CUJET2.0: A Perturbative QCD Model for Azimuthal Jet Flavor Tomography at RHIC and LHC

Jiechen Xu[1], Alessandro Buzzatti[1,2], Miklos Gyulassy[1,2,3]

[1]Department of Physics, Columbia Unverisity, New York, NY, USA

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

[3]Institute for Particle and Nuclear Physics, Wigner RCP, HAS, Budapest, Hungary

Introduction

Motivation Use perturbative QCD based approach to quantitatively predict jet quenching observables in ultrarelativistic heavy-ion collisions at RHIC and LHC, particularly high transverse momentum ($p_T > 5$ GeV/c) nuclear modification factor $R^f_{AA}(p_T,\phi,\eta=0;\sqrt{s},b)$ and elliptic flow $v^f_2(p_T,\eta=0;\sqrt{s},b)$ for jet fragment flavor $f=\pi,D,B,e$ in AA collisions at $\sqrt{s_{NN}} = 0.2-2.76$ TeV with impact parameter $b=0-10$ fm.

Model We built a pQCD based jet tomography model, CUJET2.0 [1, 2], which combined running coupling (D)GLV opacity series [3, 4], Thoma-Gyulassy (TG) elastic energy loss [5], and 2+1D viscous hydrodynamical bulk evolution profile [7].

(D)GLV Opacity Expansion For radiative jet energy loss, we compute $n=1$ DGLV opacity series, with multi-scale running strong coupling, in a dynamcial QCD medium [3]:

$$x_E\frac{dN_g^{n=1}}{dx_E} = \frac{18C_R}{\pi^2}\frac{4+n_f}{16+9n_f}\int d\tau\,\rho(\mathbf{z})\int d\mathbf{k}\int d\mathbf{q}$$
$$\times\ \alpha_s\!\left(\frac{\mathbf{k}^2}{x_+(1-x_+)}\right)\frac{\alpha_s^2(\mathbf{q}^2)}{(\mathbf{q}^2+f_E^2\mu^2(\mathbf{z}))(\mathbf{q}^2+f_M^2\mu^2(\mathbf{z}))}$$
$$\times\ \frac{-2(\mathbf{k}-\mathbf{q})}{(\mathbf{k}-\mathbf{q})^2+\chi^2(\mathbf{z})}\left(\frac{\mathbf{k}}{\mathbf{k}^2+\chi^2(\mathbf{z})}-\frac{(\mathbf{k}-\mathbf{q})}{(\mathbf{k}-\mathbf{q})^2+\chi^2(\mathbf{z})}\right)$$
$$\times\ \left(1-\cos\left(\frac{(\mathbf{k}-\mathbf{q})^2+\chi^2(\mathbf{z})}{2x_+E}\tau\right)\right)\left(\frac{x_E}{x_+}\right)J(x_+(x_E))\ .$$

Here $\mathbf{z}=(x_0+\tau\cos\phi, y_0+\tau\sin\phi;\tau)$; $\chi^2(\mathbf{z}) = M^2x_+^2 + m_g^2(\mathbf{z})(1-x_+)$, $m_g^2(\mathbf{z}) = f_E^2\mu^2(\mathbf{z})/2$, 1-HTL Debye mass $\mu(\mathbf{z}) = g(\mathbf{z})T(\mathbf{z})\sqrt{1+n_f/6}$, $g(\mathbf{z}) = \sqrt{4\pi\alpha(4T^2(\mathbf{z}))}$.

Running Strong Coupling $\alpha_s(Q^2)$ takes the form of Zakharov's 1-loop pQCD running [6] that is cutoff in the infrared when coupling strength reaches a maximum value α_{max}:

$$\alpha_s \longrightarrow \alpha_s(Q^2) = \begin{cases}\alpha_{max} & \text{if } Q^2\le Q^2_{min}\ ,\\ \dfrac{4\,\pi}{9\,\log(Q^2/\Lambda^2_{QCD})} & \text{if } Q^2 > Q^2_{min}\ .\end{cases}$$

Where the minimum running scale Q_{min} is fixed by α_{max} with $Q^2_{min} = \Lambda^2_{QCD}\exp\{4\pi/9\alpha_{max}\}$.

