EFFECTS OF COLOR DECOHERENCE AND VIRTUALITY ON JET QUENCHING

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Abstract

In this study, we discuss the effects of color decoherence and virtuality evolution on jet quenching observed in relativistic heavy-ion collisions. First, we show that the jet multiplicity, calculated according to the color coherence picture, provides a reasonable description of inclusive jet data up to $p_T \sim 1000$ GeV in p + p collisions at the LHC. Building on this understanding of the virtuality evolution of vacuum jets, we combine the color coherence picture (angular ordering) with color decoherence in QCD matter at a virtuality determined by the interplay between vacuum evolution and medium-induced momentum broadening. Using radiative energy loss calculated within the BDMPS-Z formalism and modeling QCD bulk matter with the (2+1)-dimensional OSU hydrodynamic code, we perform a detailed calculation of the inclusive jet modification factor R_{AA} in Pb + Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Our results demonstrate that the observed R_{AA} spectrum at high p_T, which requires larger energy loss than at lower p_T, is correlated with jet multiplicity as predicted by the virtuality evolution of jets. This study indicates that virtuality evolution and color decoherence play critical roles in providing a comprehensive understanding of jet quenching.

1. Nuclear Modification Factor R_{AA}

Differential cross section in p + p collisions:

$$\frac{\mathrm{d}\sigma^{pp}}{\mathrm{d}p_{Tc}} = 2p_{Tc}\sum_{a,b,d}\int \mathrm{d}y_c\mathrm{d}y_d x_a f_{a/p}(x_a,\mu^2)x_b f_{b/p}(x_b,\mu^2)\,\frac{\mathrm{d}\hat{\sigma}_{ab\to cd}}{\mathrm{d}\hat{t}} \tag{1}$$

Differential cross section in A + A collisions:

$$\frac{\mathrm{d}\sigma^{AA}}{\mathrm{d}p_T} = \int \mathrm{d}x\mathrm{d}y\hat{T}_{AB}(x,y)\frac{\mathrm{d}\phi}{2\pi}\int \mathrm{d}\epsilon D(\epsilon,\omega_c(x,y,\phi;\hat{q}_0))\left.\frac{\mathrm{d}\sigma^{pp}}{\mathrm{d}p'_T}\right|_{p'_T=p_T+\epsilon} \tag{2}$$

BDMPS-Z formalism:

$$\epsilon D(\epsilon) = \sqrt{\frac{\alpha^2\omega_c}{2\epsilon}}\exp\left\{-\pi\frac{\alpha^2\omega_c}{2\epsilon}\right\} \tag{3}$$

$$\omega_c = \frac{\hat{q}L^2}{2} = \int \hat{q}\tau\mathrm{d}\tau = \hat{q}_0\int\frac{T^3(\tau)}{T_0^3(\tau_0)}\tau\mathrm{d}\tau \tag{4}$$

Nuclear modification factor:

$$R_{AA} = \frac{1}{\int \mathrm{d}x\mathrm{d}y\hat{T}_{AB}(x,y)}\,\frac{\mathrm{d}\sigma^{AA}/\mathrm{d}p_T}{\mathrm{d}\sigma^{pp}/\mathrm{d}p_T} \tag{5}$$

