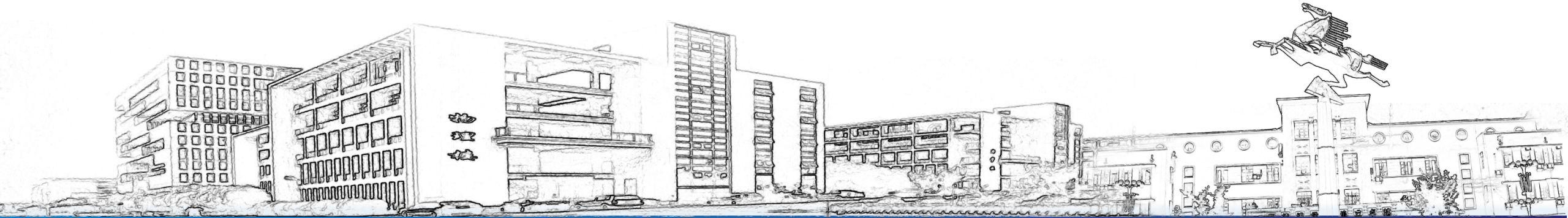




物理与力学学院
School of Physics and Mechanics



Initial and final state effects on the higher order fluctuations of the mean transverse momentum at LHC

Chao Zhang

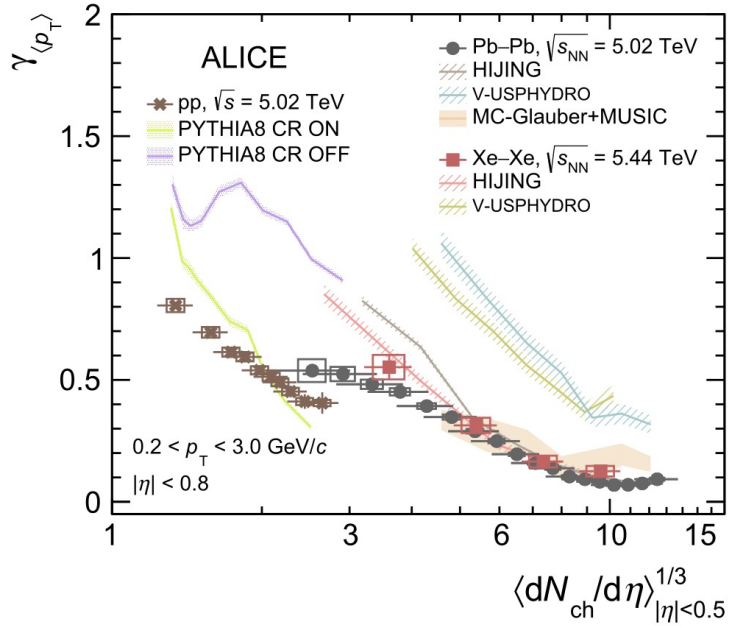
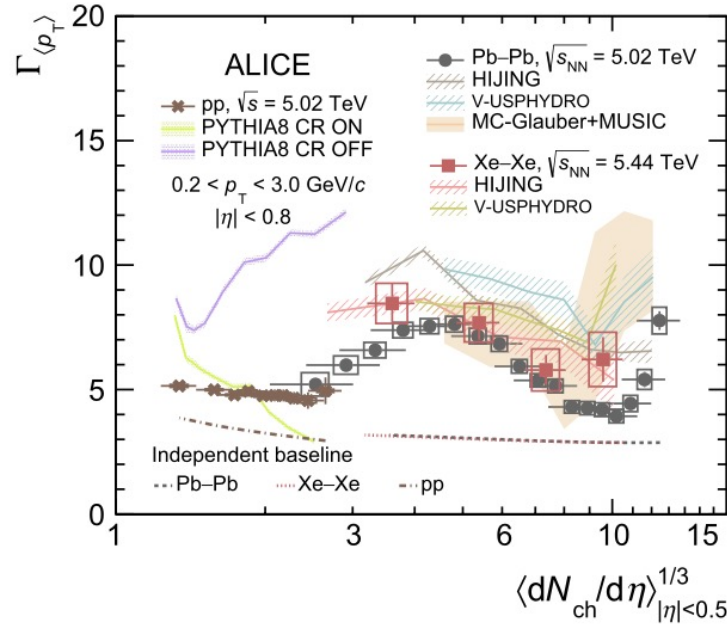
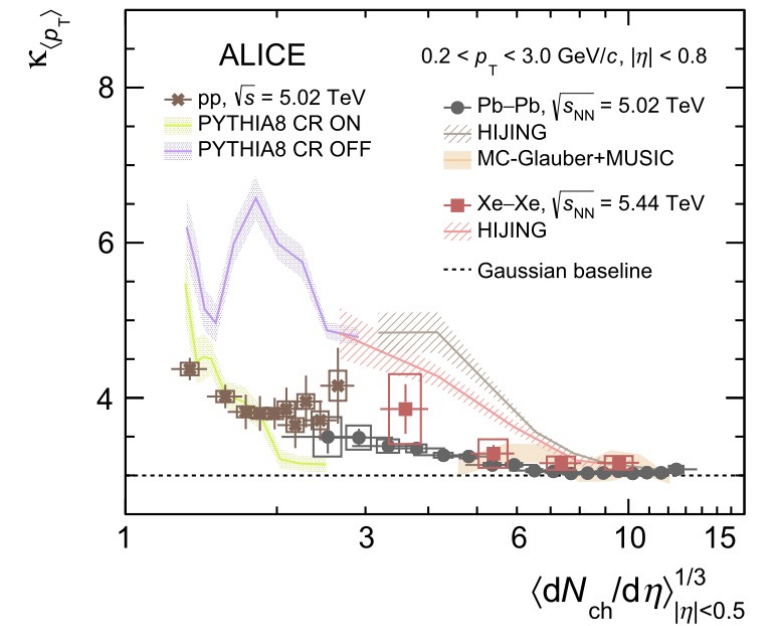
Wuhan University of Technology(WUT)

