Light and heavy flavor jet quenching at RHIC & LHC

W.-J. Xing[1], X.-Y. Wu[1], S. Cao[2], T. Luo[1], L.-G. Pang[3], G.-Y. Qin[1], X.-N. Wang[1,3]

[1]Instituted of Particle Physics & Key Laboratory of Quark and Lepton Physics (MOE), Central China Normal University, Wuhan, Hubei 430079, China

[2]Department of Physics and Astronomy, Wayne State University, 666 W. Hancock St. Detroit, MI 48201, USA

[3]Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Abstract

Jet quenching is one of the most important signatures for the hot and dense quark-gluon plasma (QGP) produced in heavy-ion collisions at the Relativistic Heavy-Ion Collider (RHIC) and the Large Hadron Collider (LHC). In this work, we develop the Linear Boltzmann Transport (LBT) model to study the interactions of both light and heavy flavor partons with the hot and dense QGP. The LBT model includes both elastic and inelastic interactions with the medium constituents for all the jet shower partons within the framework of perturbative QCD. Our results can simultaneously describe the experimental data on heavy and light flavor hadron suppression for various centralities in RHIC and the LHC heavy-ion collisions [1, 2]. The prediction for Xe-Xe collisions at 5.44A TeV is also presented.

Linear Boltzmann Transport (LBT) model

In the LBT model [1, 2, 3, 4], the evolution of an incoming parton (denoted as "a") is described by

$$p \cdot \partial f_a(x,p) = E(\mathcal{C}_{\text{el}} + \mathcal{C}_{\text{inel}}), \tag{1}$$

where $\mathcal{C}_{\text{el}}$ and $\mathcal{C}_{\text{inel}}$ denote collision integrals for elastic and inelastic scatterings, respectively.

For an elastic scattering process ($a + b \to c + d$), the collision integral is given as:

$$\begin{aligned}\mathcal{C}_{\text{el}} = & \sum_{b,c,d} \frac{\gamma_b}{2E} \int \frac{d^3p_b}{(2\pi)^3 2E_b} \int \frac{d^3p_c}{(2\pi)^3 2E_c} \int \frac{d^3p_d}{(2\pi)^3 2E_d} \\ & \times \Big\{ f_c(\vec{p}_c) f_d(\vec{p}_d) \left[1 \pm f_a(\vec{p})\right] \left[1 \pm f_b(\vec{p}_b)\right] - \\ & f_a(\vec{p}) f_b(\vec{p}_b) \left[1 \pm f_c(\vec{p}_c)\right] \left[1 \pm f_d(\vec{p}d)\right] \Big\} S_2(s,t,u) \\ & \times (2\pi)^4 \delta^{(4)}(p + p_b - p_c - p_d) |\mathcal{M}_{ab\to cd}|^2,\end{aligned} \tag{2}$$

To include the inelastic process of medium-induced gluon radiation, we calculate the average number of emitted gluons from a hard parton in each time step Δt as follows:

$$\langle N_g^a \rangle (E,T,t,\Delta t) = \Delta t \int dx dk_\perp^2 \frac{dN_g^a}{dx dk_\perp^2 dt}. \tag{3}$$

The gluon radiation spectrum is taken from the higher-twist energy loss formalism [5, 6, 7]:

$$\frac{dN_g^a}{dx dk_\perp^2 dt} = \frac{2\alpha_s C_A \hat{q}_a P_a(x) k_\perp^4}{\pi \left(k_\perp^2 + x^2 m^2\right)^4} \sin^2\left(\frac{t - t_i}{2\tau_f}\right), \tag{4}$$

