Heavy and light flavor jet quenching in Au+Au,Pb+Pb and Xe+Xe collisions

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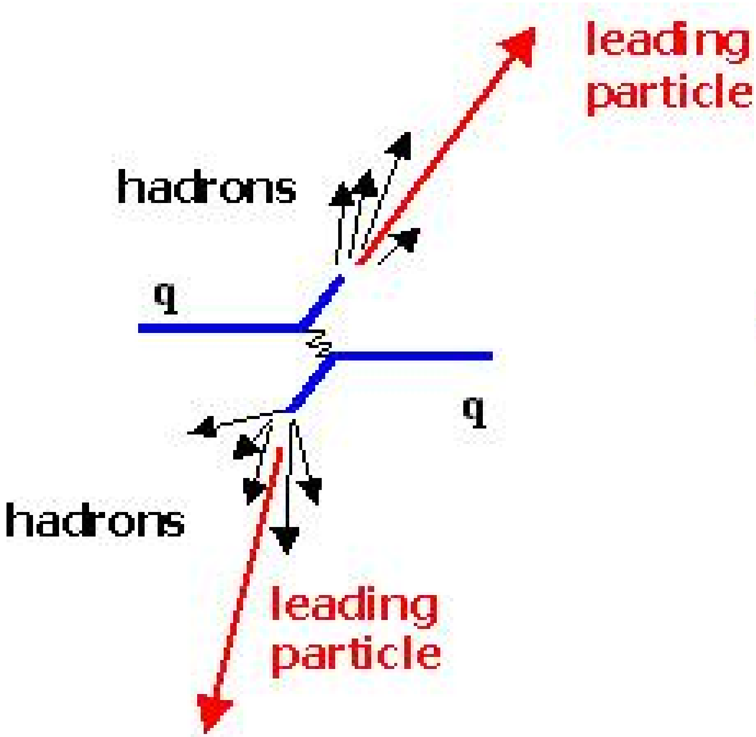
Outline

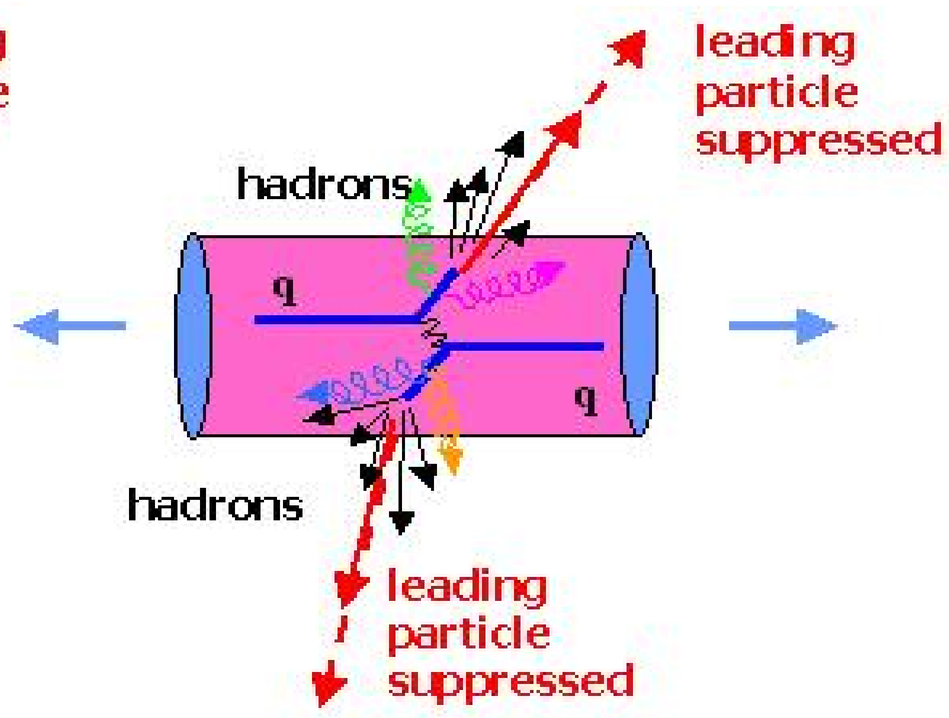
- **Introduction**
- **A Linear Boltzmann Transport (LBT) model for heavy and light flavor jet quenching**
- **The nuclear modification factor of heavy and light hadrons**
- **Summary**

