Available online at www.sciencedirect.com

ScienceDirect

ELSEVIER

Nuclear and Particle Physics Proceedings 289–290 (2017) 289–292

www.elsevier.com/locate/nppp

Rapidity-dependent jet energy loss in small systems with finite-size effects and running coupling

Chanwook Park[a], Chun Shen[a,b], Sangyong Jeon[a], Charles Gale[a]

[a] *Department of Physics, McGIll University, 3600 University Street, Montreal, QC, H3A 2T8, Canada*
[b] *Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA*

Abstract

Longitudinal dynamics of particle production and rapidity-dependent jet energy loss are investigated in small and asymmetric colliding systems. We utilize an improved version of MARTINI in which two improvements are implemented to calculate the effect of the strongly coupled QGP droplet on jet energy loss. We show that those realistic prescriptions improve the results of nuclear modification factor calculations. We also observe visible energy loss of jets in a thermal background of high-multiplicity p-Pb collisions, and a clear correlation between the energy loss and elliptic flow coefficients for energetic particles. We conclude that systematic measurements of jet quenching in central collisions of small systems can support the formation of the QGP droplet.

Keywords: jet energy loss, small systems, finite-size effect, running coupling

---

1. Introduction

In LHC and RHIC experiments, strong collective behavior is being observed in high multiplicity events in p-p and p-A collisions, suggesting that quark-gluon plasma can be created in such small systems [1, 2, 3]. In this work, we introduce two improvements to the treatment of inelastic processes in MARTINI [4]: finite formation time for emission, and the running coupling constant, which enable us to study jets in small QGP droplets. Those two features are expected to be essential in small systems [5].

Using this improved version of MARTINI, we analyze the effect of the formation time and the running coupling in the particle production rate for a given rapidity regime, and calculate jet energy loss by the QGP droplet created in small and asymmetric systems. We find sizeable medium-induced jet energy loss in high-multiplicity events of p-Pb collisions, in which temperatures can be comparable to those realized in heavy ion collisions. Furthermore, we show that the elliptic flow coefficient for energetic particles in rapidity space are closely related to the amount of jet quenching.

2. MARTINI: New developments

In contrast to the soft scattering processes in a thermal medium, the formation time of the inelastic radiations increases with the energy of a parton. The moment of the emission is not uniquely defined within the formation time. Hence, during that time, a hard parton and an emitted parton are coherent and additional emissions from the two partons are prohibited until they are fully separated. This interference between the two partons highly suppresses the radiation rates at early times after the original radiation.

In order to take the effects of finite formation time into account in the momentum-space AMY formalism [6], the light-cone path integral formalism [7] reformulated in Ref. [8] is written as

$$\frac{d\Gamma^a_{bc}(t)}{dk} \equiv \frac{P^{a(0)}_{bc}(x)}{\pi p} \times \mathrm{Re} \int_0^t dt_1 \int_{\mathbf{q},\mathbf{p}} \frac{i\mathbf{q}\cdot\mathbf{p}}{\delta E(\mathbf{q})} \times C(t) K(t,\mathbf{q};t_1,\mathbf{p}). \quad (1)$$

Here, $d\Gamma^a_{bc}(t)/dk$ is defined as the rate of the $a \rightarrow b + c$ radiation process and $P^{a(0)}_{bc}(x)$ is the leading or-

