 and 3+1 dimensional ideal and viscous hydrodynamics [20–23]. In these studies, the initial conditions for the hydrodynamical evolution were taken to be smooth in space. Recently, the effect of initial event-by-event fluctuations on jet quenching has been investigated in a static medium [24]. It was found that the strong correlation between the fluctuation in the spatial distribution of initial hard scatterings from which jets are produced and the fluctuation in the density distribution of the initial medium has significant effects on jet quenching. In particular, the jet energy loss is reduced by up to 50% after the inclusion of initial fluctuations. However, the transverse expansion of the produced hot dense medium has been neglected in this study. As shown in Ref. [25], including the transverse expansion via a 2+1 dimensional ideal hydrodynamics results in a much smaller effect of at most 20% reduction in the jet energy loss. In this study, the jet energy loss in a medium is taken to depend on the local energy density as $\epsilon^{3/4}$. Since the jet energy loss may depend on other properties of the medium, such as the local parton density, it is of interest to see how this would influence the effects of the initial-state fluctuations. In the present paper, we carry out such a study using the 2+1 dimensional ideal hydrodynamic model of Refs. [26, 27]. For calculating the hadron spectra at large transverse momentum, we use the next-to-leading order (NLO) perturbative QCD. Our results show that including transverse expansion of the medium and assuming that the jet energy loss depends on the local parton density slightly enhance the energy loss of jets, contrary to the reduced jet energy loss found in Refs. [24, 25]. We further investigate the effect of initial fluctuations for different path-length dependence of jet energy loss in the medium.

This paper is organized as follows. We first give a brief description of the 2+1 dimensional ideal hydrodynamic model in Sec. II and the jet quenching models in Sec. III. Results from our study are shown in Sec. IV. We then present some discussions in Sec. V and finally summarize our study in Sec. VI.

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II. 2+1 DIMENSIONAL HYDRODYNAMICS

In the 2+1 dimensional ideal hydrodynamics, which assumes the boost invariance along the longitudinal direction, the energy-momentum tensor $T^{\mu\nu} = (\epsilon + p)u^\mu u^\nu - pg^{\mu\nu}$, with u^μ, ϵ and p being the local four velocity, energy density, and pressure of a system can be expressed in terms of the proper time τ and the two transverse coordinates x and y perpendicular to the beam direction [28–31]. Conservations of energy and momentum then give

$$\begin{aligned}\partial_\tau(\tau T^{00}) + \partial_x(\tau T^{0x}) + \partial_y(\tau T^{0y}) &= -p,\\ \partial_\tau(\tau T^{0x}) + \partial_x(\tau T^{xx}) + \partial_y(\tau T^{xy}) &= 0,\\ \partial_\tau(\tau T^{0y}) + \partial_x(\tau T^{xy}) + \partial_y(\tau T^{yy}) &= 0. \end{aligned} \quad (1)$$

To solve these equations requires information on the initial conditions of a collision, particularly the initial entropy density, and the equation of state of the produced matter. For the initial entropy density, it is taken as

$$\frac{ds}{d\eta} = C\left\{(1-\xi)\frac{n_{\rm part}}{2} + \xi\ n_{\rm bin}\right\}, \quad (2)$$

where $n_{\rm part}$ and $n_{\rm bin}$ are the number densities of participants and binary collisions, respectively.

In heavy ion collisions, the initial conditions vary from event to event as the positions of colliding nucleons are randomly distributed according to the density distributions of the colliding nuclei. As in our previous studies [26], two nucleons are considered as participants and a binary collision takes place at their middle point if the transverse distance between a nucleon from one nucleus and a nucleon from the other nucleus is smaller than $\sqrt{\sigma_{\rm in}/\pi}$, where $\sigma_{\rm in} = 42$ mb is the nucleon-nucleon inelastic cross section at RHIC energies. A smearing parameter σ is then introduced in evaluating the number densities of participants and binary collisions, i.e.,

$$n_{\rm part(bin)}(\mathbf{r}) = \frac{1}{2\pi\sigma^2}\sum_{i=1}^{N_{\rm part(bin)}} \exp\left(-\frac{|\mathbf{r}_i - \mathbf{r}|^2}{2\sigma^2}\right), \quad (3)$$

where $\mathbf{r}_i$ is the transversal position of a participant (binary collision). Here we use the same smearing parameter σ for both the participant and binary collision number densities. In the present study, we consider the two cases of $\sigma = 0.4$ fm and 0.8 fm. Also, we choose the initial thermalization time $\tau_0 = 0.6$ fm/c for starting the hydrodynamical evolution.