Jet Quenching in heavy-ion collisions



p+p

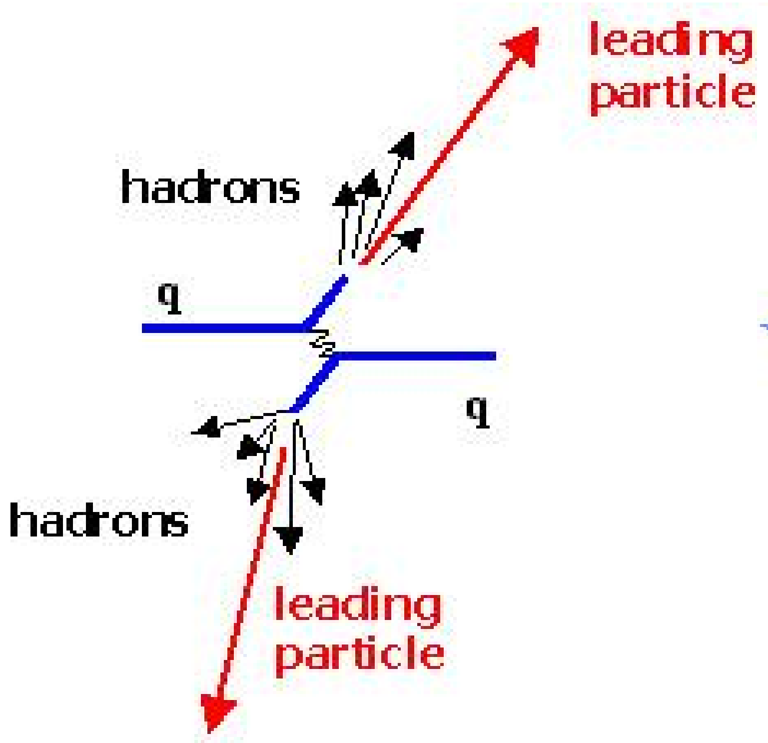
Jet quenching in quark-gluon plasma



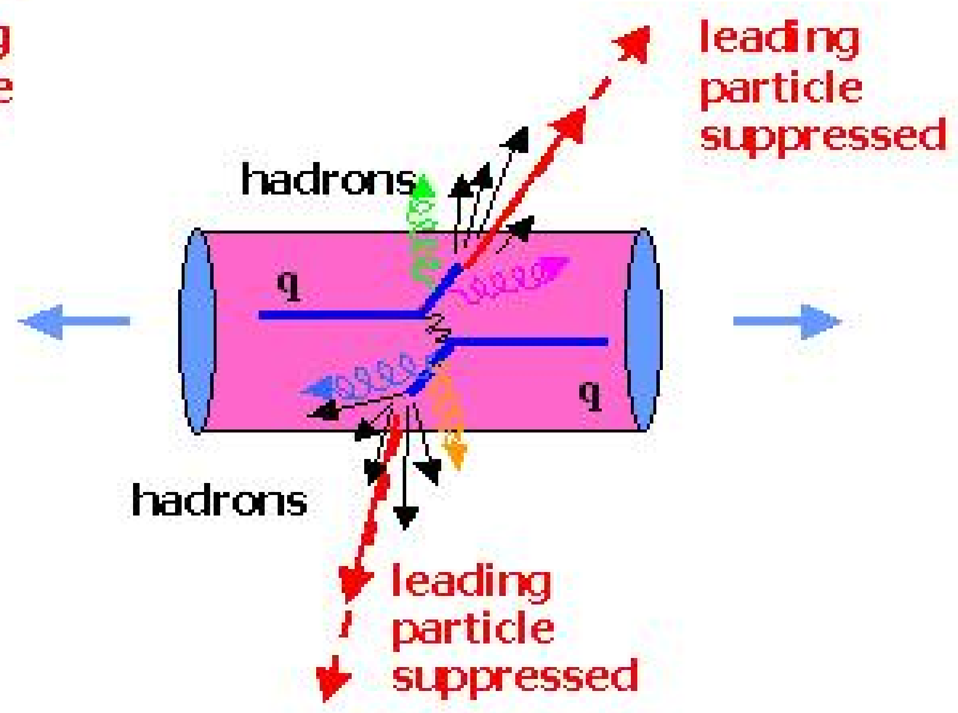
A+A

In medium parton energy loss -> "Jet quenching" (Bjorken 1982)