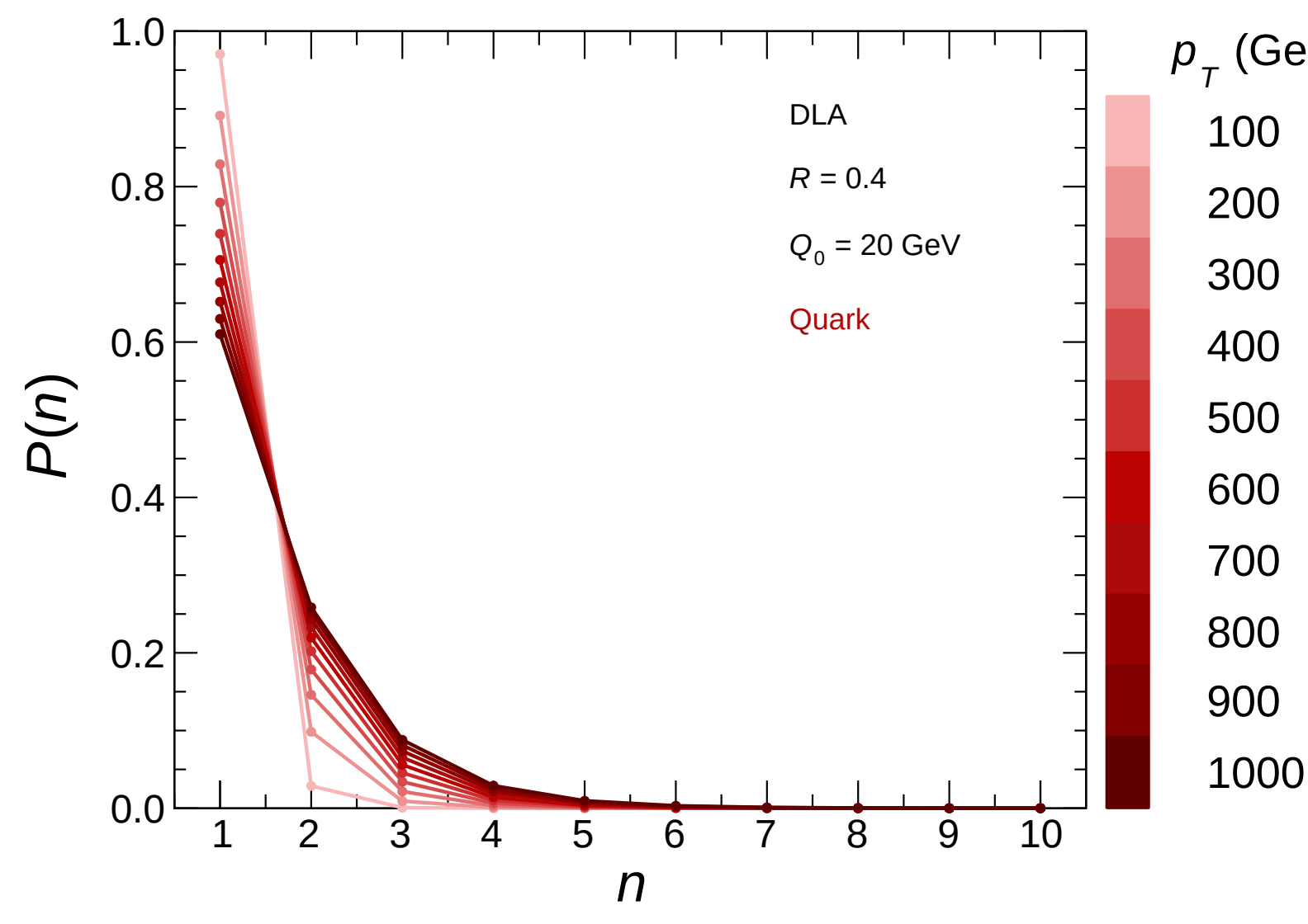
3. Jet Multiplicity Distributions

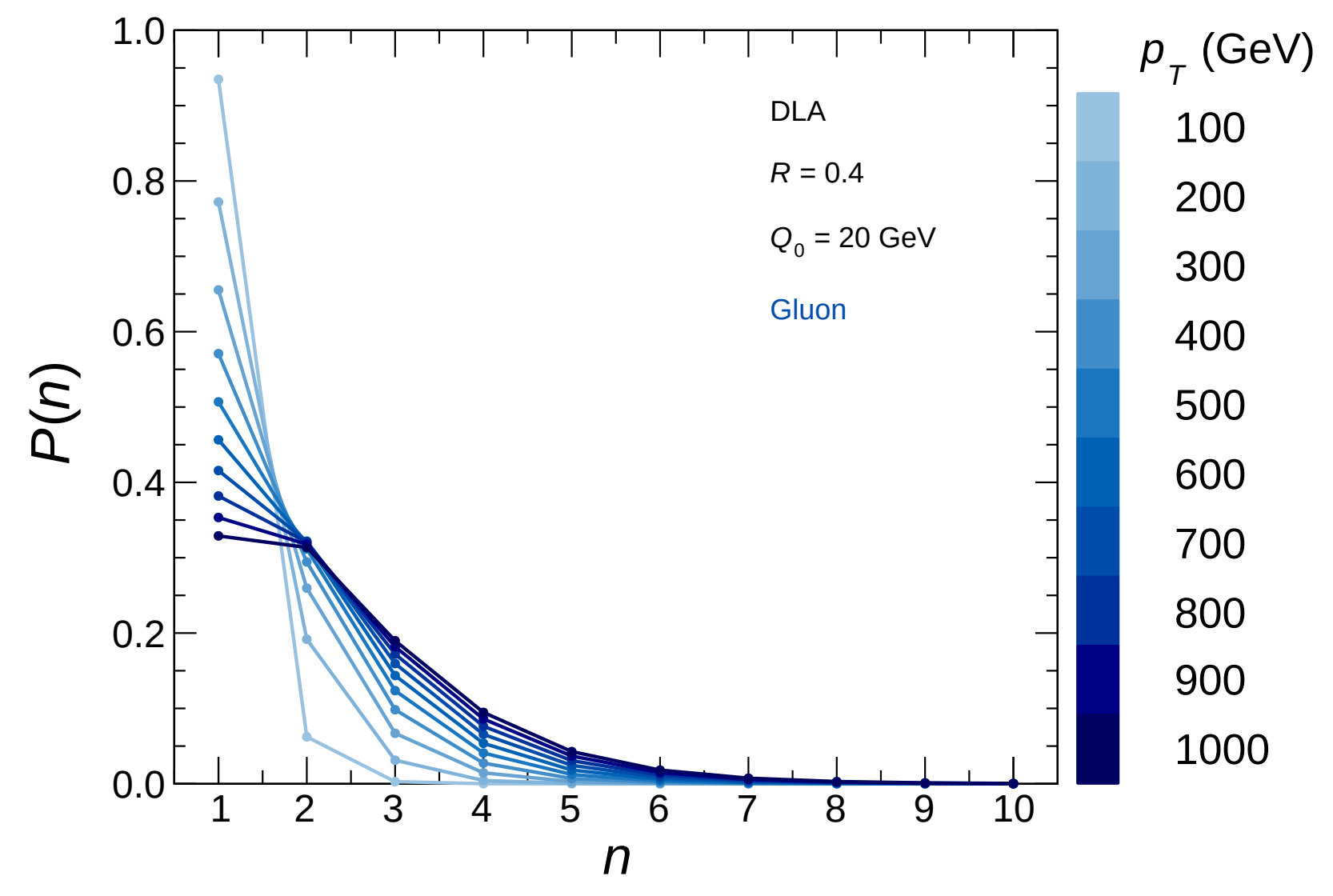
Jet multiplicity distributions in double logarithmic approximation (DLA):

$$P_a(1) = \exp\left\{-c_a\int_0^y \mathrm{d}\bar{y}\,(y-\bar{y})\gamma_0^2\right\} \tag{6}$$

$$P_a(n+1) = \sum_{k=1}^{n}\frac{k}{n}P_a(n+1-k) \times c_a\int_0^y \mathrm{d}\bar{y}\,(y-\bar{y})\gamma_0^2 P_g(k,\bar{y}) \tag{7}$$

where the subscript a denotes the parton type. $\gamma_0^2 = 2N_c\alpha_s(k_\perp^2)/\pi$, and $c_a = c_g \equiv C_A/N_c = 1$ for gluon jets and $c_a = c_q \equiv C_F/N_c = 4/9$ for quark jets. We compute $P_a(n)$ up to $n = 10$ with $Q_0 = 20$ GeV and $R = 0.4$.