For the equations of state, we use the quasi-particle model based on the lattice QCD data from the Wuppertal-Budapest collaboration [32], which shows a smooth transition from the quark-gluon plasma to the hadron gas below $T = 140$ MeV. We solve the hydrodynamic equations Eq. (1) numerically by using the HLLE algorithm [33–35] until the temperature drops to $T = 160$ MeV.

The parameters C and ξ in Eq. (2) are determined from fitting the centrality dependence of the final charged-particle multiplicity [36]. Using the Cooper-Frye freeze-out formula and assuming that the multiplicity does not change after chemical freeze-out at temperature $T = 160$ MeV, we obtain $C = 19.3$ and $\xi = 0.11$.

In studies with smooth initial conditions, both the participant number and the binary collision number densities are normally obtained from the optical Glauber thickness functions of the colliding nuclei evaluated from their density distributions [37]. In the present study, they are obtained by averaging over a large number of initial fluctuating events. Because of the smearing parameter introduced in generating the initial conditions for hydrodynamical evolutions, the resulting smooth participant number and the binary collision number densities have a larger spread in space than that obtained from the optical Glauber nuclear thickness functions.

III. JET QUENCHING MODELS

For a jet of energy E produced at the position $\mathbf{r}$ from a hard nucleon-nucleon collision and moving along a path in the transverse plane of a nucleus-nucleus collision that makes an azimuthal angle ϕ with respect to the reaction plane, its total energy loss can be expressed as

$$\Delta E = \int d\tau f(E, \phi, \mathbf{r}, \tau)\rho(\mathbf{r}, \phi, \tau), \quad (4)$$

where $\rho(\mathbf{r}, \phi, \tau)$ is the local parton density at time τ along the jet path, and the function $f(E, \phi, \mathbf{r}, \tau)$ is the jet energy loss per unit time through a unit density of medium.

Averaging over the production positions and moving directions of the jet in the transverse plane gives

$$\langle\Delta E\rangle = \frac{1}{2\pi}\int d\phi d^2\mathbf{r} d\tau n(\mathbf{r}) f(E, \phi, \mathbf{r}, \tau)\rho(\mathbf{r}, \phi, \tau), \quad (5)$$

where $n(\mathbf{r}) = n_{\rm bin}(\mathbf{r})/N_{\rm bin}$, with $n_{\rm bin}(\mathbf{r})$ and $N_{\rm bin}$ denoting, respectively, the number density of binary collisions at $\mathbf{r}$ and the total number of binary collisions, is the probability density for jet production at $\mathbf{r}$. The average jet energy loss rate along the jet path is then

$$\frac{d\langle\Delta E\rangle}{d\tau} = \frac{1}{2\pi}\int d\phi d^2\mathbf{r} n(\mathbf{r}) f(E, \phi, \mathbf{r}, \tau)\rho(\mathbf{r}, \phi, \tau). \quad (6)$$

According to recent theoretical studies [16, 17, 38–40], the total quark energy loss in a finite and expanding medium is approximately given by

$$\Delta E = \left\langle\frac{dE}{dL}\right\rangle \int_{\tau_0}^{\infty} d\tau \left(\frac{\tau - \tau_0}{\tau_0}\right)^\alpha \frac{\rho(\tau, \mathbf{r})}{\rho(\tau_0, 0)}\frac{p^\mu u_\mu}{p_0}. \quad (7)$$

