Effects of initial fluctuations on jet quenching

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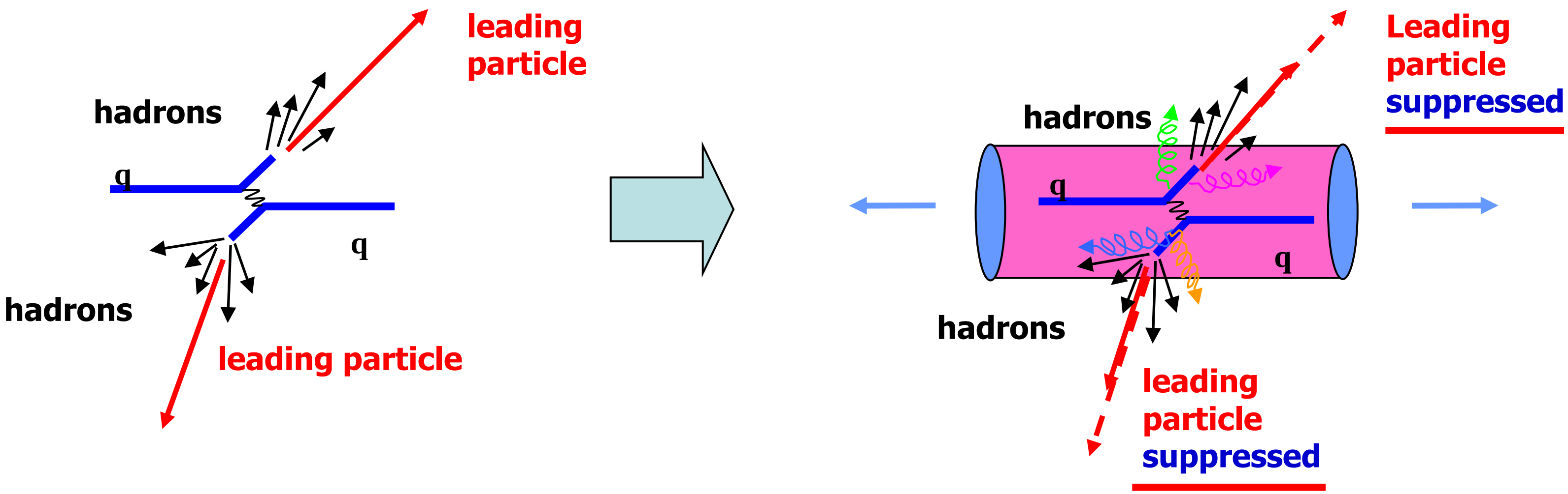
Outline

- Introduction
- A NLO pQCD parton model
- Event-by-event hydrodynamics for HIC
- Initial-fluctuation effects on jet quenching
- Conclusions

Evidence for the formation of Quark Matter

Jet quenching: X.-N. Wang and M. Gyulassy, Phys.Rev.Lett.68,1480(1992)

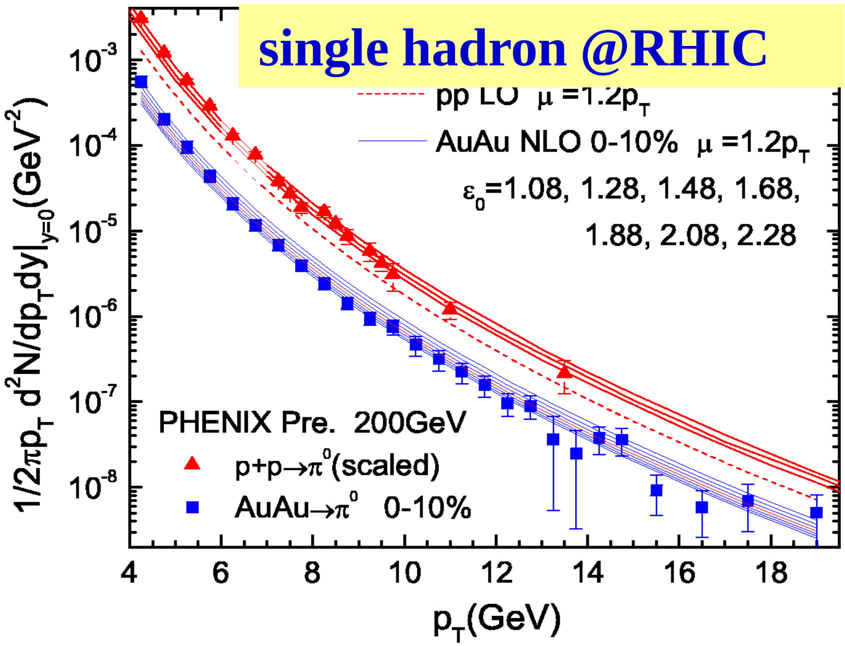
The hard jet loses a large amount of its energy via radiating gluon induced by multiple scattering.