Jet Quenching in heavy-ion collisions



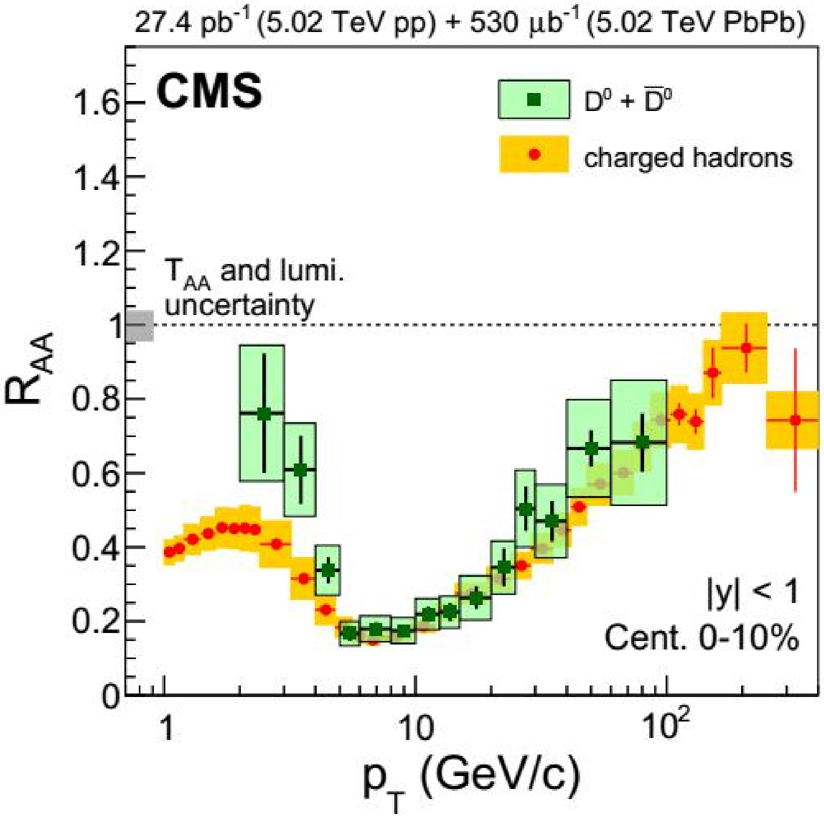
Jet quenching in quark-gluon plasma



Jet quenching observables for understanding the parton-medium interaction:

=> the nuclear modifications of single inclusive hadron production, di-hadron and photon-hadron correlations, full jet production and substructure, as well as heavy-flavor meson production

Heavy and light flavor hadrons

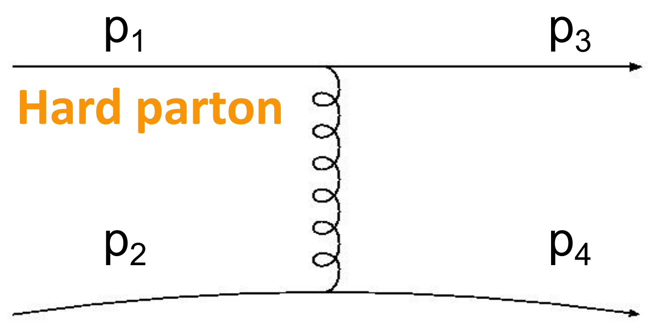


arXiv:1708.04962

$$R_{AA} = \frac{dN^{AA} / d^2 p_T dy}{N_{coll} dN^{pp} / d^2 p_T dy}$$

- **Strong nuclear modification (R_{AA}) for heavy flavor mesons comparable to light flavors:** contradictory to expectations of the mass hierarchy of parton energy loss $\Delta E_g > \Delta E_{u,d} > \Delta E_c$
- **Need a comprehensive and consistent jet quenching framework to simulate heavy and light partons dynamical evolution inside QGP medium**

A Linear Boltzmann transport (LBT) model



Elastic (collisional)

Boltzmann equation for parton "1" evolution:

$$p_1 \cdot \partial f_1(x_1, p_1) = E_1 C[f_1]$$

The collisioin term is:

$$C[f_1] \equiv \int d^3k \left[\omega(\vec{p}_1 + \vec{k}, \vec{k}) f_1(\vec{p}_1 + \vec{k}) - \omega(\vec{p}_1, \vec{k}) f_1(\vec{p}_1)\right]$$

For elastic (2->2) process, the transition rate is related to microscopic cross section as:

$$\omega_{12\to 34}(\vec{p}_1, \vec{k}) = \gamma_2 \int \frac{d^3 p_2}{(2\pi)^3} f_2(\vec{p}_2) \ \left[1 \pm f_3(\vec{p}_1 - \vec{k})\right] \ \left[1 \pm f_4(\vec{p}_1 - \vec{k})\right]$$

$$\times v_{rel} d\sigma_{12\to 34}(\vec{p}_1, \vec{p}_2 \to \vec{p}_1 - \vec{k}, \vec{p}_2 + \vec{k})$$

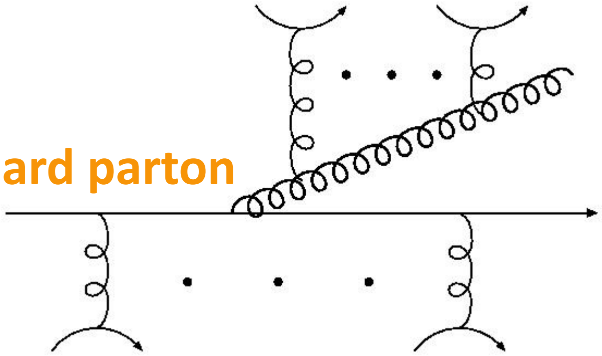
The elastic scattering rate for (2->2) process:

$$\Gamma\,(\vec{p}_1, \vec{k}) = \int d^3k\, \omega(\vec{p}_1, \vec{k})$$

$$\omega(\vec{p}_1, \vec{k}) \equiv \sum_{2,3,4} \omega_{12\to 34}(\vec{p}_1, \vec{k})$$

Cao, Luo, GYQ, Wang, PRC 2016 ; arXiv:1703.00822, etc.