In the above, α is the parameter for specifying the path-length dependence of jet energy loss with possible values 0, 1 and 2, corresponding, respectively, to linear, quadratic, and cubic path-length dependence for the jet energy loss; and p^μ and u^μ are, respectively, the four momentum of the jet and the four flow velocity of the local medium. The density $\rho(\tau,\mathbf{r})$ decreases with time and is set to zero once the local temperature of the QGP drops below the critical temperature which is taken to be $T = 160$ MeV in the present study. The average energy loss per unit length $\langle dE/dL\rangle$ has the following parametrization [39]:

$$\left\langle \frac{dE}{dL}\right\rangle = \epsilon_0 (E/\mu_0 - 1.6)^{1.2}/(7.5 + E/\mu_0), \quad (8)$$

where ϵ_0 is the energy loss parameter with a value that is 9/4 times larger for a gluon than for a quark, and $\mu_0 = 1.5$ GeV [7] is the Debye mass. The value of ϵ_0 is about 5.0 GeV/fm in the case of $\alpha = 1$ from fitting the experimental data for the nuclear modification factor in the most central $A+A$ collisions using the smooth initial conditions. This value is larger than that in a previous study [16] using the more slowly expanding 1-dimensional Bjorken hydrodynamics. Comparing Eq.(7) to Eq.(4) leads to the following jet energy loss rate through a unit density of medium:

$$f(E,\phi,\mathbf{r},\tau) = \left\langle \frac{dE}{dL}\right\rangle \left(\frac{\tau-\tau_0}{\tau_0}\right)^\alpha \frac{1}{\rho(\tau_0,0)}\frac{p^\mu u_\mu}{p_0}. \quad (9)$$

The inclusive invariant differential cross section for producing hadrons of species h in a collision of nuclei of types A and B from the fragmentation of jets after their energy loss can be written as

$$\begin{aligned}\frac{d\sigma^h_{AB}}{dyd^2p_T} &= \sum_{abcd}\int d\mathbf{r}^2 n_{\rm coll}(\mathbf{r})\int dx_a dx_b f_{a/A}(x_a,\mu^2,\mathbf{r})\\ &\times f_{b/B}(x_b,\mu^2,|\mathbf{b}-\mathbf{r}|)\frac{d\sigma}{d\hat{t}}(ab\to cd)\\ &\times \frac{D_{h/c}(z_c,\mu^2,\Delta E(b,\mathbf{r}))}{\pi z_c} + \mathcal{O}(\alpha_s^3), \quad (10)\end{aligned}$$

where the cross sections for the hard scattering are calculated using the CTEQ6M parameterizations [41] for the parton distributions in a nucleon and including both $2\to 3$ tree level contributions and 1-loop virtual corrections to $2\to 2$ tree processes [42]. Parton energy loss is included into the effective medium-modified parton fragmentation functions [15–17] via

$$\begin{aligned}D_{h/c}(z_c,\mu^2,\Delta E) &= (1-e^{-\langle\frac{L}{\lambda}\rangle})\left[\frac{z'_c}{z_c}D^0_{h/c}(z'_c,\mu^2)\right.\\ &\left.+\langle\frac{L}{\lambda}\rangle\frac{z'_g}{z_c}D^0_{h/g}(z'_g,\mu^2)\right]\\ &+e^{-\angle\frac{L}{\lambda}\angle}D^0_{h/c}(z_c,\mu^2). \quad (11)\end{aligned}$$

In the above, $z'_c = p_T/(p_{Tc}-\Delta E)$ and $z'_g = \langle L/\lambda\rangle p_T/\Delta E$ are the rescaled momentum fractions for partons with transverse momentum p_{Tc} fragmenting into hadrons with p_T with the parton energy loss ΔE given by Eq. (7) and $\langle L/\lambda\rangle$ being the number of scatterings along the parton propagating path [15–17]. For the parton fragmentation function in vacuum $D^0(z_c,\mu^2)$, we use the AKK08 parameterizations [43].