第十二届中国LHC物理会议, 10月28日-11月1日,
2026年, 武汉, 中国

Outline

- Motivation
- Improvements on the multi-phase transport model
- The final state effects on the mean p_T fluctuations
- Summary

Motivation



1. ALICE collaboration reports the higher order p_T fluctuations in three collision systems
2. $\gamma_{\langle p_T \rangle}$ and $\kappa_{\langle p_T \rangle}$: Decrease with centrality; $\Gamma_{\langle p_T \rangle}$: Non-monotonic dependence on centrality
3. Hydrodynamics: p_T fluctuations sensitive to initial state

Method

The multiparticle p_T correlators method is used in this analysis:

$$\langle \Delta p_{T,i} \Delta p_{T,j} \rangle = \left\langle \frac{\sum_{\substack{i,j \\ i \neq j}}^{N_{\text{ch}}} (p_{T,i} - \langle \langle p_T \rangle \rangle) (p_{T,j} - \langle \langle p_T \rangle \rangle)}{N_{\text{ch}}(N_{\text{ch}} - 1)} \right\rangle = \left\langle \frac{Q_1^2 - Q_2}{N_{\text{ch}}(N_{\text{ch}} - 1)} \right\rangle - \left\langle \frac{Q_1}{N_{\text{ch}}} \right\rangle^2,$$

$$\begin{aligned} & \langle \Delta p_{T,i} \Delta p_{T,j} \Delta p_{T,k} \rangle \\ &= \left\langle \frac{\sum_{\substack{i,j,k \\ i \neq j \neq k}}^{N_{\text{ch}}} (p_{T,i} - \langle \langle p_T \rangle \rangle) (p_{T,j} - \langle \langle p_T \rangle \rangle) (p_{T,k} - \langle \langle p_T \rangle \rangle)}{N_{\text{ch}}(N_{\text{ch}} - 1)(N_{\text{ch}} - 2)} \right\rangle = \left\langle \frac{Q_1^3 - 3Q_2Q_1 + 2Q_3}{N_{\text{ch}}(N_{\text{ch}} - 1)(N_{\text{ch}} - 2)} \right\rangle - 3 \left\langle \frac{Q_1^2 - Q_2}{N_{\text{ch}}(N_{\text{ch}} - 1)} \right\rangle \end{aligned}$$