Model Parameters CUJET2.0 has 3 adjustable parameters: (α_{max}, f_E, f_M), corresponding to an assumed upper bound on the vacuum running coupling in the infrared, a chromo-electric screening mass scale, and a chromo-magnetic screening mass scale. We present results with $(f_E,f_M)=(1,0)$, corresponding to HTL scenario in dynamical QCD medium [3].

Bulk Evolution Profile Quark-Gluon Plasma's local number density $\rho(\mathbf{z})$ and temperature $T(\mathbf{z})$ are generated from VISH2+1 code [7], which has MC-Glauber initial condition, $\tau_0 = 0.6$ fm/c, s95p-PCE equation of state, $\eta/s = 0.08$ and $T_f = 120$ MeV. The DGLV and TG integral is cutoff at a dynamical $T(\mathbf{z})|_{\tau_{max}} = T_f$ hypersurface to take into account realistic path length fluctuations.

Elastic Energy Loss For elastic energy loss, Thoma-Gyulassy [5] formula with running coupling [4] is computed:

$$\frac{dE(\mathbf{z})}{d\tau} = -C_R\pi\,\alpha_s(\mu(\mathbf{z})^2)\,\alpha_s(E(\mathbf{z})T(\mathbf{z}))\,T(\mathbf{z})^2\left(1+\frac{n_f}{6}\right)$$
$$\times\ \log\left\{\frac{4T(\mathbf{z})\sqrt{E(\mathbf{z})^2-M^2}}{\left[E(\mathbf{z})-\sqrt{E(\mathbf{z})^2-M^2}+4T(\mathbf{z})\right]\mu(\mathbf{z})}\right\}\ .$$

Fluctuations and Convolutions Poisson ansatz is assumed in the radiative sector for incoherent multiple gluon emissions. Gaussian fluctuation is applied to the elastic energy loss. The total energy loss probability distribution is the convolution of radiative and elastic. It is then convoluted with (1) pQCD pp production spectra, (2) Glauber AA initial jet distribution, and (3) fragmentation functions to get the inclusive leading hadron spectra in AA collisions.