IV. RESULTS

Fitting the lattice equation of state with the quasiparticle model of Ref. [30, 31], we obtain the temperature dependent quark and gluon masses in the QGP. The local parton density is then determined from these massive partons. Results for the nuclear modification factor of jets in both central and mid-central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV can then be evaluated. As in experiments, the nuclear modification factor in the case of fluctuating initial conditions is calculated from the average charged hadron spectrum $d\bar{\sigma}_{AA}/dp_T^2dy$ obtained from the fluctuating events and divided by the product of the average number of binary collisions $\bar{N}_{\rm bin}$ and the hadron spectrum $d\sigma_{NN}/dp_T^2dy$ from the $N+N$ collisions at same energy, i.e.

$$R_{AA} = \frac{d\bar{\sigma}^h_{AA}/dp_T^2dy}{\bar{N}^i_{\rm bin}d\sigma_{NN}/dp_T^2dy}. \quad (12)$$

For the case of smooth initial conditions, the nuclear modification factor is similarly calculated by using the corresponding hadron spectrum.

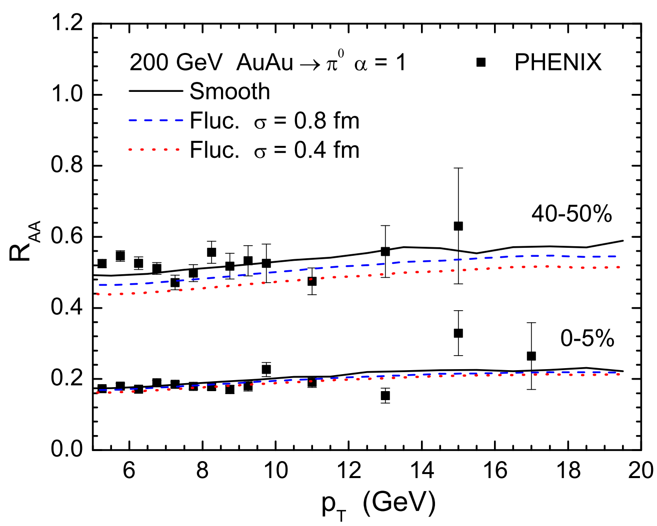

FIG. 1: (Color online). Nuclear modification factors with and without initial fluctuations in 0-5% and 40-50% centralities of Au+Au collisions at $\sqrt{s} = 200$ GeV. The experimental data are taken from [44].

Figure 1 shows the nuclear modification factors of high-p_T particles in 0-5% and 40-50% centralities of Au+Au collisions at $\sqrt{s} = 200$ GeV with and without initial fluctuations. It is seen that including initial fluctuations leads to a smaller R_{AA}, and the effect is stronger for larger initial fluctuations (corresponding to smaller σ) and in noncentral than in central collisions.

V. DISCUSSIONS

The smaller R_{AA} in the case of fluctuating initial conditions obtained in the present study is opposite to the results reported in previous studies based on a static medium [24] or 2+1 dimensional ideal hydrodynamics [25], where a larger R_{AA} was obtained when initial fluctuations were included. To understand this difference, we define the jet energy loss difference $\delta\langle\Delta E\rangle \equiv \langle\Delta E\rangle^{\rm fluc} - \langle\Delta E\rangle^{\rm smth}$ between the average energy loss calculated with fluctuating initial conditions and that with smooth initial conditions. From Eq. (6), we then obtain the following rate for this difference along the jet path:

$$\frac{d[\delta\langle\Delta E\rangle]}{d\tau} = \frac{1}{2\pi}\int d\phi d^2\mathbf{r} f(E,\phi,\mathbf{r},\tau)(\delta n\delta\rho), \qquad (13)$$

where δn and $\delta\rho$ are, respectively, the differences in the jet production probabilities and the medium densities in the cases of fluctuating and smooth initial conditions. We note that the terms $\rho\delta n$ and $n\delta\rho$ are not present in Eq.(13) since both vanish after integration over the jet production positions and moving directions. Eq. (13) indicates that the energy loss difference is determined not only by the fluctuation in the jet production probability density but also by the fluctuation in the local parton density on the jet path [24].