$$\begin{aligned} & \langle \Delta p_{T,i} \Delta p_{T,j} \Delta p_{T,k} \Delta p_{T,l} \rangle = \left\langle \frac{\sum_{\substack{i,j,k,l \\ i \neq j \neq k \neq l}}^{N_{\text{ch}}} (p_{T,i} - \langle \langle p_T \rangle \rangle) (p_{T,j} - \langle \langle p_T \rangle \rangle) (p_{T,k} - \langle \langle p_T \rangle \rangle) (p_{T,l} - \langle \langle p_T \rangle \rangle)}{N_{\text{ch}}(N_{\text{ch}} - 1)(N_{\text{ch}} - 2)(N_{\text{ch}} - 3)} \right\rangle \\ &= \left\langle \frac{Q_1^4 - 6Q_4 + 8Q_1Q_3 - 6Q_1^2Q_2 + 3Q_2^2}{N_{\text{ch}}(N_{\text{ch}} - 1)(N_{\text{ch}} - 2)(N_{\text{ch}} - 3)} \right\rangle - 4 \left\langle \frac{Q_1^3 - 3Q_2Q_1 + 2Q_3}{N_{\text{ch}}(N_{\text{ch}} - 1)(N_{\text{ch}} - 2)} \right\rangle \left\langle \frac{Q_1}{N_{\text{ch}}} \right\rangle \\ &+ 6 \left\langle \frac{Q_1^2 - Q_2}{N_{\text{ch}}(N_{\text{ch}} - 1)} \right\rangle \left\langle \frac{Q_1}{N_{\text{ch}}} \right\rangle^2 - 3 \left\langle \frac{Q_1}{N_{\text{ch}}} \right\rangle^4. \end{aligned}$$

$$\gamma_{\langle p_T \rangle} = \frac{\langle \Delta p_{T,i} \Delta p_{T,j} \Delta p_{T,k} \rangle}{\langle \Delta p_{T,i} \Delta p_{T,j} \rangle^{3/2}},$$

$$\Gamma_{\langle p_T \rangle} = \frac{\langle \Delta p_{T,i} \Delta p_{T,j} \Delta p_{T,k} \rangle \langle \langle p_T \rangle \rangle}{\langle \Delta p_{T,i} \Delta p_{T,j} \rangle^2}.$$

$$\kappa_{\langle p_T \rangle} = \frac{\langle \Delta p_{T,i} \Delta p_{T,j} \Delta p_{T,k} \Delta p_{T,l} \rangle}{\langle \Delta p_{T,i} \Delta p_{T,j} \rangle^2}$$

With $Q_n = \sum_{i=1}^{N_{\text{ch}}} p_{T,i}^n$, the standard skewness, intensive skewness and kurtosis are then defined with:

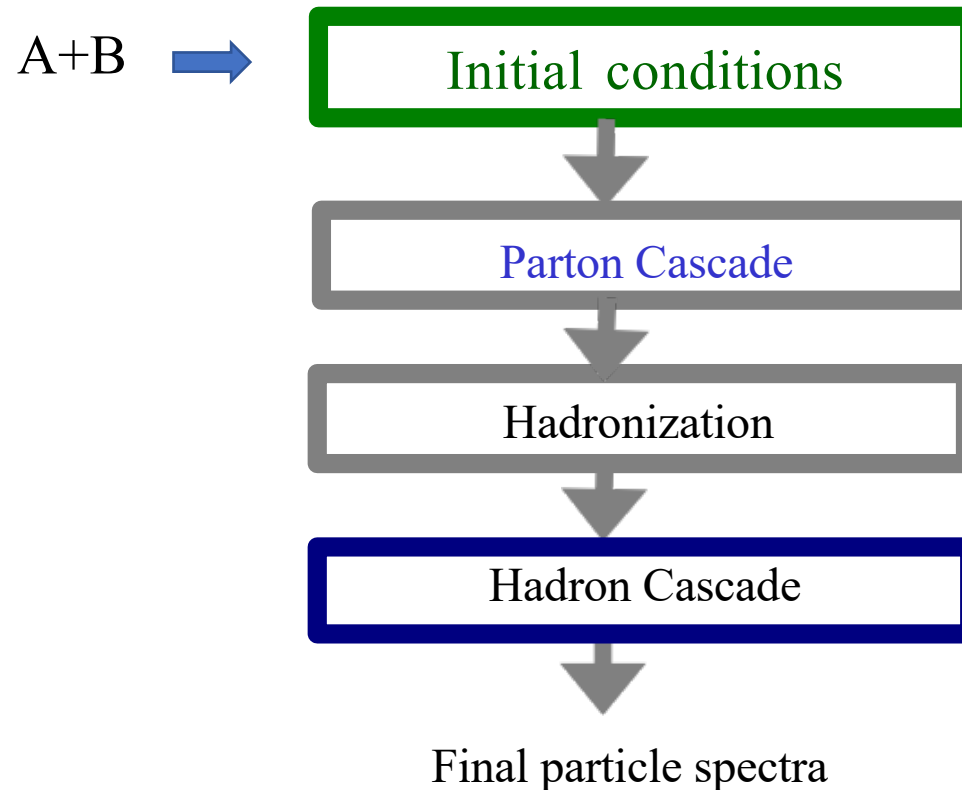
Improvement on the multi-phase transport model

We use a multi-phase transport (AMPT) model for this study.

It was constructed as a self-contained kinetic description of heavy ion collisions:

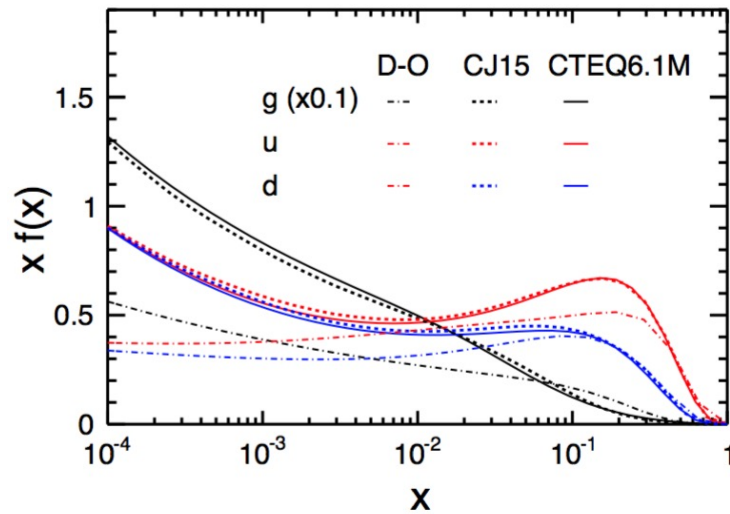
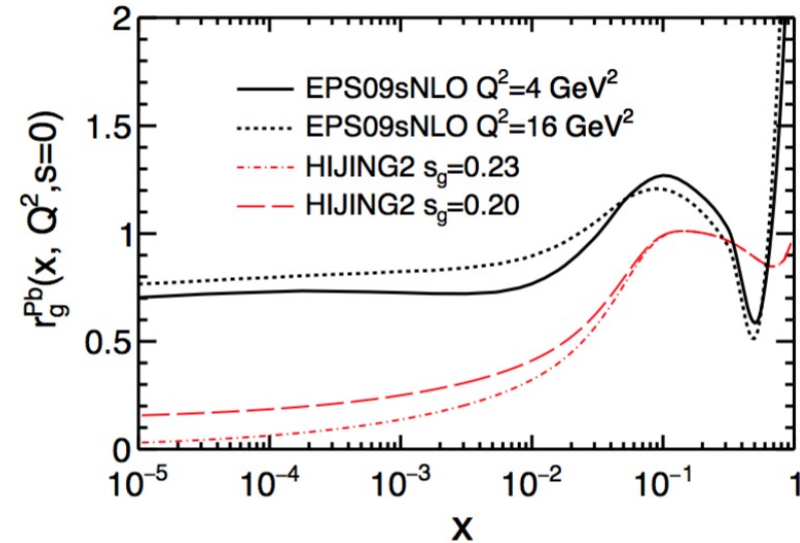
- evolves the system from initial condition to final observables;
- particle productions of all flavors from low to high p_T ;
- addresses non-equilibrium evolution/dynamics (*more important for smaller systems*).