Heavy and light flavor parton energy loss in LBT model

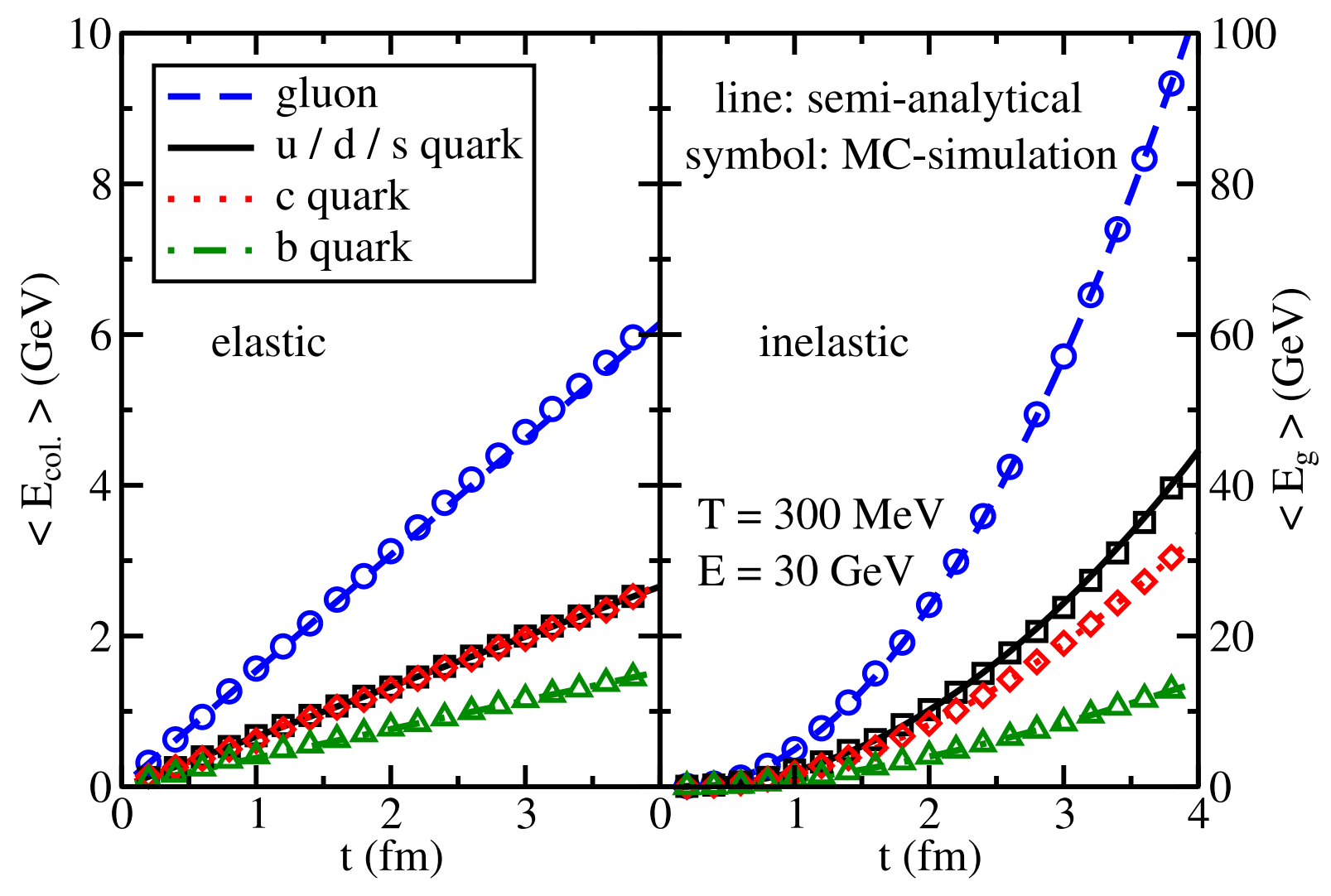

Figure 1: Elastic and inelastic energy loss in a static medium: semi-analytical calculation vs. Monte-Carlo simulation.

Our LBT simulations give rise to an elastic energy loss that increases linearly with time, and the slopes are in agreement with those from semi-analytical calculations of $\hat{e} = 1.54$ GeV/fm for gluon, 0.664 GeV/fm for light quark, 0.668 GeV/fm for charm quark and 0.382 GeV/fm for beauty quark. For inelastic processes, our LBT model shows a quadratic increase with time for the cumulative energy carried by the radiated gluons, and the MC results agree with the semianalytical calculation as well.