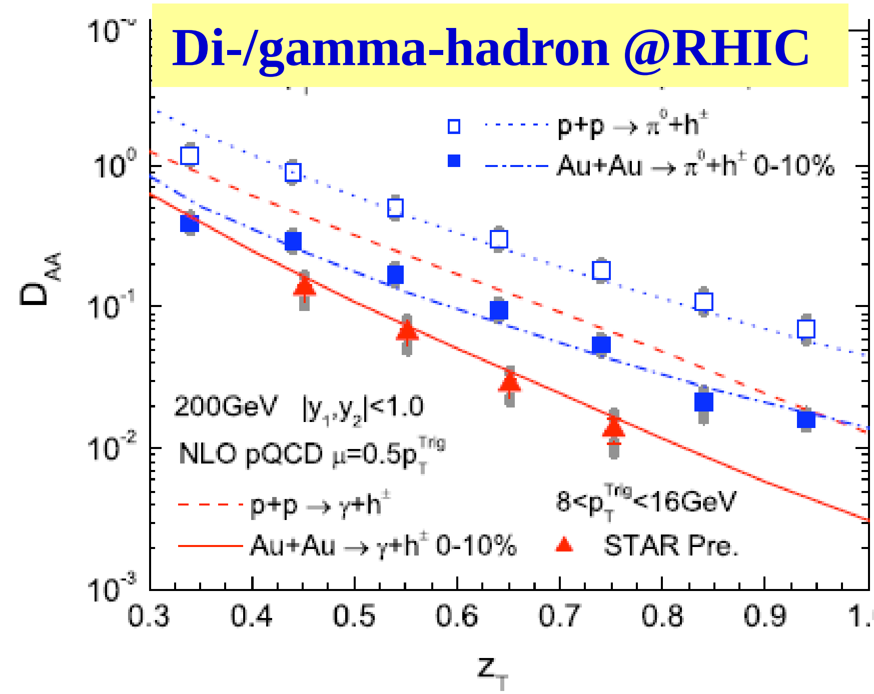


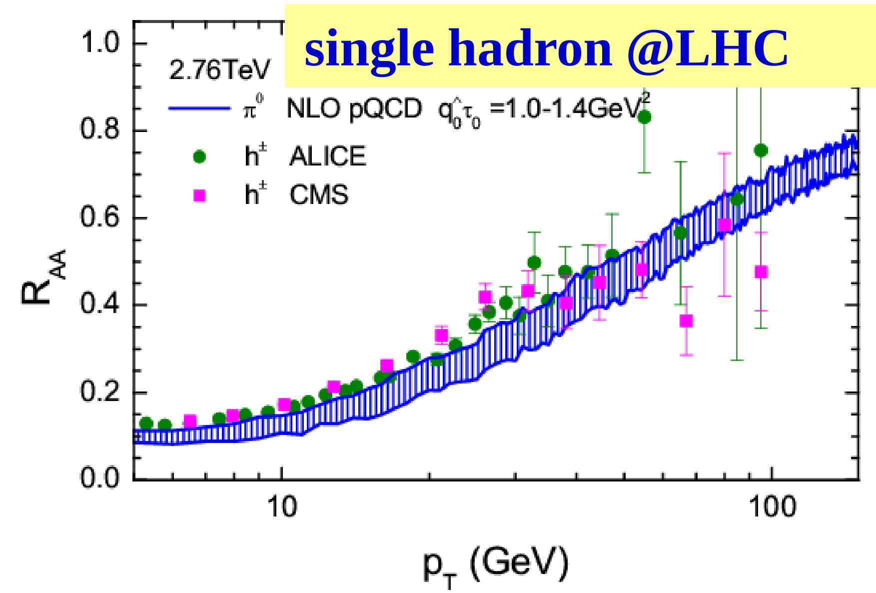
N-N collision A-A collision

Energy loss is sensitive to the property of the matter

Simultaneous fits to single, di-/gamma-hadron at RHIC/LHC







H.Z. Zhang et al, PRL 98(2007)212301

H.Z. Zhang et al, PRL 103(2009)032302

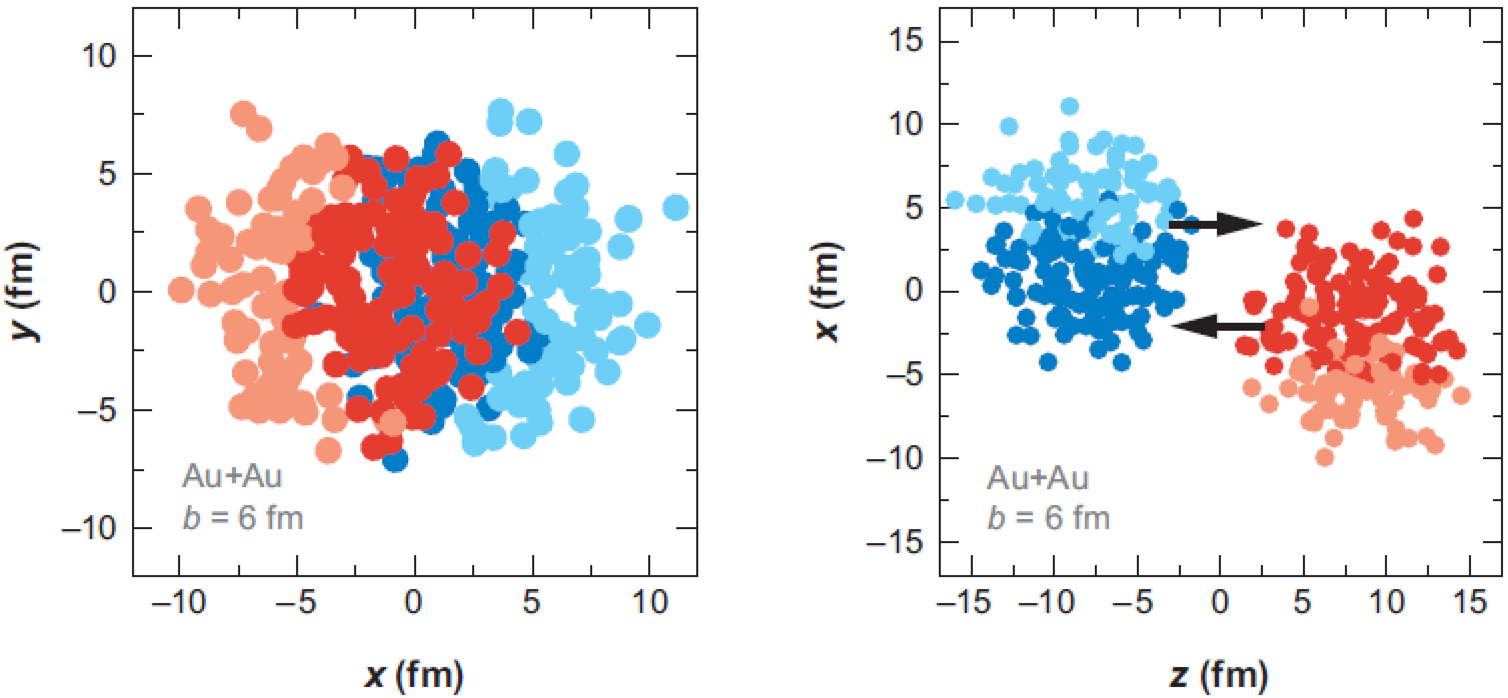
X.F. Chen et al, PRC 84(2011)034902

H.Z. Zhang et al, JPG38(2011)124115

Within a same energy loss formalism, simultaneous fit to data.

1) **JQ is consistent**
2) **An evidence for JQ description**

Initial geometry fluctuations in AA collisions



Figures taken from Annu. Rev. Nucl. 57(2007)205-243

How and why does the fluctuation affect jet energy loss ?