ZWL, Ko, Li, Zhang & Pal, PRC (2005);
ZWL & Zheng, NST (2021)



Modern PDF and nPDFs

- *Duke-Owens*: used in the published AMPT model. *Outdated*;
- Modern PDF(CTEQ6.1M): gluon and quark distribution are much higher than Duke-Owens parameterization. important for LHC energies



- A spatial dependence of nuclear shadowing functions(eps09s NLO) is incorporated in the AMPT model.
- Energy dependence of the momentum cutoff p_0 and soft cross-section σ_{soft} are needed for the pp collisions.
- A larger value of p_0 is needed for the AA collisions than pp collisions. *related to $Q_s \propto A^{1/6}$*

Chao Zhang et al. PRC (2019)

Local scaling for self-consistent size dependence in AMPT

Lund symmetric string fragmentation function: $f(z) \propto z^{-1}(1-z)^{a_L} e^{-b_L m_T^2/z}$

b_L typical values (in $1/\text{GeV}^2$):

~ 0.58 (PYTHIA6.2), 0.9 (HIJING1.0), 0.7 - 0.9 (AMPT for pp)

$b_L \sim 0.15$ is needed for string melting AMPT to describe
the bulk matter at high energy AA collisions.

ZWL, PRC (2014)

This corresponds to a much higher string tension:

$$\langle p_T^2 \rangle \propto K \propto \frac{1}{b_L(2 + a_L)}$$

ZWL et al. PRC (2005)

pp and AA collisions need different values of b_L ;

Chao Zhang et al. PRC (2019)

same for minijet cutoff p_0 (*for modern PDFs, is related to $Q_s \propto A^{1/6}$*)

Zheng et al. PRC (2020)

→ We scale them with local nuclear thickness functions:

$$b_L(s_A, s_B, s) = \frac{b_L^{pp}}{[\sqrt{T_A(s_A)T_B(s_B)}/T_p]^{\beta(s)}}$$

$$p_0(s_A, s_B, s) = p_0^{pp}(s) [\sqrt{T_A(s_A)T_B(s_B)}/T_p]^{\alpha(s)}$$

Chao Zhang et al. PRC (2021)