A Linear Boltzmann transport (LBT) model



Include the inelastic process:

$$p_1 \cdot \partial f_1(x_1, p_1) = E_1\left(C_{el} + C_{inel}\right)$$

The inelastic scattering rate (average gluon number per unit time) is:

$$\Gamma^{inel} = \langle N_g \rangle (E, T, t, \Delta t) / \Delta t = \int dx dk_\perp^2 \frac{dN_g}{dx dk_\perp^2 dt}$$

The medium-induced gluon spectrum is:

$$\frac{dN_g}{dx dk_\perp^2 dt} = \frac{2\alpha_s C_A P(x)}{\pi k_\perp^4} \hat{q} \left(\frac{k_\perp^2}{k_\perp^2 + x^2 M^2}\right)^4 \sin^2\left(\frac{t - t_i}{2\tau_f}\right)$$

$\hat{q} : \; dp_\perp^2 / dt$ **is the momentum broadening due to (2->2) elastic process**

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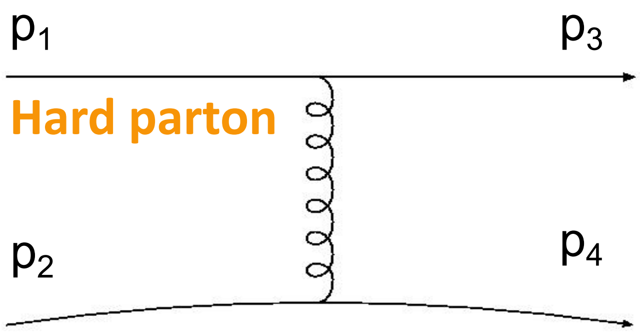
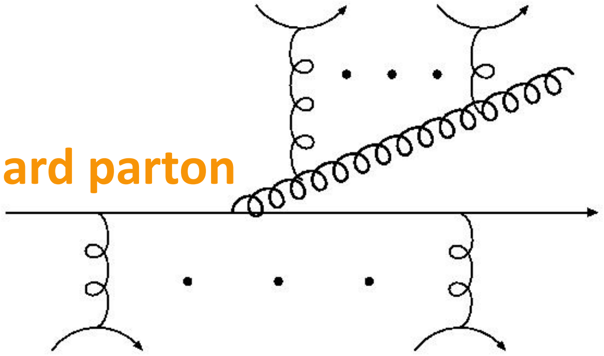
A Linear Boltzmann transport (LBT) model



Elastic (collisional)



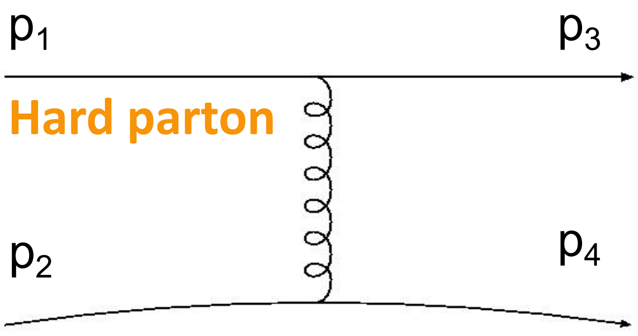
Inelastic (radiative)

- $$\Gamma_{12\rightarrow 34} = \frac{\gamma_2}{2E_1}\int \frac{d^3p_2}{(2\pi)^3 2E_2}\int \frac{d^3p_3}{(2\pi)^3 2E_3}\int \frac{d^3p_4}{(2\pi)^3 2E_4}$$
  $$\times f_2(\vec{p}_2)\left[1 \pm f_3(\vec{p}_1 - \vec{k})\right]\left[1 \pm f_4(\vec{p}_2 + \vec{k})\right] S_2(s,t,u)$$
  $$\times (2\pi)^4 \delta^{(4)}(p_1 + p_2 - p_3 - p_4)\left|M_{12\rightarrow 34}\right|^2$$
- $\Gamma_{el} = \sum_i \Gamma_i$
- $P_{el} = 1 - e^{-\Gamma_{el}\Delta t}$

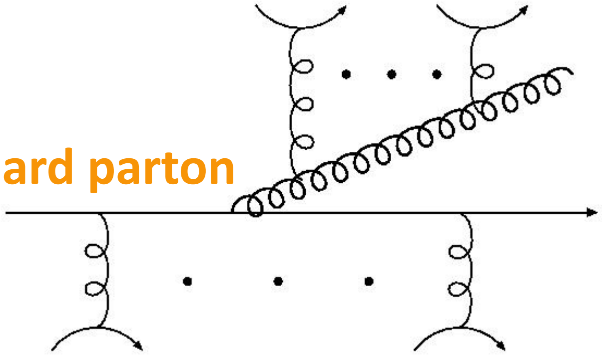
- $\langle N_g \rangle (E,T,t,\Delta t) = \Delta t \int dx dk_\perp^2 \frac{dN_g}{dx dk_\perp^2 dt}$
- $P_{inel} = 1 - e^{-\langle N_g \rangle}$
- $P(n) = \frac{\langle N_g \rangle^n}{n!} e^{-\langle N_g \rangle}$

Cao, Luo, GYQ, Wang, PRC 2016 ; arXiv:1703.00822, etc.