Nuclear modifications of light and heavy flavor hadrons

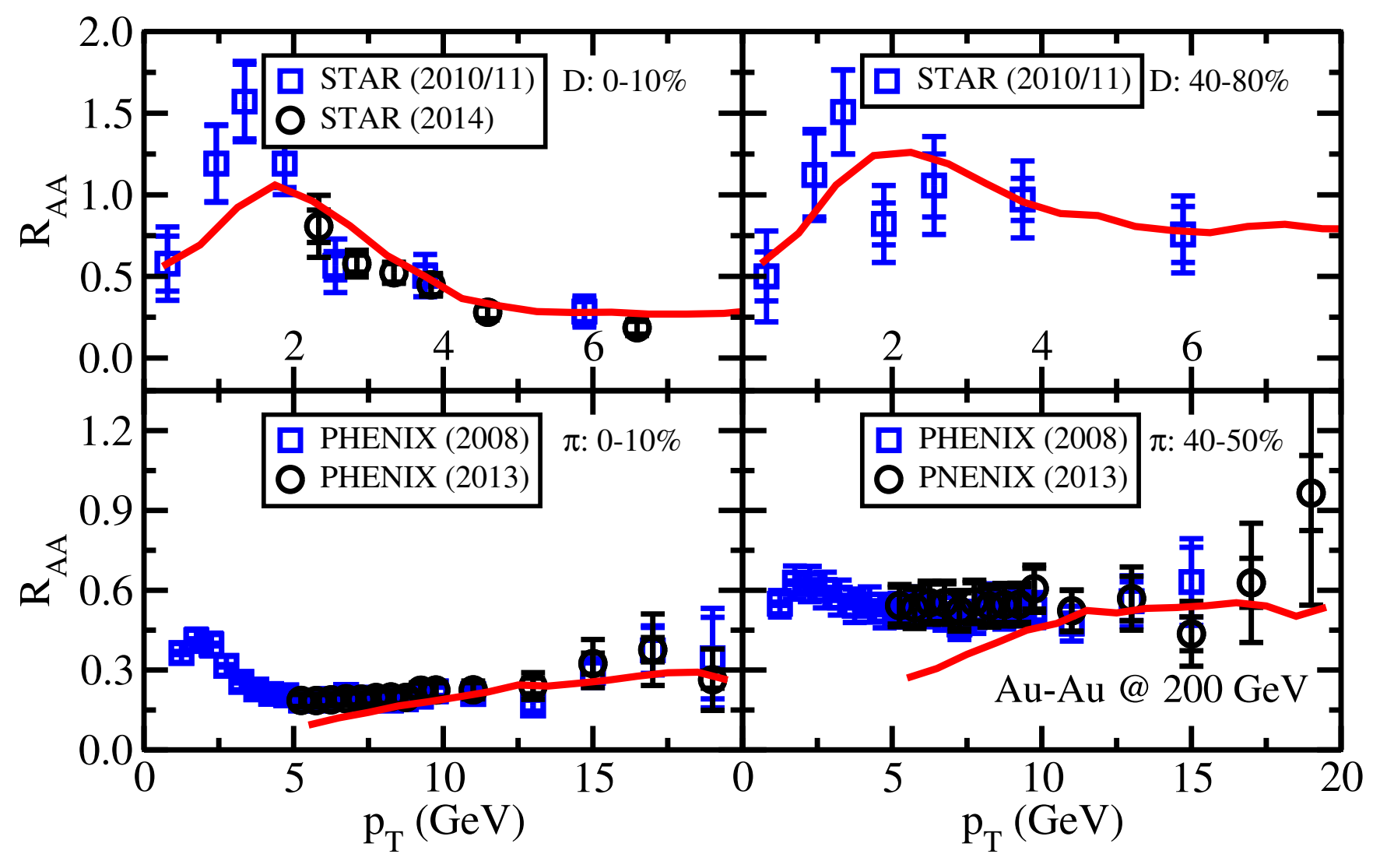

Figure 2: Nuclear modification factor $R_{\rm AA}$ for D and π productions in 200 AGeV Au-Au collisions at RHIC.