A NLO pQCD parton model in A+A collisions

$$d\sigma^{AA} \propto T_{AB} \otimes PDFs \otimes d\sigma \otimes FFs$$

(1) **Woods-Saxon or fluctuating nucleon distribution**

(2) **CTEQ6.1M used for PDFs**

(3) **Hard scattering cross section: NLO**

(4) **Modified FFs due to Jet quenching, AKK08 used**

Modified fragmentation functions

$$D_{h/c}(z_c,\mu^2,\Delta E_c) \approx \left(1-e^{-\langle L/\lambda\rangle}\right)\left[\frac{1}{1-\Delta z}D^0_{h/c}\left(\frac{z_c}{1-\Delta z},\mu^2\right)\right]+e^{-\langle L/\lambda\rangle}D^0_{h/c}(z_c,\mu^2)$$

$$\Delta z = \Delta E_c / p_{Tc}$$

(X. -N. Wang , PRC70(2004)031901)

Total energy loss written as a path integration depending on L and ρ,

$$\Delta E_c \approx \left\langle \frac{dE}{dL} \right\rangle \int_{\tau_0}^{\infty} d\tau \left(\frac{\tau-\tau_0}{\tau_0}\right)^{\alpha} \frac{\rho_g(\tau,\vec{b},\vec{r}+\vec{n}\tau)}{\rho_0}\frac{p^{\mu}u_{\mu}}{p_0}$$

$\alpha = 0$ **linear L dependence of elastic collisions loss**

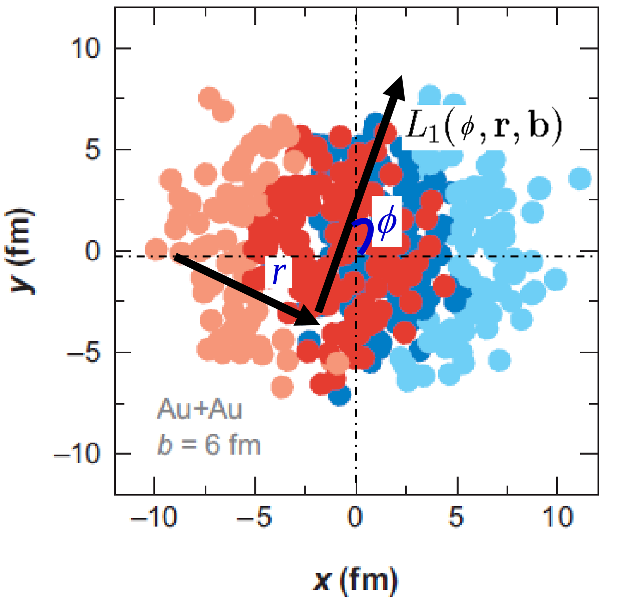
$\alpha = 1$ **quadratic L dependence of radiative loss**

$$\left\langle \frac{dE}{dL} \right\rangle = \varepsilon_0 (E/\mu_0 - 1.6)^{1.2} / (7.5 + E/\mu_0)$$

Energy loss parameter $\varepsilon_0 \propto \hat{q}$

(a parameterization form of theory calculations)

Enke Wang , X. -N. Wang , PRL87(2001)142301)



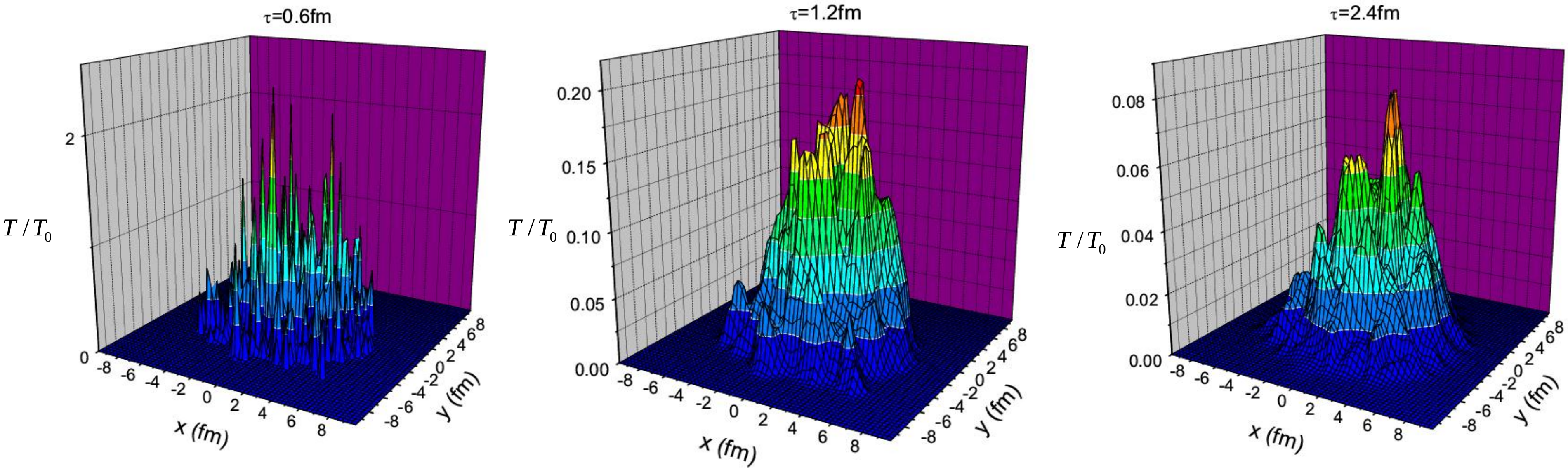
2+1D Hydrodynamics description for medium evolution