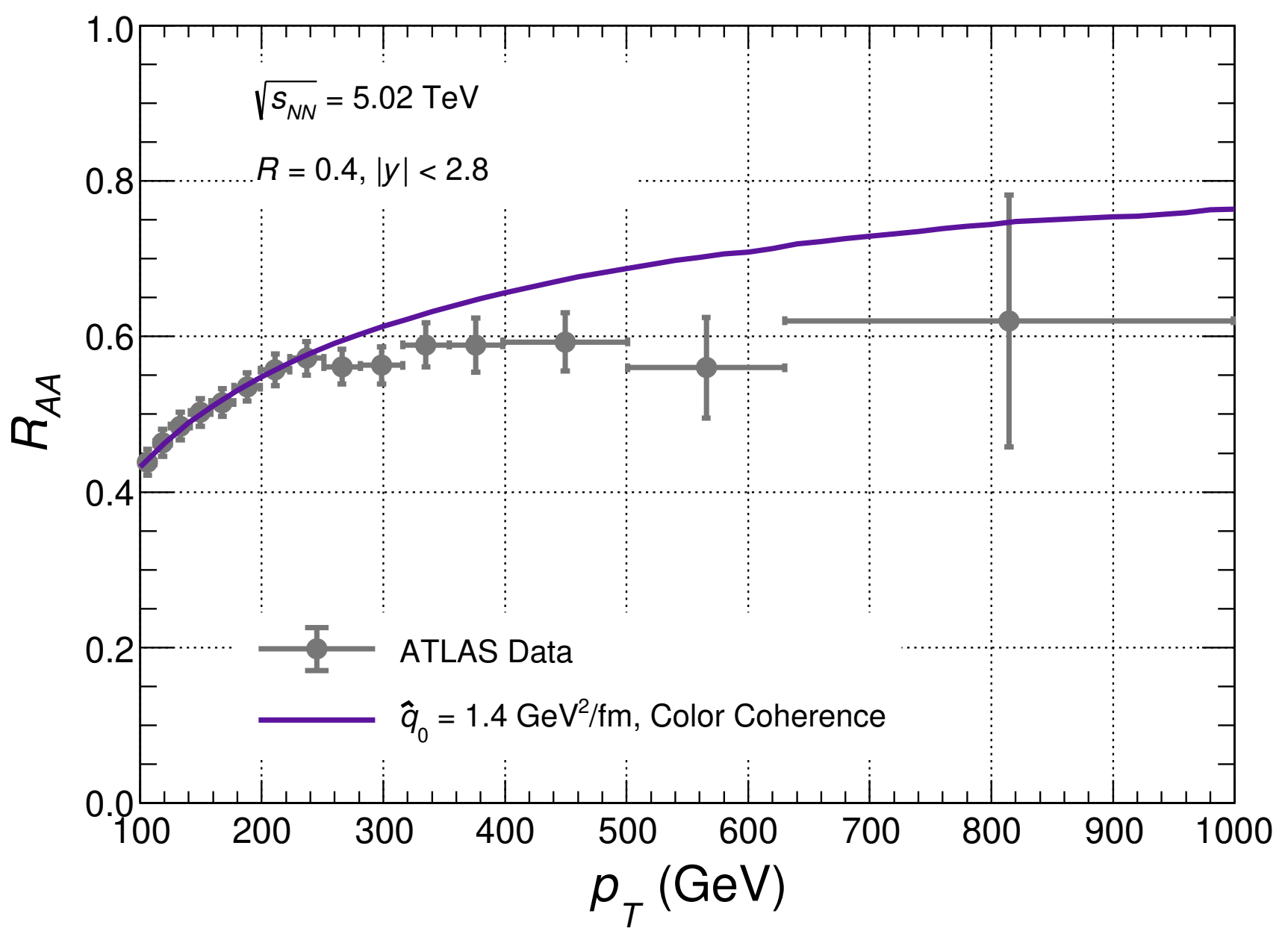




2. Jet R_{AA} for Color Coherence

For the low p_T region, our results align with ATLAS experimental data, highlighting the impact of the color coherence effect.

For the high p_T region, the energy loss predicted by BDMPS-Z formalism is smaller than that observed in experimental data for single inclusive jets.