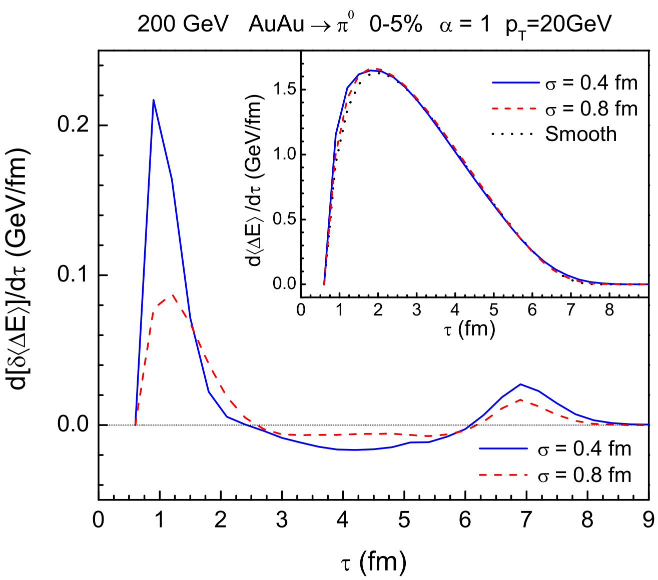

FIG. 2: (Color online). Rate of jet energy loss difference, averaged over all jet paths, in 0-5% central $Au+Au$ collisions at $\sqrt{s} = 200$ GeV for smearing parameter $\sigma = 0.4$ fm and 0.8 fm. The inset shows the averaged energy loss rate along the jet path calculated with fluctuating and smooth initial fluctuations.

In Fig. 2, we show the rate of the energy loss difference for jets with the transverse momentum $p_T = 20$ GeV, averaged over all jet paths, in 0-5% central Au+Au collisions at $\sqrt{s} = 200$ GeV for smearing parameter $\sigma = 0.4$ fm and 0.8 fm. It shows that the correlation between the fluctuation in the production probability of initial parton jets and the fluctuation in the local medium density is positive during the early stage of jet propagation but changes to negative during the later stage, resulting in enhanced and reduced energy losses, respectively. This result is consistent with that in Ref. [24] for a transversely static medium. The net effect of the fluctuations on the jet energy loss is determined by the sum of the positive and negative differences. As shown in the inset of Fig. 2, which gives the averaged energy loss rate along the jet path calculated with fluctuating and smooth initial fluctuations, most energy losses happen close to the initial path of the jet. Because of the dominance of the initial positive difference, the total energy loss calculated with fluctuating initial conditions is greater than that with smooth initial conditions.

The relation between the jet propagation and the medium evolution can be further clarified if we approximate the time evolution of the parton density $\rho(\tau, r)$ along a jet path in the hydrodynamic evolution of the medium as $\rho(\tau, r) \sim 1/\tau^\beta$. The value of β increases with time during the hydrodynamic evolution and rapidly reaches infinity near the end of the QGP phase. With the quasiparticle model for lattice equation of state, the average value of β is about 1.2 during the first 3 fm/c of the jet propagation and is larger than 2 for the whole duration of the jet propagation. According to Eq. (9), the time evolution of the medium-dependent jet energy loss can then be simply written as

$$\Delta E \sim \tau^{\alpha-\beta}, \qquad (14)$$

if we neglect the small flow effect. As the jet transverses through the medium, its increasing energy loss with the path-length (τ^α) is thus suppressed by the decreasing density of the bulk medium ($1/\tau^\beta$). Consequently, the total effect of the initial fluctuations on jet quenching is related to the competition between the path-length dependence and the medium-density evolution dependence of the jet energy loss. Since α is always smaller than β in our study, the total energy loss mainly takes place during early times when the correlation between the fluctuation in the production probability of initial parton jets and the fluctuation in the local medium density is positive, thus resulting in more energy loss in the case of fluctuating initial conditions. In non-central collisions, the fireball expands faster than in central collisions ($\beta^{40-50\%} > \beta^{0-5\%}$), so most energy loss happens earlier than in central collisions. As a result, the R_{AA} for the case of initial fluctuations with $\sigma = 0.4$ fm decreases by 7% in central collisions and by 13% in the 40-50% centrality of the collisions as shown in Fig. 1.

