Extracting jet transport coefficient via single hadron and dihadron productions in high-energy heavy-ion collisions[1]

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Abstract

We study the suppressions of high transverse momentum single hadron and dihadron productions in high-energy heavy-ion collisions based on the framework of a next-to-leading-order perturbative QCD parton model combined with the higher-twist energy loss formalism. Our model can provide a consistent description for the nuclear modification factors of single hadron and dihadron productions in central and non-central nucleus-nucleus collisions at RHIC and the LHC energies. We quantitatively extract the value of jet quenching parameter $\hat{q}$ via a global χ^2 analysis, and obtain $\hat{q}/T^3 = 4.1 \sim 4.4$ at $T = 378$ MeV at RHIC and $\hat{q}/T^3 = 2.6 \sim 3.3$ at $T = 486$ MeV at the LHC, which are consistent with the results from JET Collaboration. We also provide the predictions for the nuclear modification factors of dihadron productions in Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV and in Xe+Xe collisions at $\sqrt{s_{\rm NN}} = 5.44$ TeV.

NLO pQCD parton model with modified fragmentation functions

♦ In A+A collisions, dihadron production can be calculated as:

$$\frac{dN^{h_1h_2}_{AB}}{dy^{h_1}d^2p_T^{h_1}dy^{h_2}d^2p_T^{h_2}} = \sum_{abcd}\int \frac{dz_c}{z_c^2}\frac{dz_d}{z_d^2} d^2r t_A(\vec{r})t_B(\vec{r}+\vec{b})x_a f_{a/A}(x_a,\mu^2,\vec{r}) \times x_b f_{b/B}(x_b,\mu^2,\vec{r}+\vec{b}) \times \frac{1}{\pi}\frac{d\sigma_{ab\to cd}}{d\hat{t}}\tilde{D}_c^{h_1}(z_c,\mu^2,\Delta E_c) \times \tilde{D}_d^{h_2}(z_d,\mu^2,\Delta E_d)\times\delta^2\left(\frac{\vec{p}_T^{h_1}}{z_c}+\frac{\vec{p}_T^{h_2}}{z_d}\right)+O(\alpha_s^3). \quad (1)$$

$t_A(\vec{r})$–thickness function: Woods-Saxon, $f_{a/A}$–PDF: CT14, EPPS16,

$\frac{d\sigma}{dt}$–hard scattering cross section, $\tilde{D}_c^{h_1}(z_c,\mu^2,\Delta E_c)$–Kretzer, modified FFs.

♦ Modified fragmentation functions in QGP medium:

$$\tilde{D}_c^h(z_c,\mu^2,\Delta E_c) = (1-e^{-\langle N_g\rangle})\left[\frac{z_c'}{z_c}D_c^h(z_c',\mu^2)+\langle N_g\rangle\frac{z_g'}{z_c}D_g^h(z_g',\mu^2)\right] + e^{-\langle N_g\rangle}D_c^h(z_c,\mu^2). \quad (2)$$

♦ Total energy loss of jet in high-twist method:

$$\frac{\Delta E}{E} = \frac{2C_A\alpha_s}{\pi}\int d\tau\int\frac{dl_T^2}{l_T^4}\int dz\times\left[1+(1-z)^2\right]\hat{q}\sin^2\left(\frac{l_T^2\tau}{4z(1-z)E}\right). \quad (3)$$