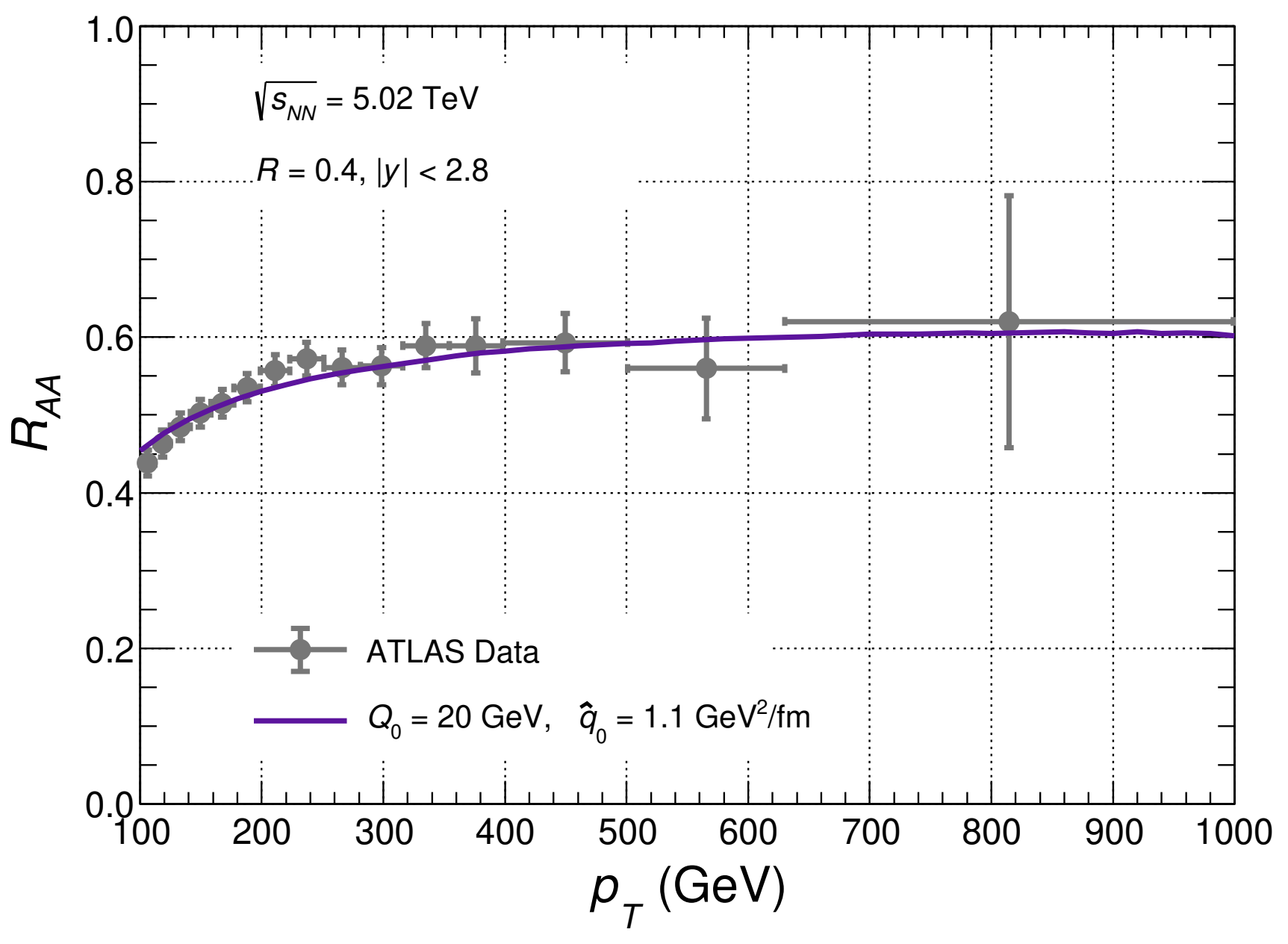


4. Jet R_{AA} for Color Decoherence

Differential cross section in A + A collisions with the jet multiplicity distributions:

$$\begin{aligned}\frac{\mathrm{d}\sigma^{AA}}{\mathrm{d}p_T} &= \sum_{a=q,g}\int \mathrm{d}x\mathrm{d}y\hat{T}_{AB}(x,y)\frac{\mathrm{d}\phi}{2\pi}P_a(1,p'_T)\int \mathrm{d}\epsilon_1 D_a(\epsilon_1,\omega_{c,a})\left.\frac{\mathrm{d}\sigma_a^{pp}}{\mathrm{d}p'_T}\right|_{p'_T=p_T+\epsilon_1}\\ &+\sum_{n=2}^{10}\sum_{a=q,g}\int \mathrm{d}x\mathrm{d}y\hat{T}_{AB}(x,y)\frac{\mathrm{d}\phi}{2\pi}P_a(n,p'_T)\int \mathrm{d}\epsilon_1 D_a(\epsilon_1,\omega_{c,a})\\ &\times\Big(\prod_{i=2}^{n}\int \mathrm{d}\epsilon_i D_g(\epsilon_i,\omega_{c,g})\Big)\left.\frac{\mathrm{d}\sigma_a^{pp}}{\mathrm{d}p'_T}\right|_{p'_T=p_T+\epsilon_1+\sum_{i=2}^{n}\epsilon_i}\end{aligned} \tag{8}$$

For the color decoherence effect, our results accurately describe the experimental data across all p_T regions.



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