The path-length dependence of jet energy loss depends on the energy loss mechanism. It is linear (α=0) for elastic energy loss, quadratic ($\alpha = 1$) for radiative energy loss [5–12], and cubic ($\alpha = 2$) for energy loss based on AdS/CFT for the strongly coupled QCD [13, 14]. How the path-length dependence affects the effect of initial fluctuations on jet energy loss is an interesting question. We illustrate this effect by considering different values for the path-length dependence parameter α but with same energy loss parameter for both smooth and fluctuating cases.

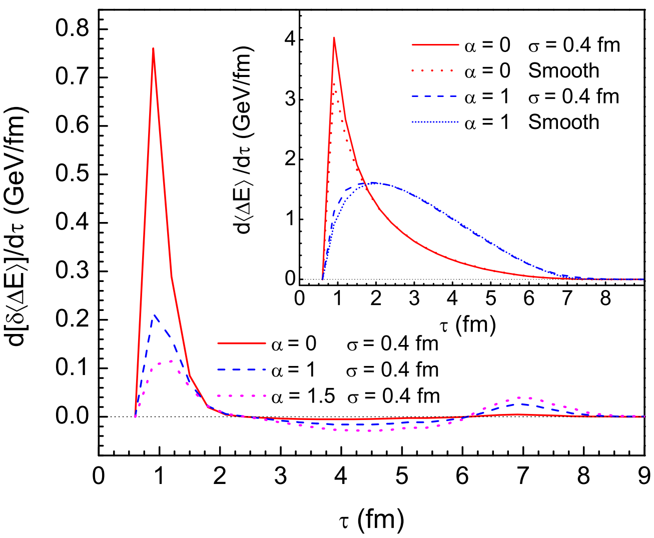

FIG. 3: (Color online). Rate of jet energy loss difference averaged over all jet paths in 0-5% central Au+Au collisions for different values of the path-length dependence parameter for jet energy loss, $\alpha = 0$, 1 and 1.5. The inset is the average energy loss rate along the jet path for $\alpha = 0$ and 1.

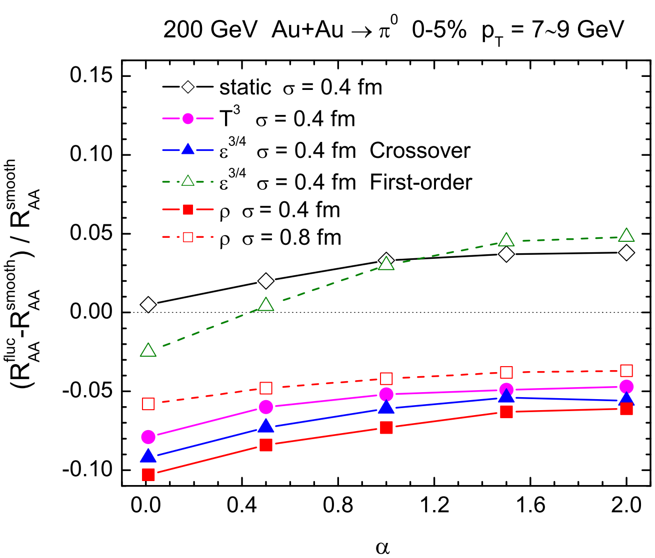

FIG. 4: (Color online). Relative difference between the nuclear modification factors of $p_T = 7 - 9$ GeV hadrons as a function of the path-length dependence parameter α for different medium dependence in central Au+Au collisions.

In Fig. 3, we show the rate of jet energy loss averaged over all jet paths in 0-5% central Au+Au collisions for different values of the path-length dependence parameter, $\alpha = 0$, 1 and 1.5. For the linear path-length dependence ($\alpha = 0$) of jet energy loss, most energy loss takes place in the initial positive correlation region of the jet path, so the initial positive correlation dominates the fluctuation effect. For the quadratic path length dependence ($\alpha = 1$), the peak for the jet energy loss rate is shifted closer to the negative correlation region as shown in the inset of Fig. 3, thus weakening the effect of the initial positive correlation. Therefore, the energy loss for the linear path-length dependence is greater than the energy loss for the quadratic path-length dependence. This conclusion is supported by the results shown in Fig. 4 for the relative difference between the nuclear modification factors of $p_T = 7 - 9$ GeV hadrons for the fluctuating and smooth initial conditions, $(R_{AA}^{\rm fluc} - R_{AA}^{\rm smooth})/R_{AA}^{\rm smooth}$, as a function of α. For the smaller smearing parameter σ =0.4 fm, including initial fluctuations decreases the suppression factor by 8-10% for the linear path-length dependence of jet energy loss while by 5-7% for the quadratic path-length dependence of jet energy loss, as shown by filled squares. The fluctuation effect is, however, reduced if a larger smearing parameter $\sigma = 0.8$ fm is used as shown by open squares.