Numerical Results

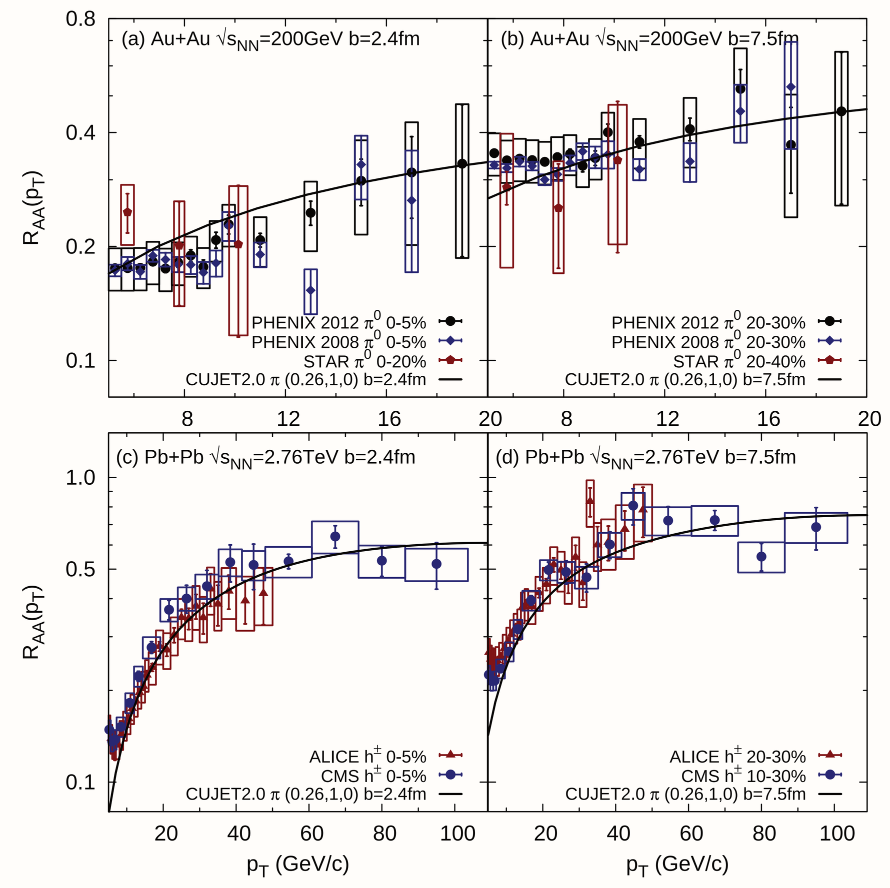

Figure 1 : CUJET2.0 $R^{\pi}_{AA}(p_T)$ compared with RHIC and LHC data of central and semi-peripheral AA collisions. In the HTL scenario ($f_E=1, f_M=0$), $\alpha_{max}=0.26$ results fit π^0, $h^{\pm}$ data from all 4 collisions.

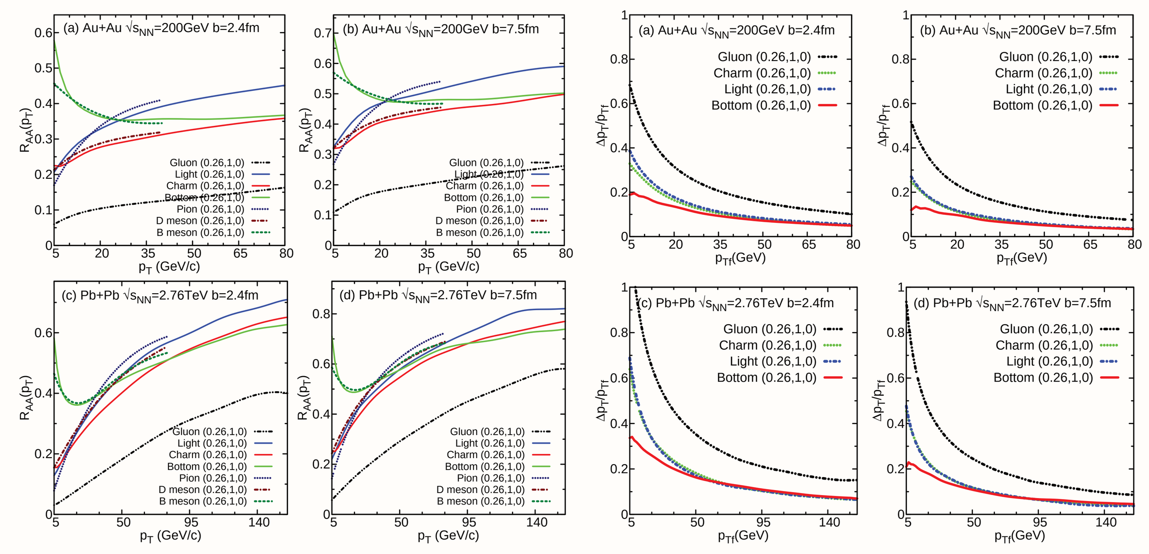

Figure 2 : CUJET2.0 results [2] of flavor dependent $R_{AA}(p_T)$ and $\frac{\Delta p_T}{p_{T_f}}(p_{T_f})$ in Au+Au 200AGeV and Pb+Pb 2.76ATeV collisions at b=2.4fm and 7.5fm.