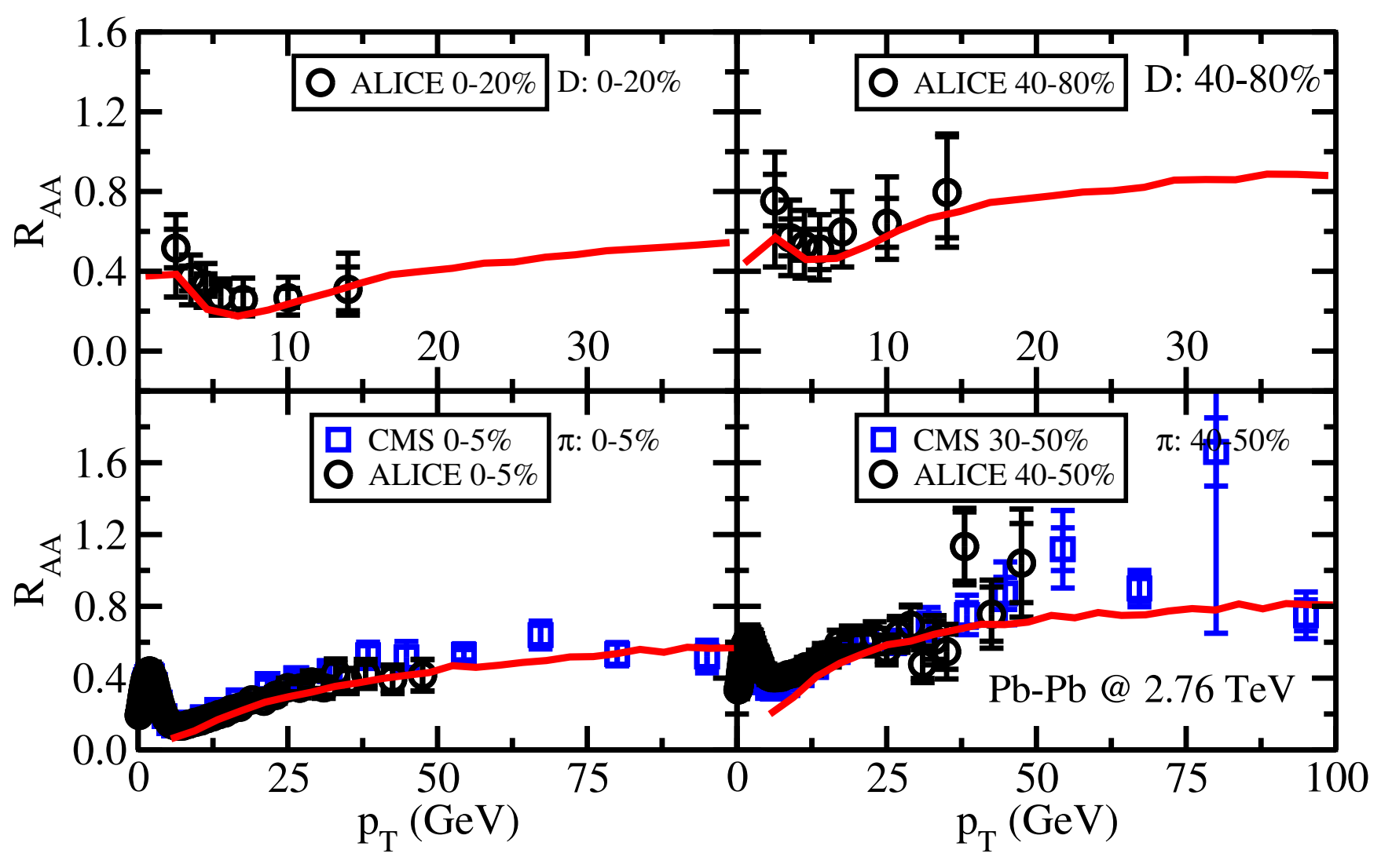

Figure 3: Nuclear modification factor $R_{\rm AA}$ for D and π productions in 2.76 A TeV Pb-Pb collisions at the LHC.