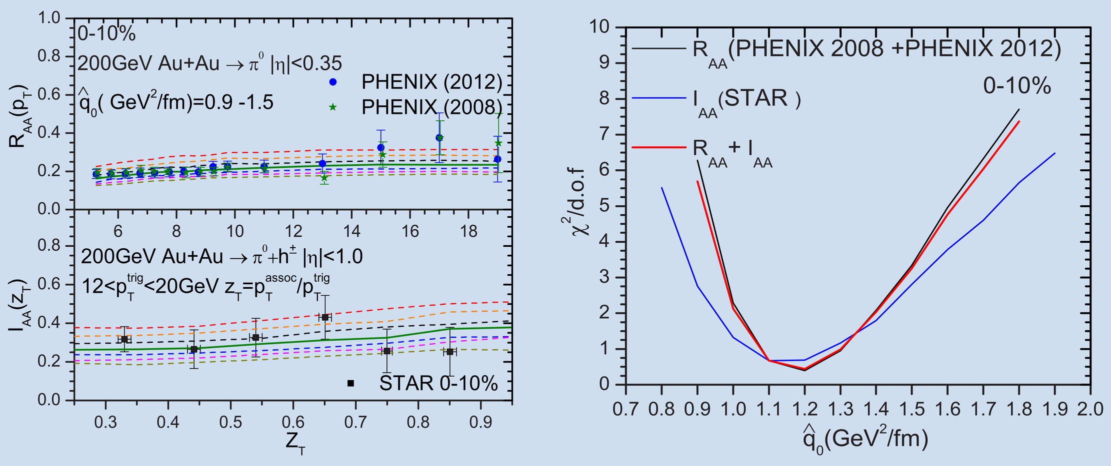
♦ Single hadron suppression factor: $R_{AA} = \frac{dN_{AA}/dyd^2p_T}{T_{AA}(b)d\sigma_{pp}/dyd^2p_T}$.

Dihadron: $I_{AA}(z_T) = \frac{D_{AA}(z_T)}{D_{pp}(z_T)} = \frac{D_{AA}(p_T^{assoc})}{D_{pp}(p_T^{assoc})}$, where $z_T = p_T^{assoc}/p_T^{trig}$.

Au + Au collisions at RHIC

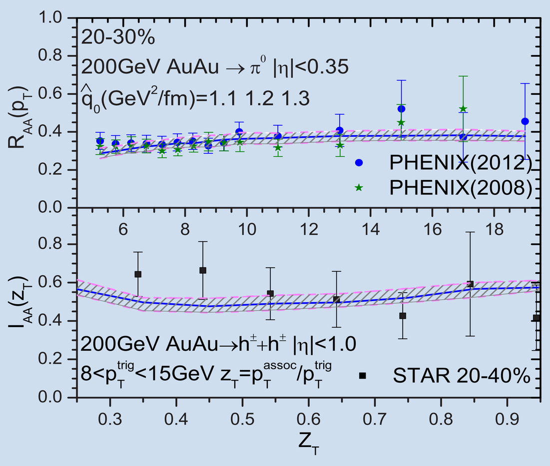
♦ 0 - 10%

Single hadron and dihadron suppression factors. And a global χ^2 fit is performed for both of them.



Dihadron $\hat{q}_0$ is consistent with the single hadron; $\hat{q}/T^3 = 4.1 \sim 4.4$ at $T = 378$ MeV at RHIC.