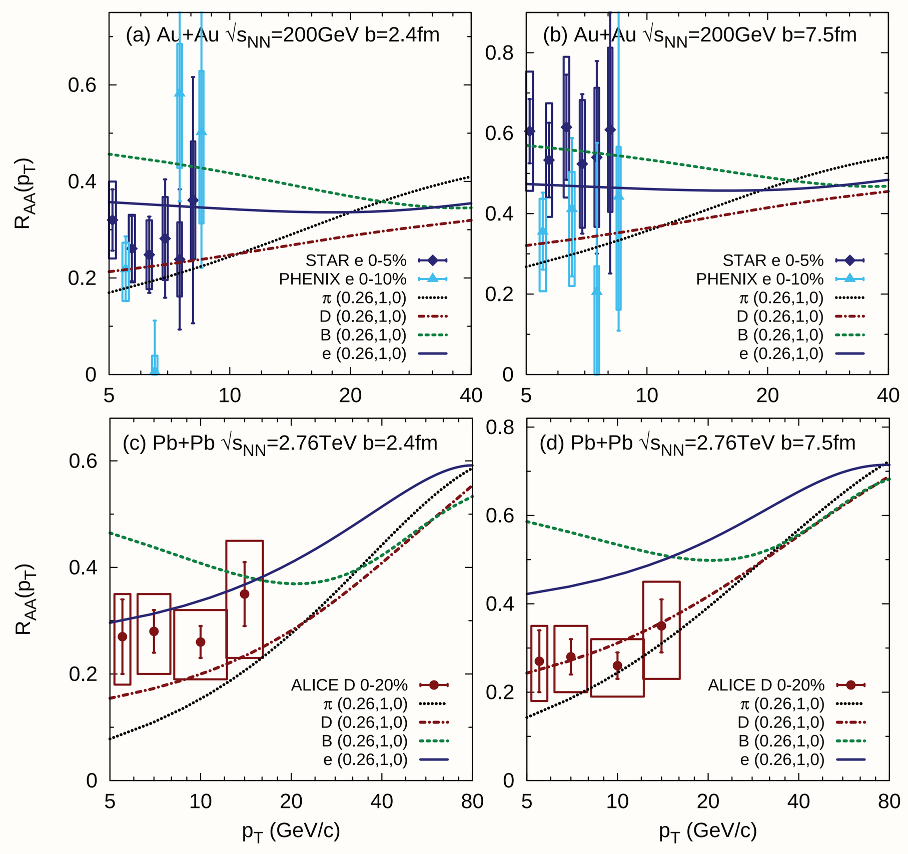

Figure 3 : Prediction of open heavy flavor and heavy flavor electron $R_{AA}(p_T)$ from CUJET2.0 $(\alpha_{max}, f_E, f_M) = (0.26, 1, 0)$. Existing data from RHIC and LHC are compared.

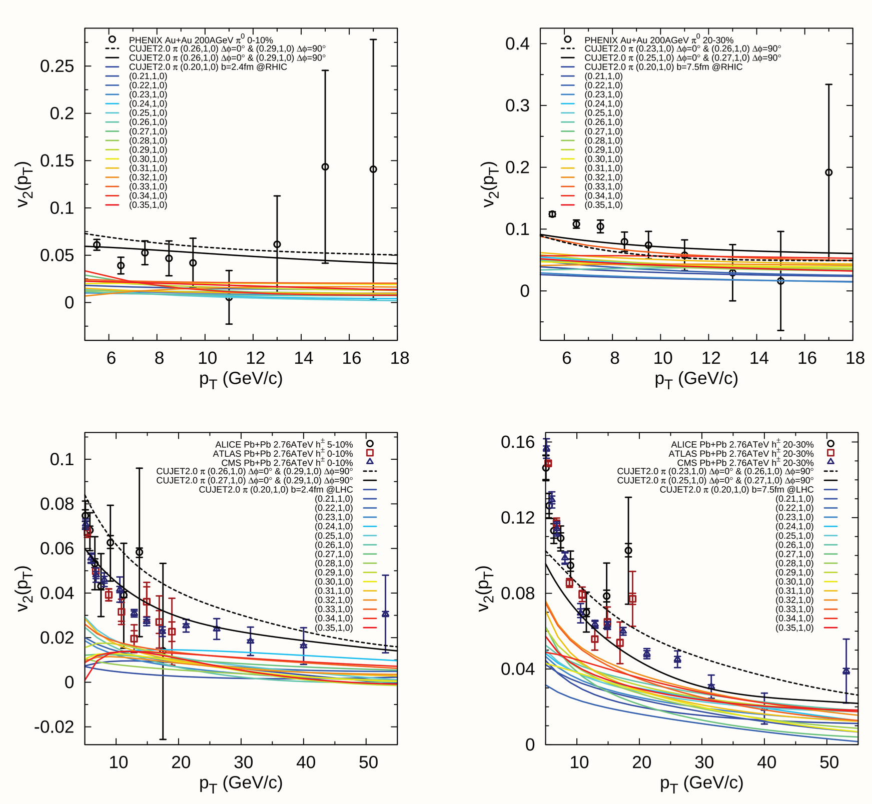

Figure 4 : CUJET2.0 $v^{\pi}_2(p_T)$ compared with corresponding RHIC and LHC $v_2^{\pi^0/h^{\pm}}(p_T)$ data.