Also shown in Fig. 4 are results from assuming that the medium dependence of jet energy loss in Eq. (7) is determined by the local temperature according to T^3 (filled circles) [20] or the local energy density according to $\epsilon^{3/4}$ (filled triangles) [25]. In these cases, including initial fluctuations results in more jet energy loss than in the case of smooth initial conditions, although less than the case the jet energy loss depends on the density of the medium.

If we do not allow the produced matter to expand as in Ref. [24] based on a static medium, the relative difference between the nuclear modification factors for the fluctuating and smooth initial conditions is then positive as shown by open diamonds in Fig. 4 for all values of α, indicating that the jet energy loss is reduced after including initial fluctuations. This is because the medium expansion parameter β $(= 0)$ is always smaller than the path-length dependence parameter α of jet energy loss, so the total energy loss is dominated by the contribution during later times when the correlation between the fluctuation in the production probability of initial parton jets and the fluctuation in the local medium density has large negative values.

Further shown by open triangles in Fig. 4 are the relative difference between the nuclear modification factors for the fluctuating and smooth initial conditions obtained with the jet energy loss that depends on energy density as in Ref. [25] and an equation of state for the hydrodynamic evolution that has a first-order phase transition [45]. Its value is seen to become positive if the path-length dependence parameter α is large. This is because the softened equation of state leads to a slower hydrodynamic expansion and thus reduces the value of the expansion parameter β. Therefore, depending on the jet energy loss mechanism and the expansion dynamics of the medium, including initial fluctuations can either increase or decrease the total jet energy loss. That our results are opposite to those in Ref. [25] may thus be due to the fact that the value of α minus β is negative in our case but is close to zero or positive in Ref. [25].

VI. SUMMARY

Based on the 2+1 dimensional ideal hydrodynamics, we have studied the effect of initial fluctuations on jet energy loss in relativistic heavy-ion collisions within the description of the NLO perturbative QCD. Our results show that fluctuating initial conditions lead to slightly more energy loss than smooth initial conditions. In general, the jet energy loss increases with time due to its path-length dependence but this increase is suppressed by the decreasing medium density with time. Where the total energy loss mainly takes place along the jet path is determined by the competition between the path-length dependence of jet energy loss and the time dependence of the medium density. For fluctuating initial conditions, our results for the rate of the average energy loss difference between the two cases of fluctuating and smooth initial conditions show that the correlation between the fluctuation in the production probability of initial parton jets and the fluctuation in the local medium density is positive during the early times along the jet path and negative during the later times. Consequently, the net effect of initial fluctuations on jet energy loss is determined by whether the energy loss mainly takes place when this correlation is positive or negative. The total energy loss in the fluctuation conditions is then larger than that in the smooth case if most energy loss takes place when the correlation is positive, while it is smaller if it takes place when the correlation is negative. Our results further show that the initial positive correlation dominates the fluctuation effect for linear and quadratic path-length dependence of jet energy loss in central as well as in non-central A+A collisions. However, because this dominance is stronger in non-central collisions than in central collisions, the difference between the nuclear modification factors calculated with fluctuating initial conditions and smooth initial conditions in non-central A+A collisions is greater than that in central A+A collisions. Similarly, the jet energy loss for the linear path-length dependence is more affected by the fluctuation effect than that for the quadratic path-length dependence. Our results are opposite to those found in Ref. [24] for a static medium and also those in Ref. [25] using a 2+1 ideal hydrodynamics and with the jet energy loss depending on the local energy density, which show a reduced jet energy loss in the QGP for the fluctuating initial conditions.

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