A Linear Boltzmann transport (LBT) model



Elastic (collisional)



Inelastic (radiative)

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  $$\times f_2(\vec{p}_2)\left[1\pm f_3(\vec{p}_1-\vec{k})\right]\left[1\pm f_4(\vec{p}_2+\vec{k})\right]S_2(s,t,u)$$
  $$\times(2\pi)^4\delta^{(4)}(p_1+p_2-p_3-p_4)\left|M_{12\to34}\right|^2$$
- $$\Gamma_{el} = \sum_i \Gamma_i$$
- $$P_{el} = 1-e^{-\Gamma_{el}\Delta t}$$

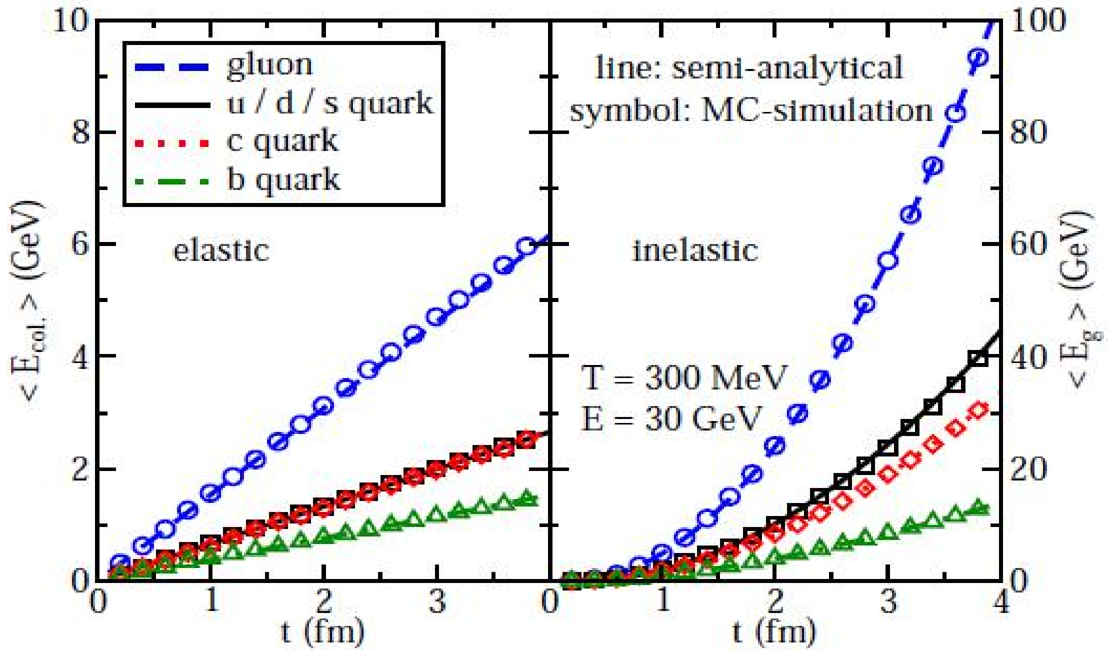
- $$\langle N_g\rangle(E,T,t,\Delta t) = \Delta t\int dx dk_\perp^2 \frac{dN_g}{dx dk_\perp^2 dt}$$
- $$P_{inel} = 1-e^{-\langle N_g\rangle}$$
- $$P(n) = \frac{\langle N_g\rangle^n}{n!}e^{-\langle N_g\rangle}$$

pure elastic inelastic

Elastic + Inelastic: $$P_{tot} = P_{el} + P_{inel} - P_{el}P_{inel} = P_{el}(1-P_{inel}) + P_{inel}$$

Cao, Luo, GYQ, Wang, PRC 2016 ; arXiv:1703.00822, etc.

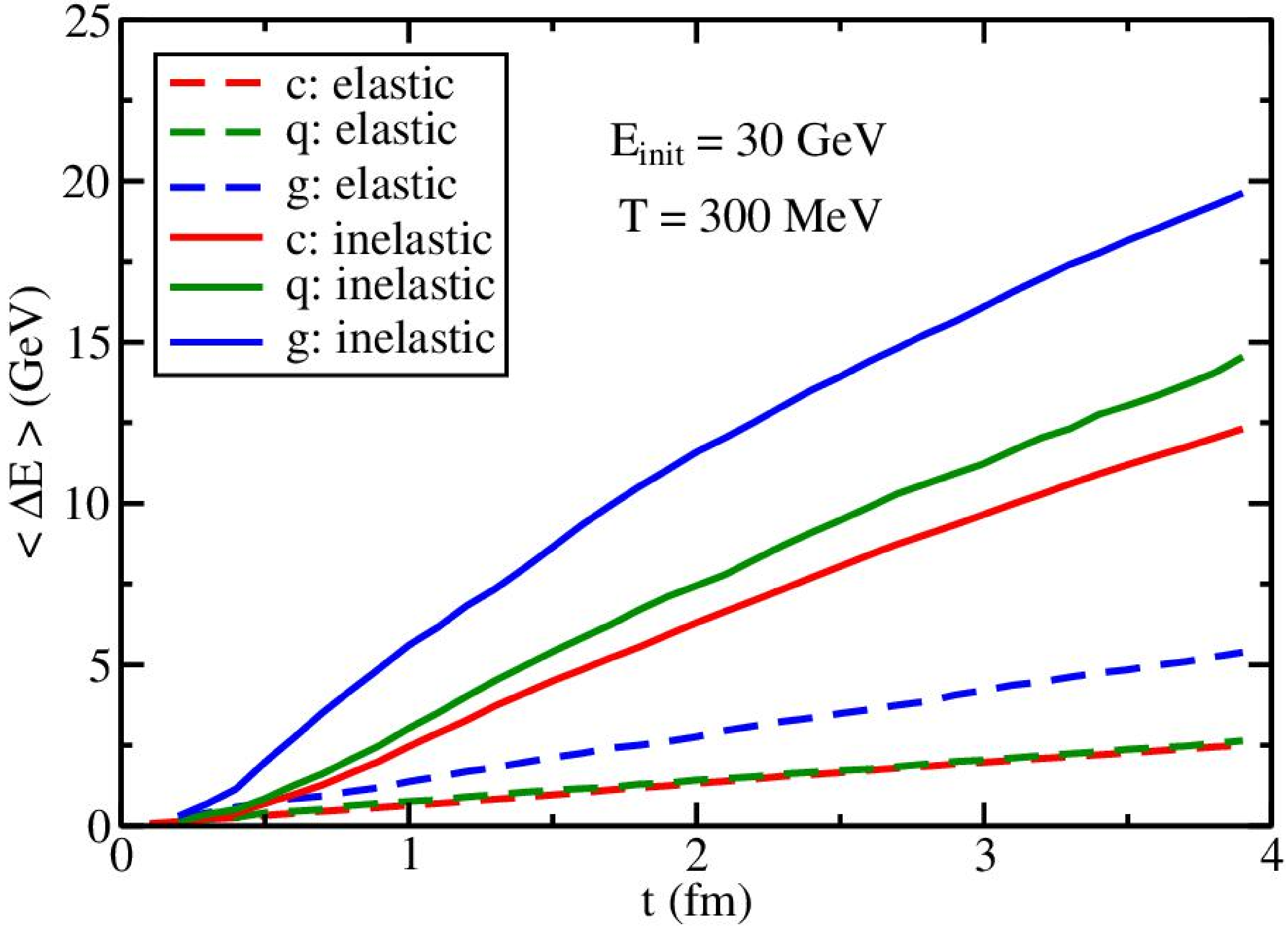
LBT model validation: parton energy loss