We fit charged hadron $\langle p_T \rangle$ in pp to determine $b_L^{pp} = 0.7$,

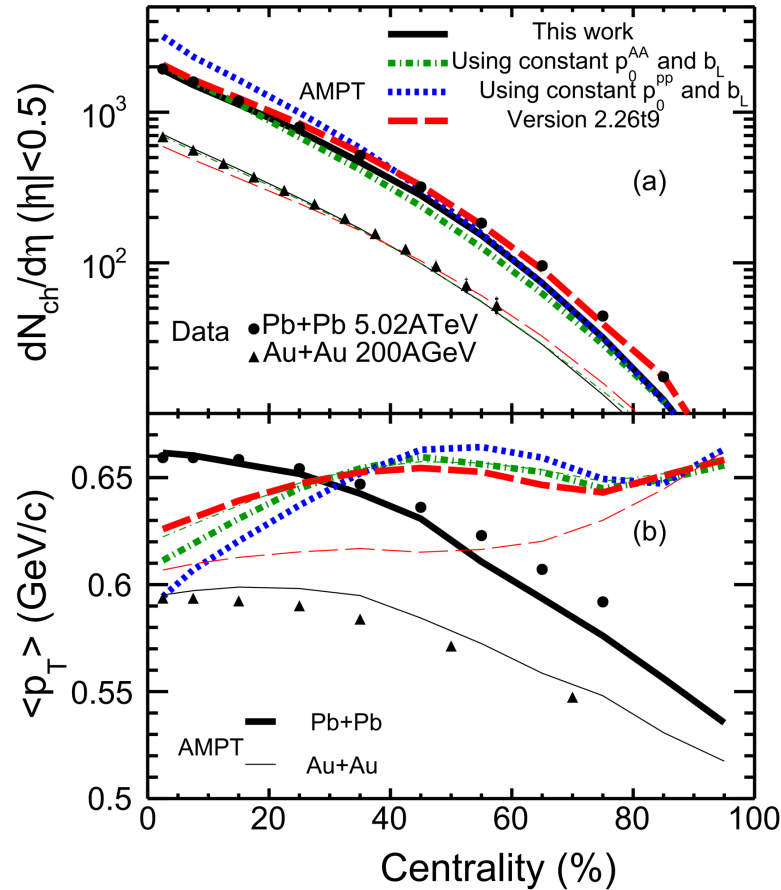
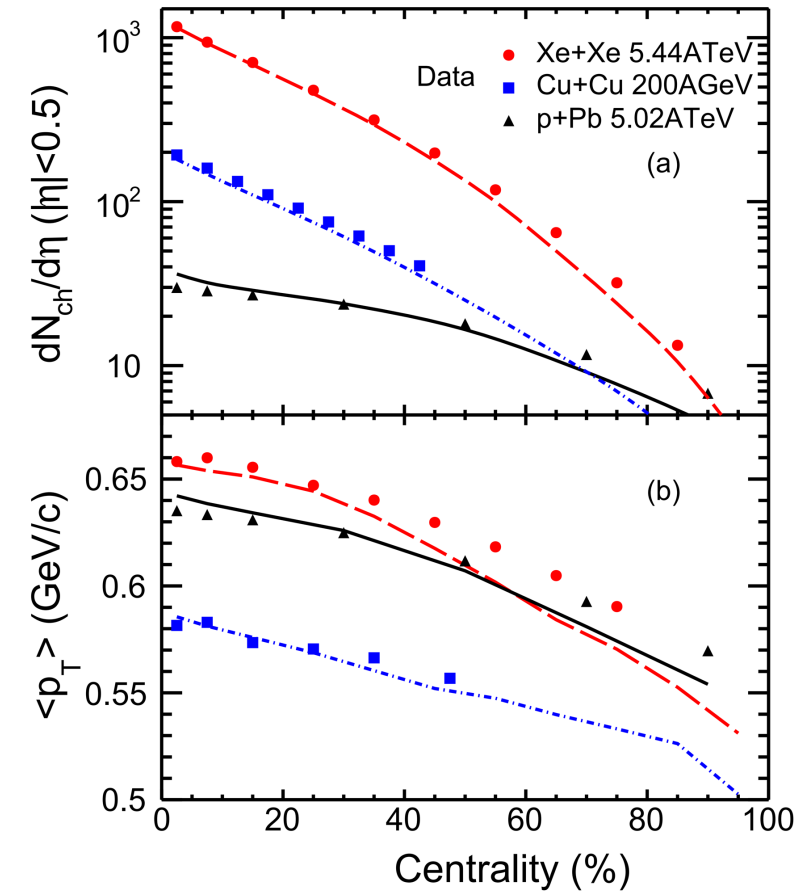
then used central AuAu/PbPb $\langle p_T \rangle$ data to determine $\alpha(s)$, $\beta(s)$ versus energy

Local scaling for self-consistent size dependence in AMPT

The scaling allows AMPT to self-consistently describe the system size dependence,

including centrality dependences of AuAu & PbPb:

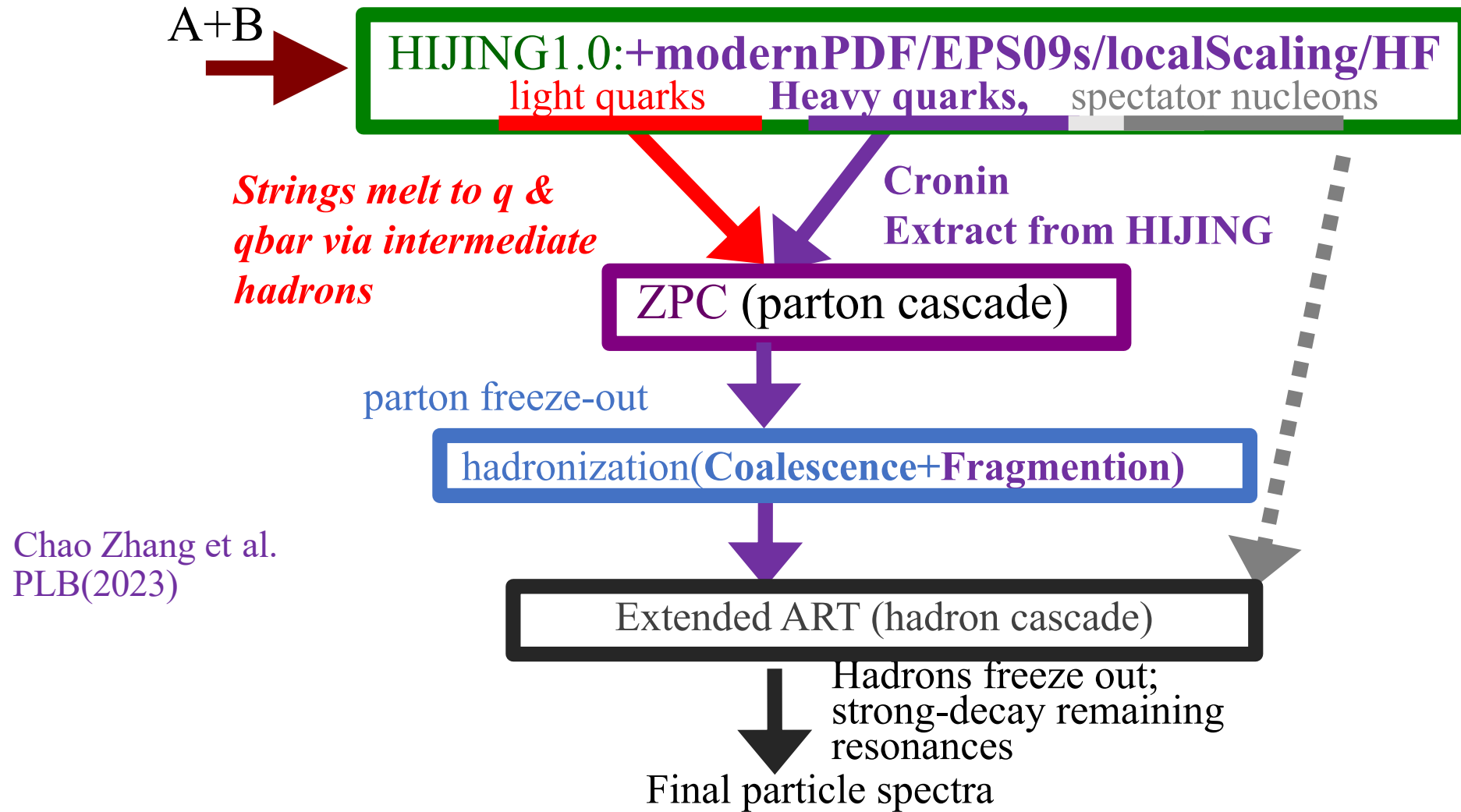
Chao Zhang et al. PRC (2021)



Centrality dependence of $\langle p_T \rangle$ is now reasonable, while previous/public AMPT (v2.26t9) fails