♦ 20 - 40%

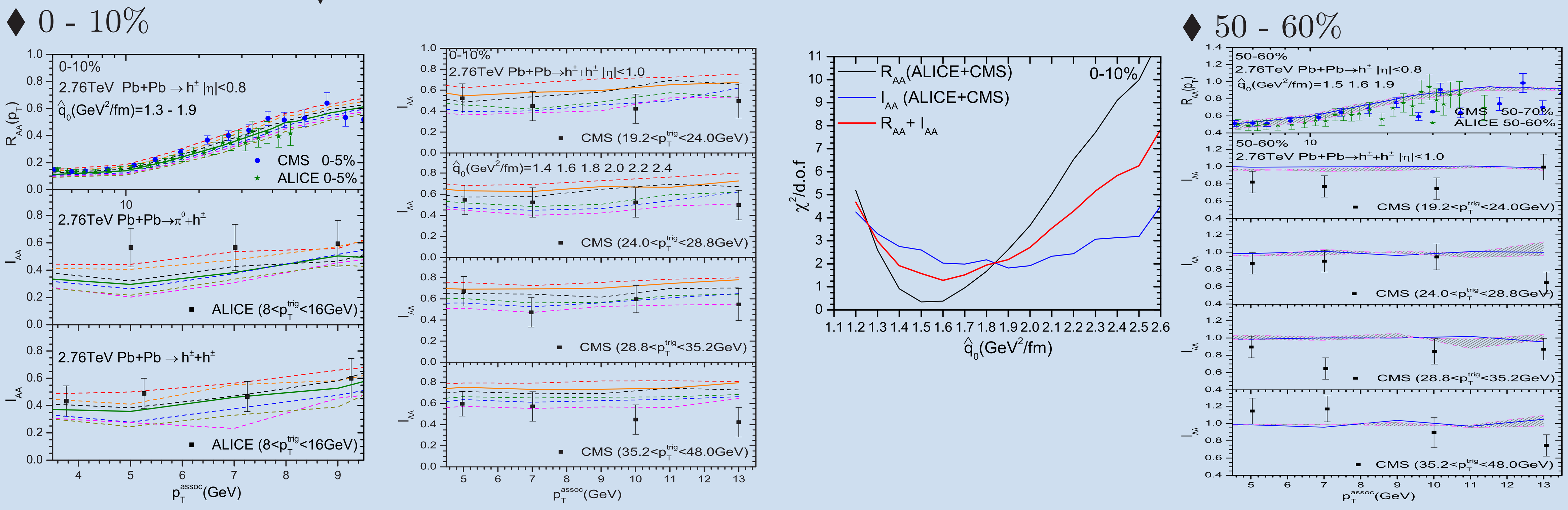


Our model can provide a good description of experimental data in both central and non-central Au + Au collisions at RHIC.

Pb + Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV at the LHC

$\hat{q}/T^3 = 2.6 \sim 3.3$ at $T = 486$ MeV at the LHC. And our jet energy loss model can provide a consistent description of both single hadron and dihadron nuclear suppression factors in both central and non-central Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV.

♦ 0 - 10% ♦ 50 - 60%



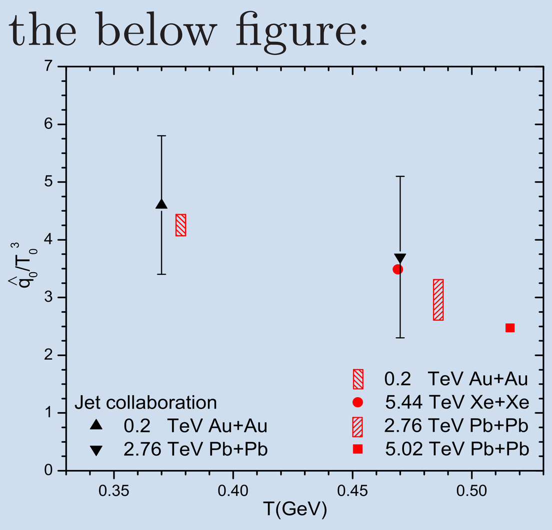
△ One interesting result is that for both Au + Au collisions at RHIC and Pb + Pb collision at the LHC, the dihadron I_{AA} are typically larger than single hadron R_{AA} given the same nucleus-nucleus collision conditions. This can be explained by that high p_T single hadrons mainly come from surface bias emission jets, while high p_T dihadrons come from a combination of surfacial and tangential jets as well as punching-through jets. On average in a A + A event, the total energy loss for jets in the surface bias case is larger than in the case with punching-through jets.

Conclusions

♦ Large p_T hadrons are studied in a NLO pQCD parton model in heavy-ion collisions with mFFs due to jet quenching.

♦ Our model can provide a consistent description for the nuclear modification factors of single hadron R_{AA} and dihadron I_{AA} in central and non-central nucleus-nucleus collisions at RHIC and the LHC energies.