- MC-simulation results are in agreement with semi-analytical calculations
- A clear hierarchy in elastic energy loss: gluon lose approximately 9/4 times as light quarks due to different color charges

  (slope:1.54GeV/fm for gluon, 0.664 GeV/fm for light quark, 0.668 GeV/fm for charm quark and 0.382GeV/fm for beauty quark)
- The elastic energy loss of charm quarks is similar to light quarks and the inelastic energy loss of charm quarks is slightly smaller than light quarks since charm quark mass is small than 30 GeV
- **The energy loss of beauty quarks is significantly smaller than light quarks**

LBT model simulation: realistic parton energy loss



Realistic simulation in LBT model

- **Initialization of hard partons: MC-Glauber model for position space and LO pQCD calculation for momentum space**

- **Preparation of QGP medium: the local temperture and flow of the medium provided by relativistic hydrodynamic model**
  - **A (2+1)-dimensional viscous hydrodynamics model VISHNew with MC Glauber initial condition**
  - **A (3+1)-dimensional viscous hydrodynamics model CLVisc**

- **Hadronization mechanism: fragmentation via PYTHIA for high momentum heavy and light flavor hadrons, coalescence mechanism for low momentum heavy flavor hadrons**

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L.-G. Pang, Y. Hatta, X.-N. Wang, and B.-W. Xiao, Phys. Rev. D91, 07027(2015)
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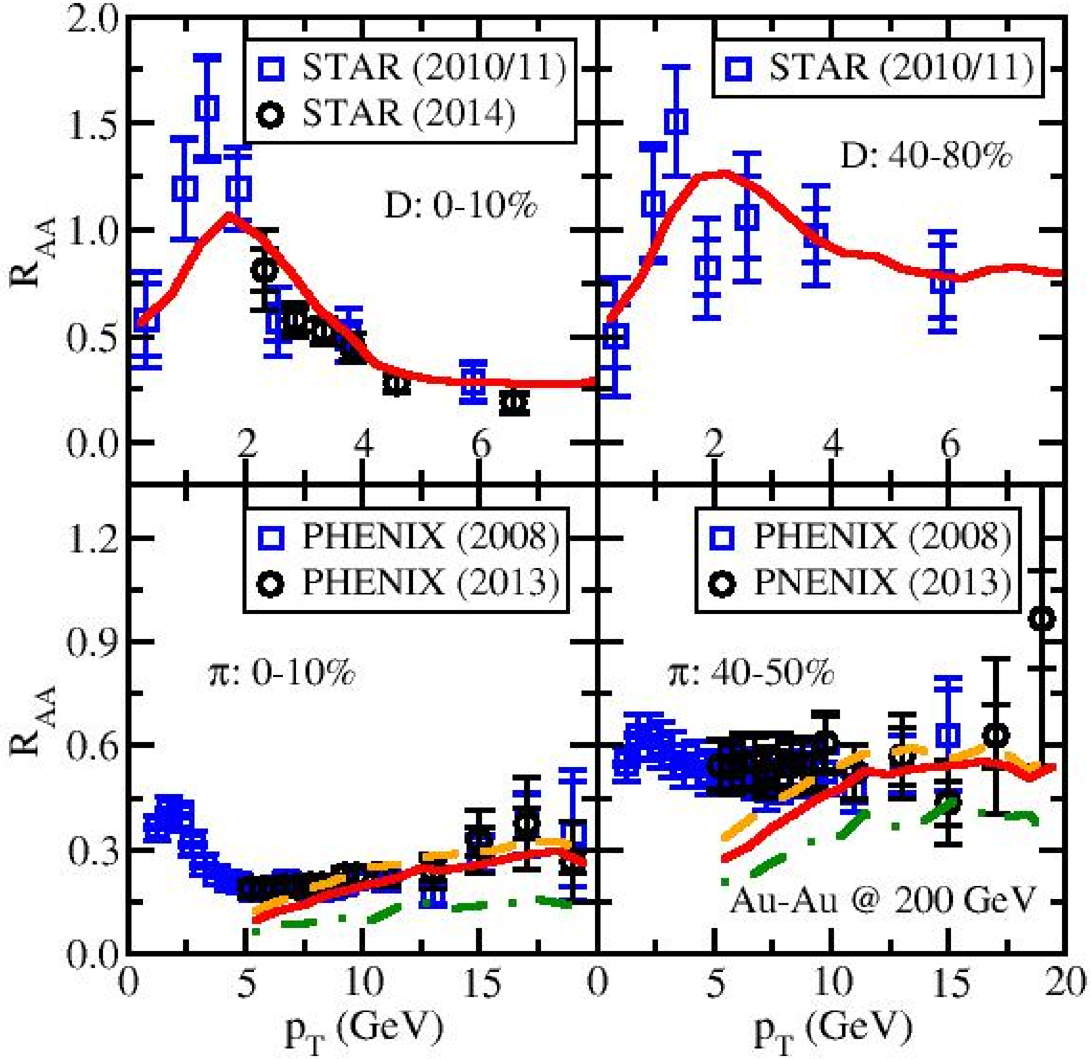
S. Cao, G.-Y. Qin, and S. A. Bass, Phys. Rev. C92, 024907(2015)

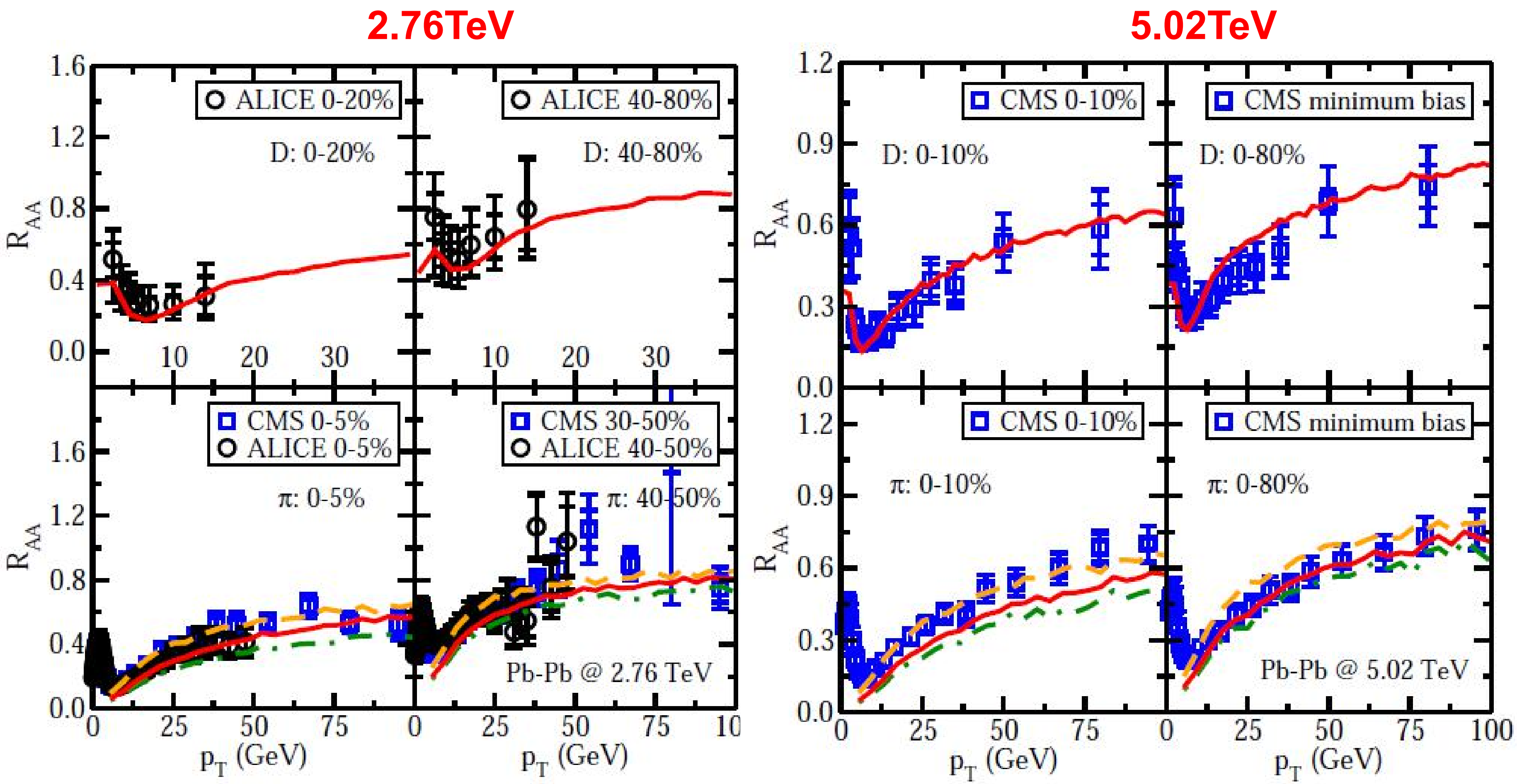
Nuclear modifications of heavy and light flavor hadron in Au+Au collision