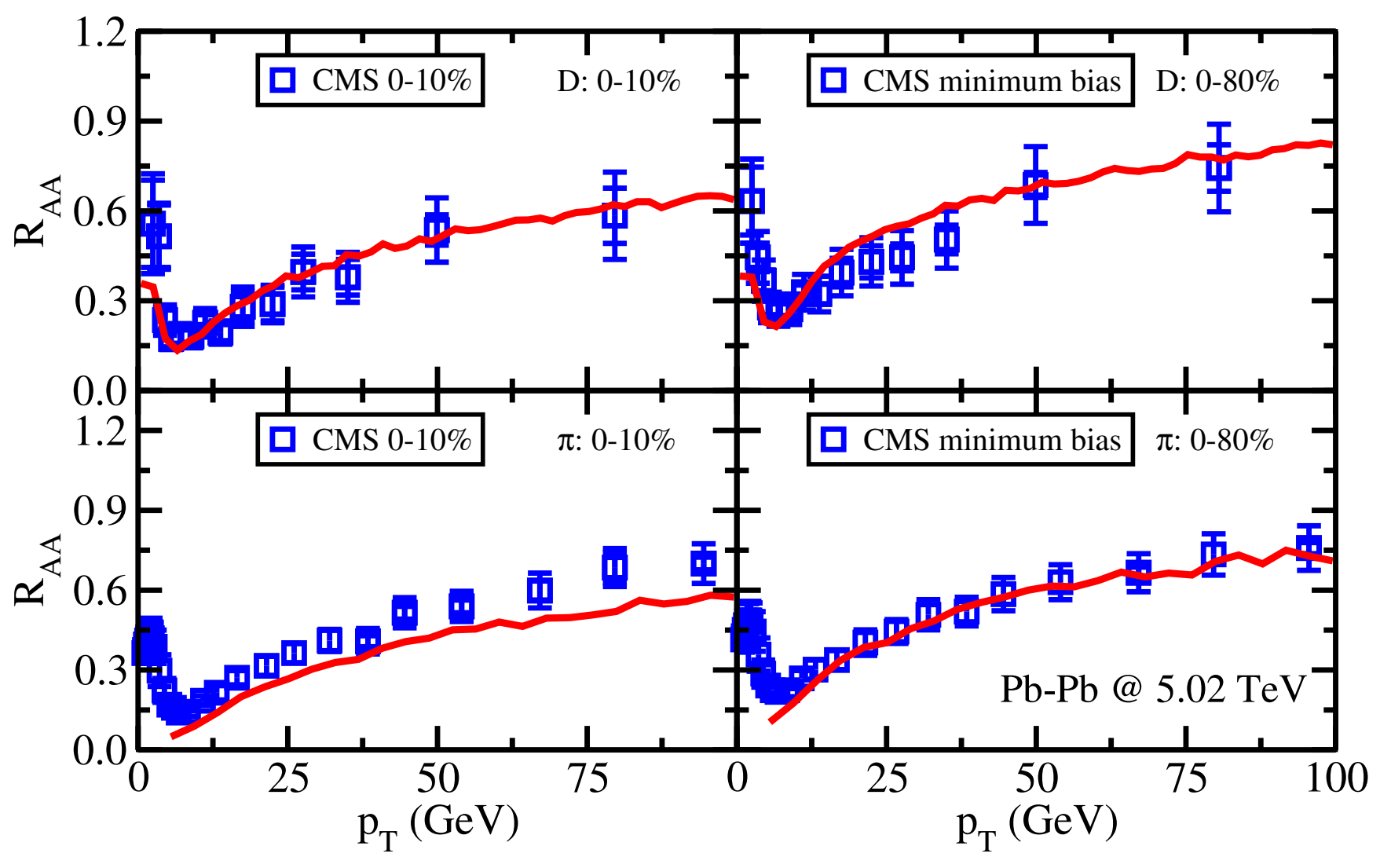

Figure 4: Nuclear modification factor $R_{\rm AA}$ for D and π productions in 5.02 A TeV Pb-Pb collisions at the LHC.

With the inclusion of the energy and temperature dependences for jet-medium interaction in our LBT model, we obtain good descriptions of the nuclear modification factors for both light and heavy flavor hadrons in various centralities at different colliding energies, as shown in Figure (2, 3, 4).