♦ The quantitative results of the scaled jet quenching parameter $\hat{q}/T^3$ via single hadron and dihadron suppression data at RHIC and the LHC are shown in the below figure:



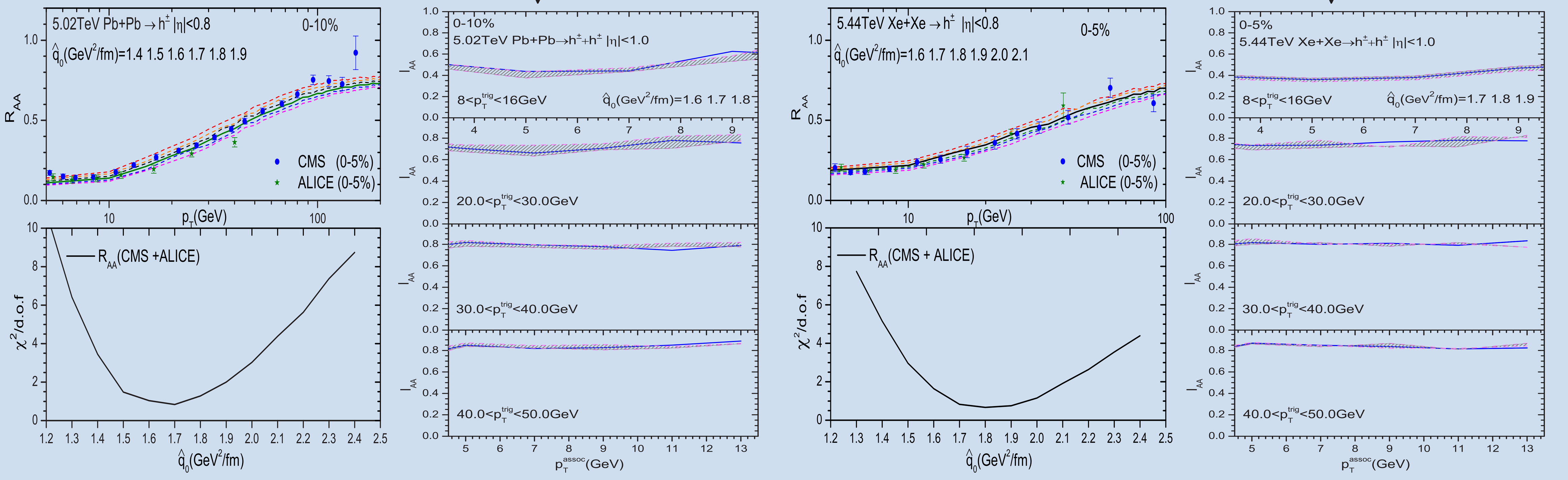
The numerical analysis shows that $\hat{q}/T^3$ decreases as one increases the temperature, which can be understood as decreasing jet-medium interaction strength with increasing temperature.

♦ The dihadron I_{AA} are typically larger than single hadron R_{AA} given the same nucleus-nucleus collision conditions and the values of I_{AA} also increase as one increases the trigger hadron p_T.

Pb + Pb at 5.02 TeV & Xe + Xe at 5.44 TeV at the LHC

Via single hadron productions, $\hat{q}/T^3 = 2.5$ at $T = 516$ MeV at Pb + Pb collisions; $\hat{q}/T^3 = 3.5$ at $T = 469$ MeV at Xe + Xe collisions. Using the extracted $\hat{q}_0$ values from fitting R_{AA} data, we present our predictions for dihadron nuclear modification factor I_{AA}.

♦ 0 - 10% Pb + Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV ♦ 0 - 5% Xe + Xe collisions at $\sqrt{s_{\rm NN}} = 5.44$ TeV



△ Another interesting observation is that as the values of I_{AA} also increase as one increases the trigger hadron transverse momentum. Similar to why $R_{AA} < I_{AA}$, this can also be explained by the contributions fraction of punching-through jets. With increasing trigger hadron p_T, the contribution from punching-through jets increases, thus the average total energy loss of jets decreases.

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