T, ρ, u are given by numerical simulation of a 2+1D ideal hydrodynamics to describe the space-time evolution of the bulk medium.

Initial fluctuating conditions are used to solve hydro equations.

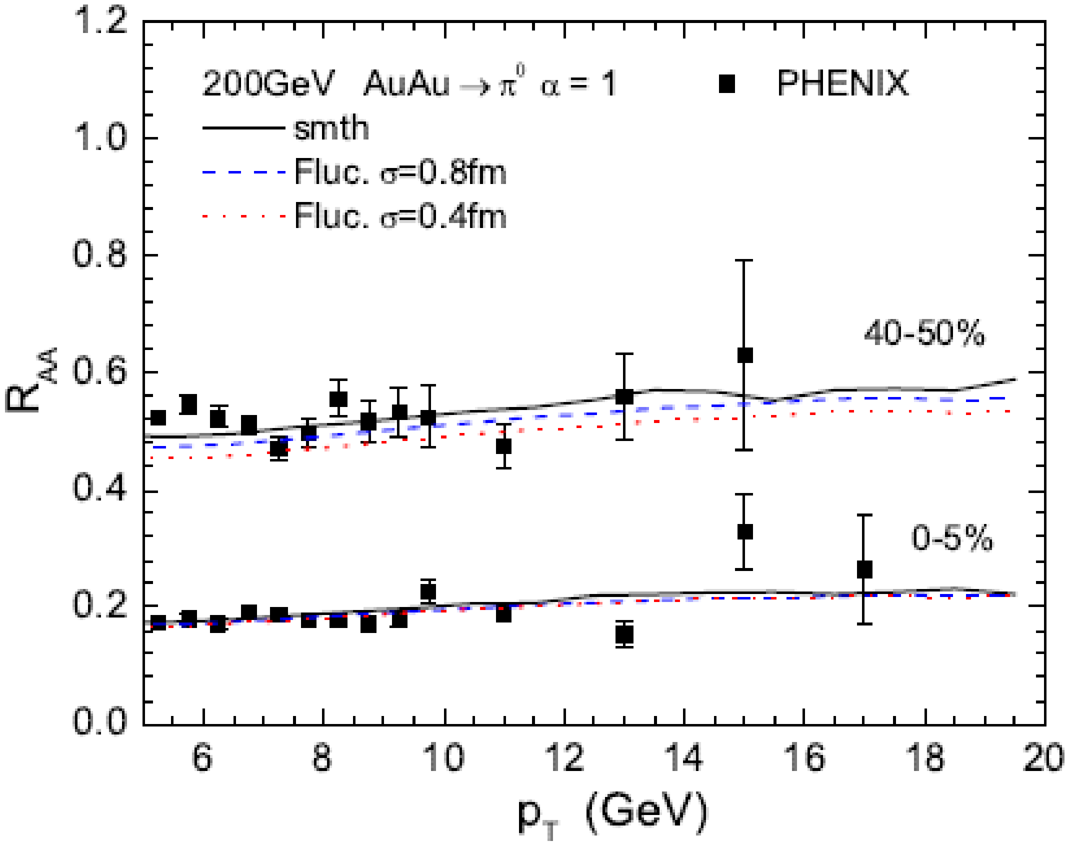
Hanzhong Zhang, Taesoo Song, Che Ming Ko, arXiv: 1208.2980