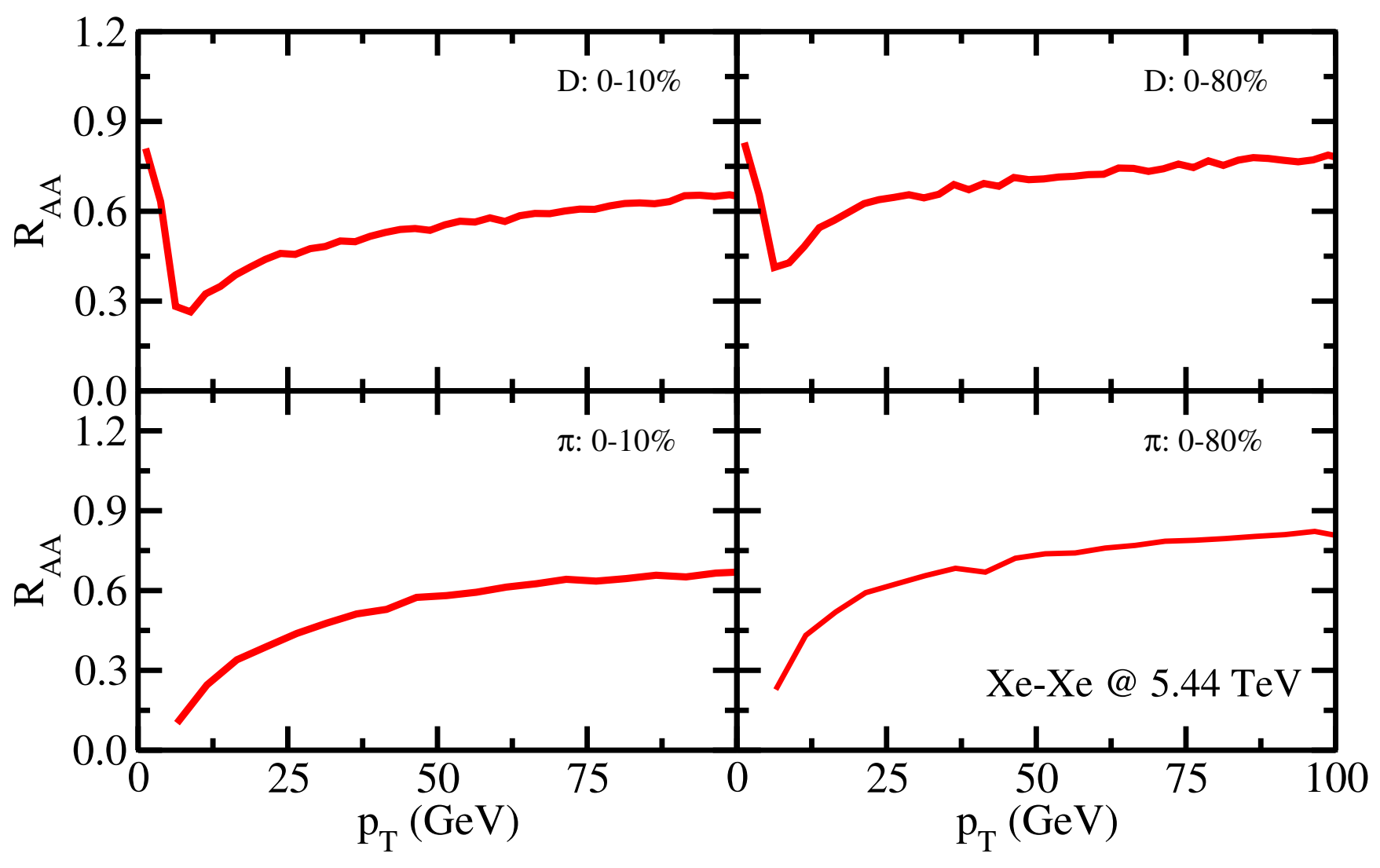

Figure 5: Nuclear modification factor $R_{\rm AA}$ for D and π production in 5.44 A TeV Xe-Xe collisions at the LHC.

The prediction for 5.44A TeV Xe-Xe collisions is presented in Figure (5). Compared to Figure (4), the nuclear modification effects in 5.44A TeV Xe-Xe collisions are typically smaller than 5.02A TeV Pb-Pb collisions for the same centrality classes due to smaller sizes of the produced QGP matter.

Conclusions

- We have built the Linearized Boltzmann Transport (LBT) model to include both heavy and light flavor partons on the same footing when they undergo both elastic and inelastic interactions in QGP.
- With a hydrodynamic description of the dynamical evolution of the bulk medium, we have achieved good descriptions of nuclear modification data for both light hadrons and D mesons for various collision centralities at RHIC and the LHC energies.
- The prediction for ligh hadron and D meson nuclear modifications in 5.44A TeV Xe-Xe collisons at the LHC is presented.
- Future directions: heavy and light flavor jets and jet substructures, heavy-light correlations, jet-induced medium excitations and medium response, hadronization, soft and hard correlations, etc.

Main references

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