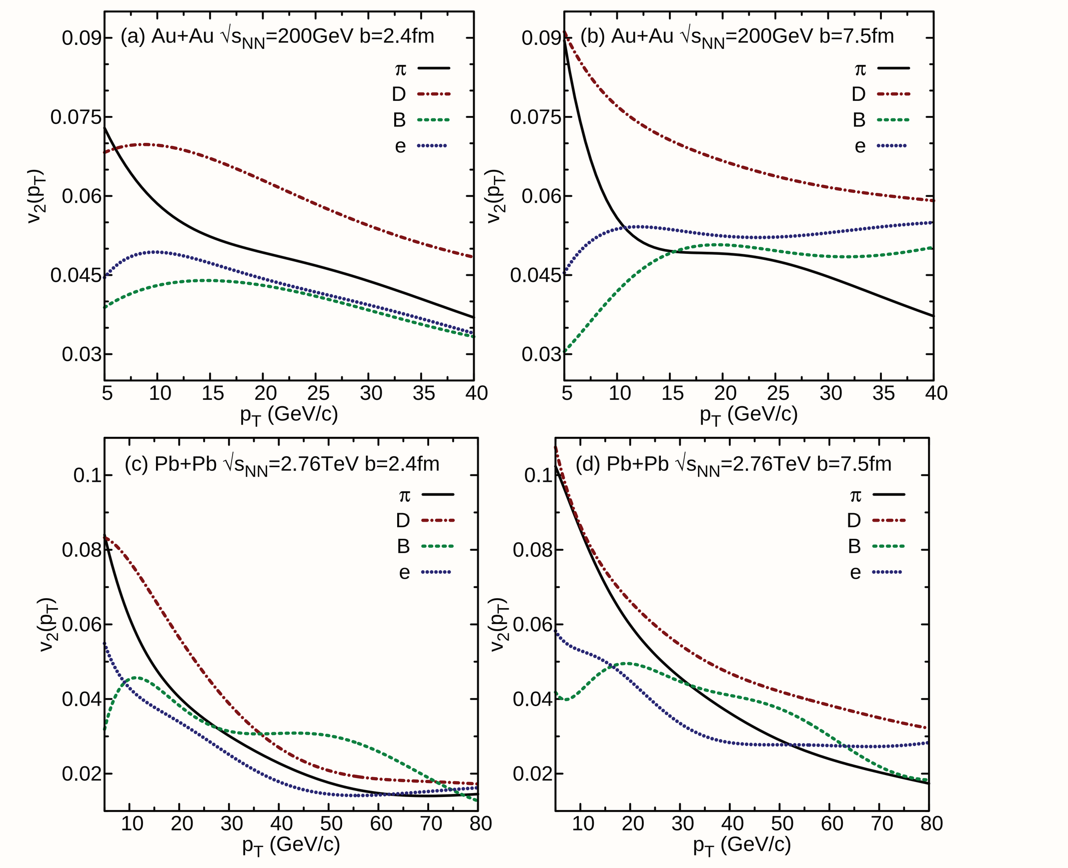

Figure 5 : CUJET2.0 prediction of heavy flavor $v_2(p_T)$ [2].