Medium temperature evolution in one event of 0-5% Au+Au



t = 0.6 fm → t = 1.2 fm → t = 2.4 fm

Initial fluctuation increases energy loss



Hanzhong Zhang, Taesoo Song, Che Ming Ko, arXiv: 1208.2980

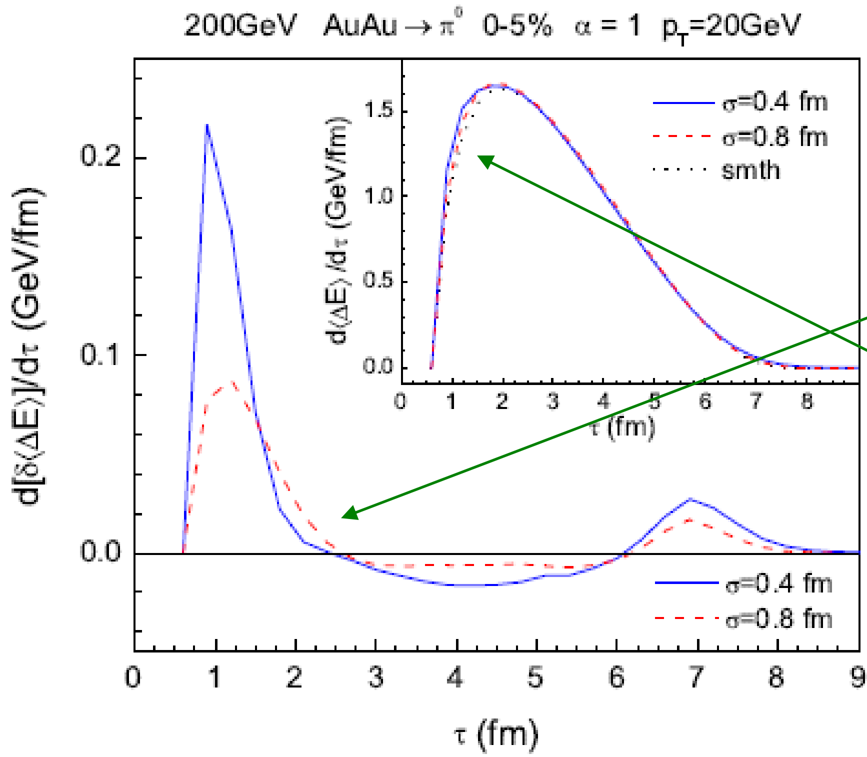
1) The initial fluctuation leads to a smaller R_AA
2) The effect is stronger in noncentral than in central collisions.

Initial positive correlation dominates deviation

Average over all jet trajectories and over 100 A+A events

Energy loss deviation $\delta(\Delta E) = \Delta E^{fluc} - \Delta E^{smth} \propto \delta n \delta\rho$

Initial jet production possibility fluctuation **medium density fluctuation**



2+1D hydro. bulk medium

1) **+ correlation at first, and then - correlation**
2) **Most enloss happens in the beginning**
3) **Beginning +correlation dominates the deviation**

Net fluctuation effect → more energy loss

Energy loss competition in jet trajectory

Path-length dependence: $\Delta E \propto (\tau/\tau_0 - 1)^{\alpha} \sim \tau^{\alpha}$

Medium-density dependence: $\Delta E \propto \rho(\tau) \sim 1/\tau^{\beta}$

$$\left.\begin{array}{l} \Delta E \propto (\tau/\tau_0 - 1)^{\alpha} \sim \tau^{\alpha} \\ \Delta E \propto \rho(\tau) \sim 1/\tau^{\beta} \end{array}\right\} \Rightarrow \Delta E \sim \tau^{\alpha-\beta}$$

1) Path-length dependence (τ^{α}) → most ΔE in a long distance;
Medium-density dependence ($1/\tau^{\beta}$) → most ΔE in a short distance.

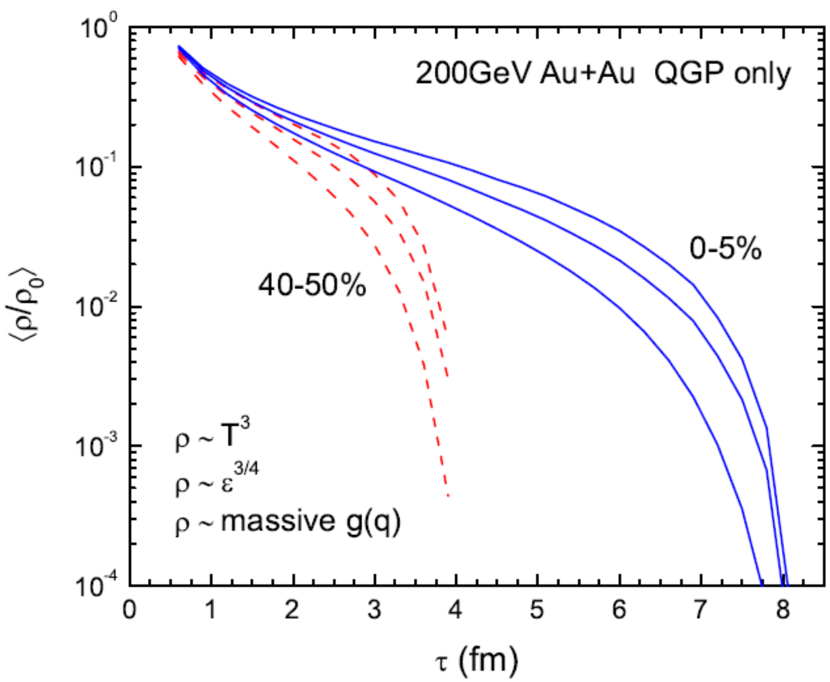
2) Consequently, total effect of the initial fluctuations on jet quenching is related to the competition between the two dependence of jet energy loss.