200GeV



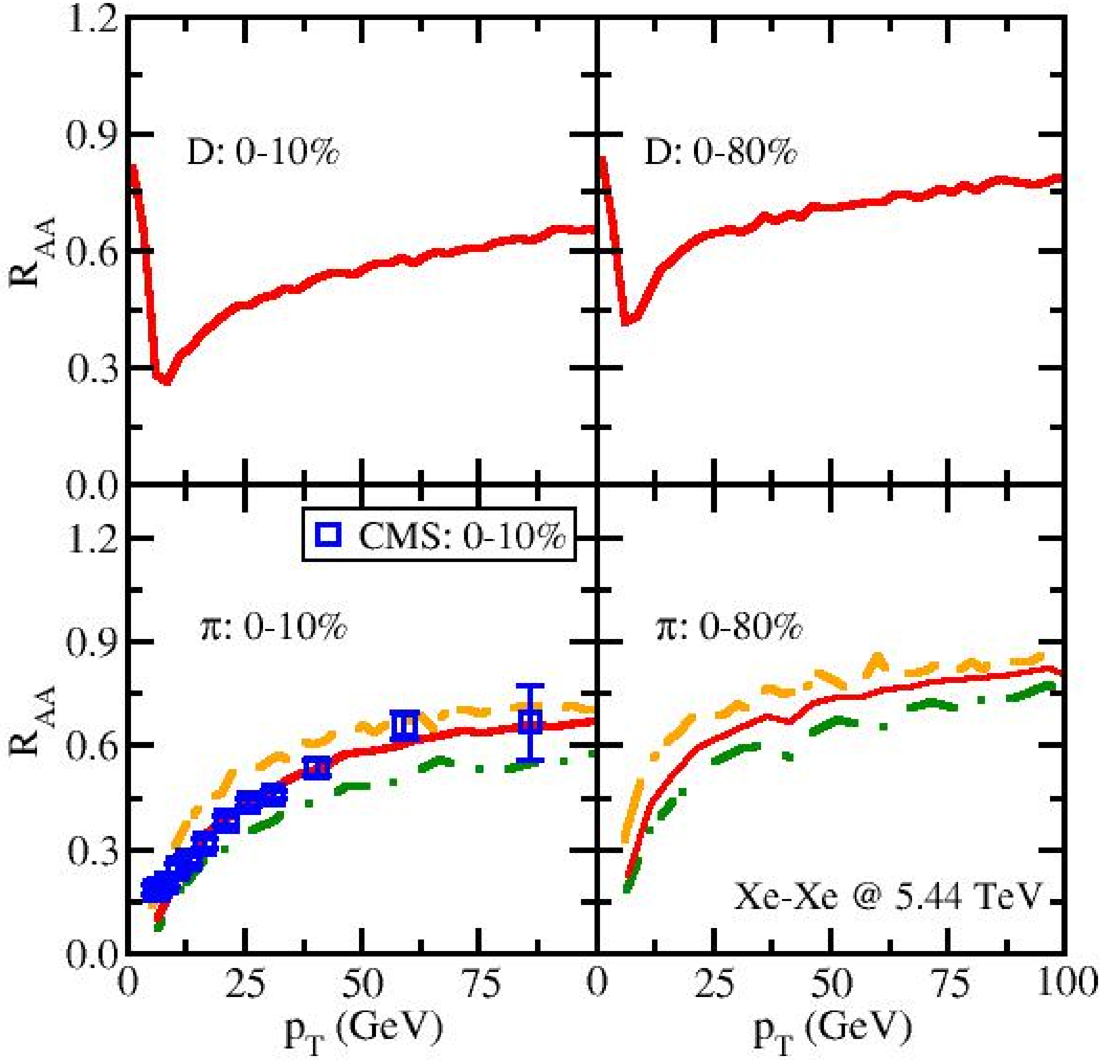
$$K_p = 1 + A_p e^{-|\vec{p}|^2/2\sigma_p^2}$$

Nuclear modifications of heavy and light flavor hadron in Pb+Pb collision



Nuclear modifications of heavy and light flavor hadron in Xe+Xe collision

5.44TeV



Summary

- Present the Linearized Boltzmann Transport (LBT) model that include both heavy and light flavor partons on the same footing

- Achieve good descriptions of nuclear modification data for light hadrons and D mesons for various collision centralities at RHIC and LHC energies

- Calculate nuclear modification factors of light hadrons and D meson for higher p_T region