https://doi.org/10.1016/j.nuclphysbps.2017.05.066

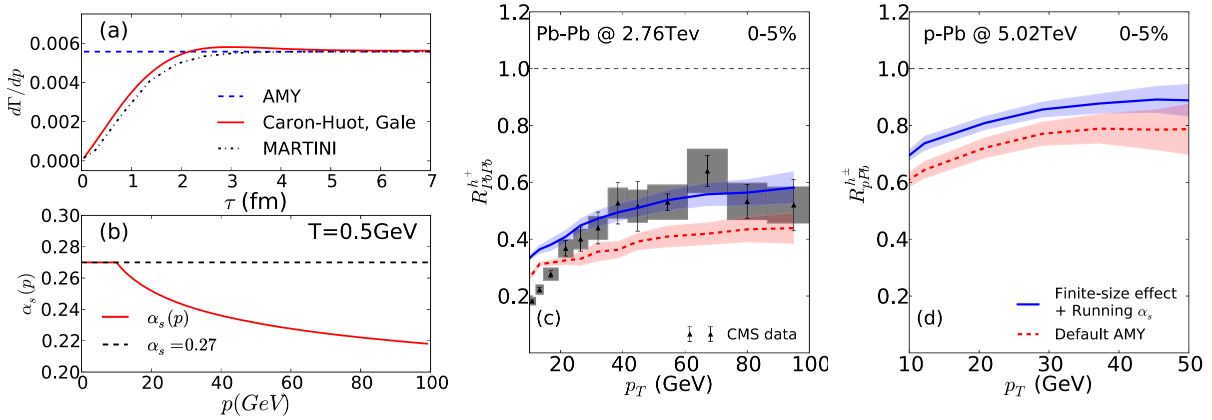

Figure 1: (a): The rate for a 50 GeV quark emitting a 5 GeV gluon. (b): Running coupling constant, α_s, as a function of momentum, p, of a particle at temperature, T= 0.5 GeV. (c): Charged hadron nuclear modification factor R_{AA} in 0-5% Pb-Pb collisions at $\sqrt{s}$ = 2.76TeV, compared with the ALICE measurement. (d): Charged hadron R_{pPb} in 0-5% p-Pb collisions at $\sqrt{s}$ = 5.02 TeV. In (c-d), the red curves correspond to the default AMY radiation rate, while the blue curves include the improved AMY rate described in the text.

der DGLAP splitting kernel. The energy denominator $\delta E(\mathbf{p})$ is given by [8]

$$\delta E(\mathbf{p}) = \frac{p\mathbf{p}^2}{2k(p-k)} + \frac{m_b^2}{2k} + \frac{m_c^2}{2(p-k)} - \frac{m_a^2}{2p}, \tag{2}$$

where m_i is the thermal mass of the parton i. The kernel $K(t, \mathbf{q}; t_1, \mathbf{p})$ is the propagator associated with the light-cone Hamiltonian. In momentum space, the time-dependent $C(t)$ acts as the Boltzmann collisional operator [8]. As noted in [8], the effects of the finite formation time on radiation rates become significant if we explore the higher energy regime.

To implement this quantum-mechanical phenomena in the Monte-Carlo event generator, we mimicked the rates calculated in [8] in the following way. After an emission, the two partons independently undergo multiple soft scatterings and momentum broadening. Once their phase-space separation satisfies the uncertainty principle $\Delta r_\perp > 1/2\Delta p_\perp$, they become fully separated and are permitted to radiate again. Fig. 1 (a) shows a rate for a 50 GeV quark emitting a 5 GeV gluon. The slight enhancement over the AMY rate shown in the figure is due to interference effects, and it is not easy to reproduce it perfectly in a Monte-Carlo method. However the difference between this implementation and the quantum-mechanical calculation is small.

The running coupling constant $\alpha_s(\mu)$ was applied for radiation processes [9]. For the renormalization scale, we use the averaged momentum transfer $\sqrt{\langle p_\perp^2\rangle}$ between the mother parton and the daughter parton estimated as follows. The definition of jet transport coefficient $\hat{q}$ is given by

$$\hat{q} = \frac{\langle p_\perp^2\rangle}{t_f}, \tag{3}$$

where t_f is the formation time of an emission. Combining Eq. 3 with $t_f = p/\langle p_\perp^2\rangle$, one gets

$$\sqrt{\langle p_\perp^2\rangle} = (\hat{q}p)^{1/4}. \tag{4}$$

Running coupling $\alpha_s(p)$ as a function of momentum p is shown in Fig. 1 (b). A 20% reduction in the strength of interaction at p = 100 GeV is found.

Both of these effects – the finite-size effects and the effect of running coupling – lead to a decrease in the energy loss rates induced by inelastic processes as shown in Fig. 1 (c-d). As can be seen in the figure, this leads to overall a better description of the Pb-Pb collisions and predicts R_{pA} to be around 0.8 – 0.9.

3. Rapidity-dependent jet energy loss

Colliding asymmetric systems such as p-Pb offer an opportunity to study underlying physics that governs different rapidity regimes. To model the non-trivial longitudinal dynamics of such collisions, we used the thermal media created by MUSIC [10], which allows full 3+1 dimensional hydrodynamic calculations [11]. Medium fluctuations were taken into account by using event-by-event simulations with Monte-Carlo Glauber initial conditions. Centrality classes were determined by the initial entropy density dS/dy, which is highly correlated with the final state charged-hadron multiplicity