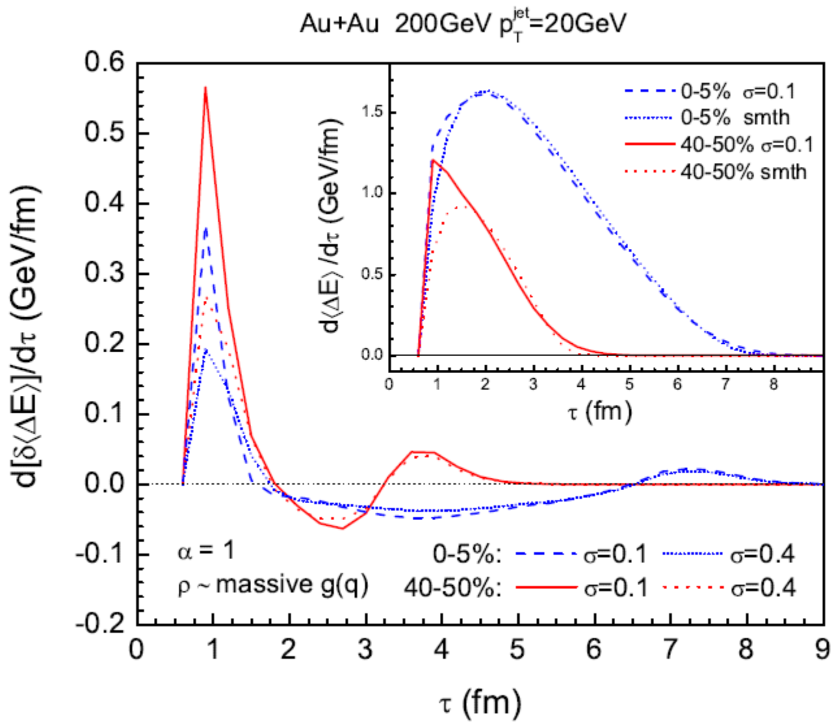
3) Since α is always smaller than β in our study, the total energy loss mainly takes place during early time where the correlation is positive, thus resulting in more energy loss in the case of fluctuating initial conditions.

Compare fluctuation effects in non-central to central collisions

$$\rho(\tau) \sim 1/\tau^{\beta} \qquad \Delta E \propto \int (\tau/\tau_0 - 1)^1 \rho(\tau) d\tau \sim \tau^{1-\beta}$$