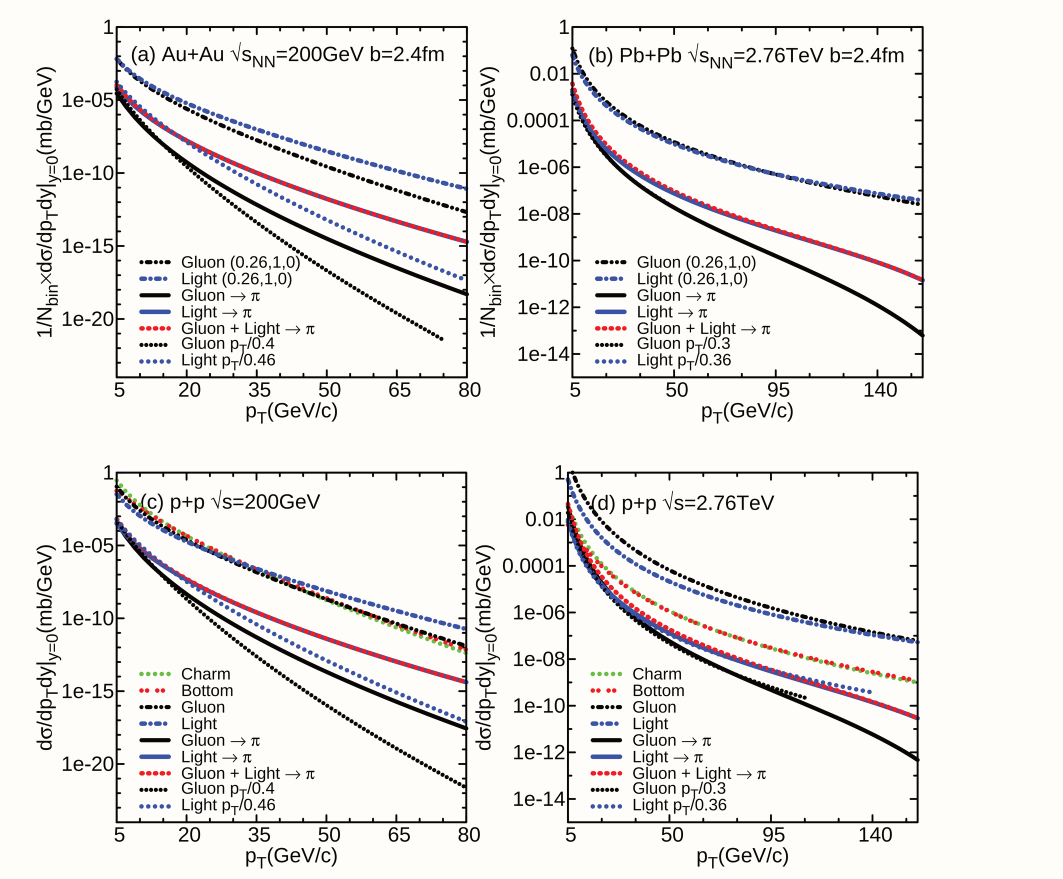

Figure 6 : Quantitative explanation of the similarity between $R^{\pi}_{AA}(p_T)$ and $R^{\text{light}}_{AA}(p_T)$ by CUJET2.0 [2].

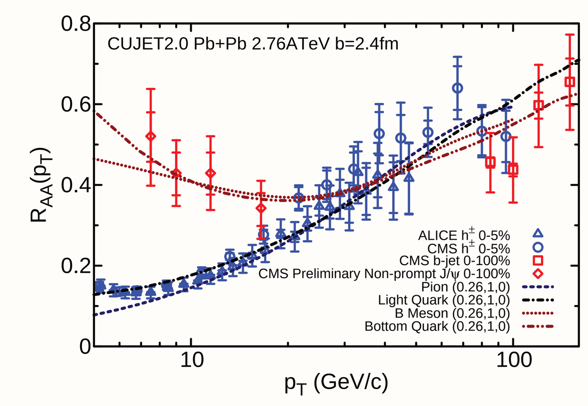

Figure 7 : The crossing of $R^{\pi}_{AA}(p_T)$ and $R^{b}_{AA}(p_T)$ predicted by CUJET2.0 [2] is consistent with LHC data.

Summary

CUJET2.0 (0.26,1,0) $R^{\pi}_{AA}(p_T)$ results agree with RHIC and LHC data at average $\chi^2/d.o.f < 1.5$ level. CUJET2.0 predicts a crossing pattern between light and heavy flavor R_{AA} which is consistent with LHC data. $v_2(p_T)$ is sensitive to 10% azimuthal variations of the path averaged α_{max}.

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