Fix $\alpha = 1$ for radiative enloss, change β for 0-5% and 40-50% collisions



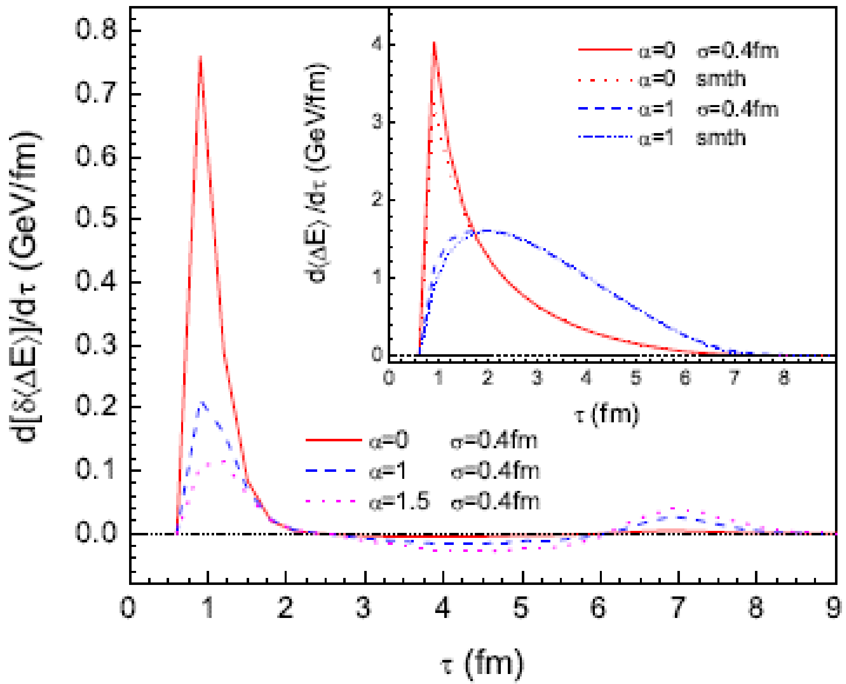


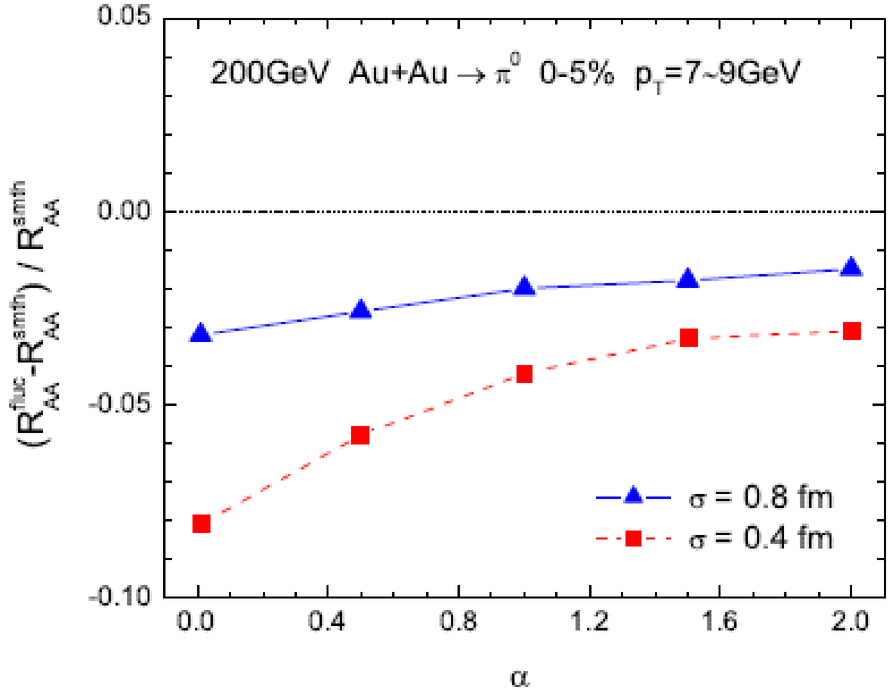
$\beta^{40-50\%} > \beta^{0-5\%}$, compared with central collisions, the most enloss takes place earlier in non-central collisions, so the initial positive correlation is more stronger in non-central collisions, leading to stronger effects.

Initial-fluctuation effect on energy loss with linear L dependence is stronger than with quadratic L dependence

$$\rho(\tau) \sim 1/\tau^{\beta} \qquad \Delta E \propto \int (\tau/\tau_0 - 1)^{\alpha} \rho(\tau) d\tau \sim \tau^{\alpha-\beta}$$

Fix centrality class (β for 0-5%), change α for linear or quadratic L depend





1) **For the linear L dependence ($\alpha = 0$), most enloss takes place in positive correlation region of the jet path, so the + correlation dominates the effect.**
2) **For the quadratic L dependence ($\alpha = 1$), the peak for the jet energy loss rate is shifted closer to the - correlation region, so the dominance of initial positive correlation is weakened by the negative correlation.**

Conclusions

- **Based on the 2+1D ideal hydro, we study the effect of initial fluctuations on jet quenchng in AA collisions within the description of the NLO perturbative QCD.**

- **We find that a jet loses slightly more energy in the expanding QGP if the latter is described by the hydrodynamic evolution with fluctuating initial conditions compared to the case with smooth initial conditions.**

- **The fluctuation effect is larger in non-central than in central AA collisions and also for jet energy loss that has a linear than a quadratic dependence of its path length in the medium.**

Thank for your attention!