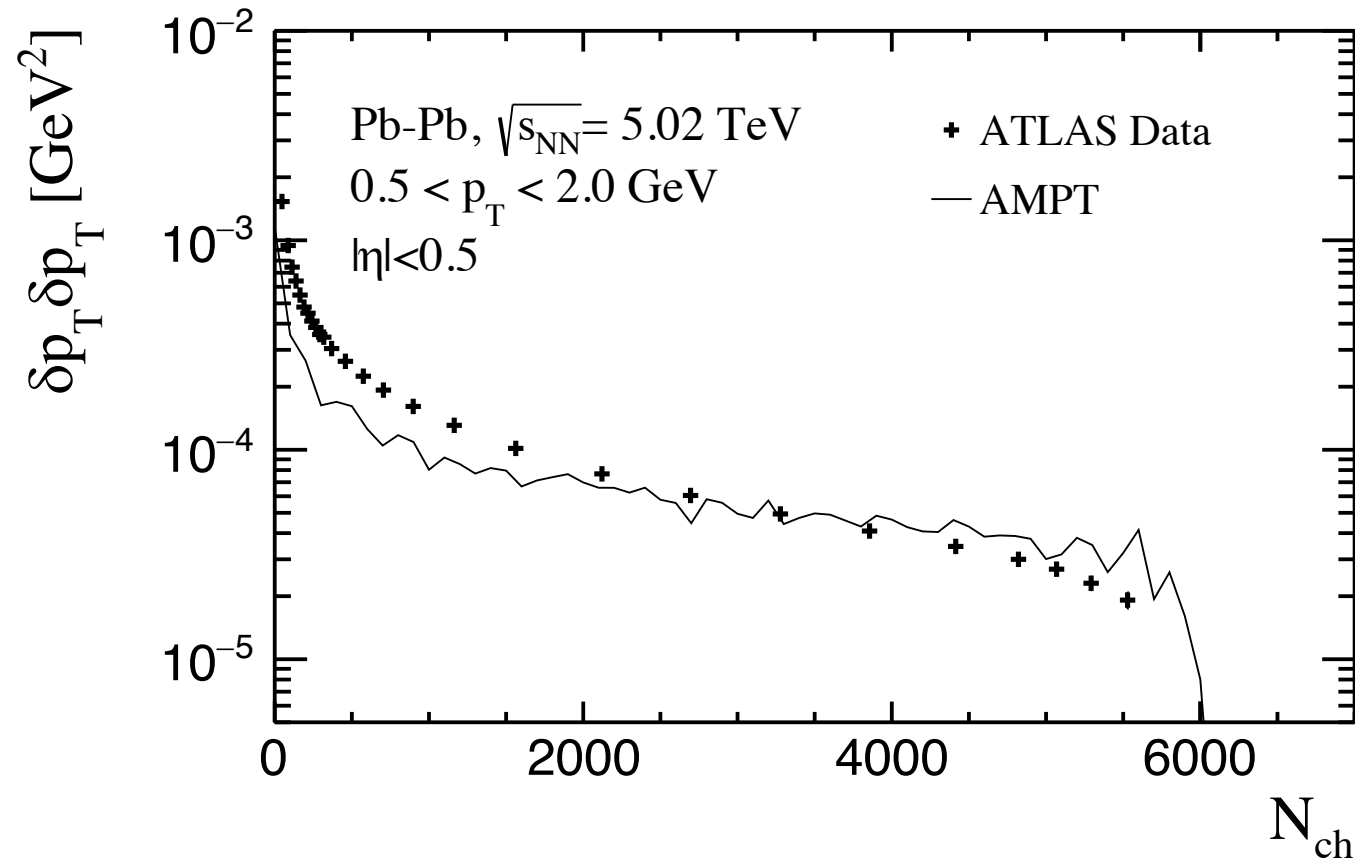
Also works for smaller systems

Structure of improvedAMPT (String Melting version)



The AMPT model used in this study contains all these improvements

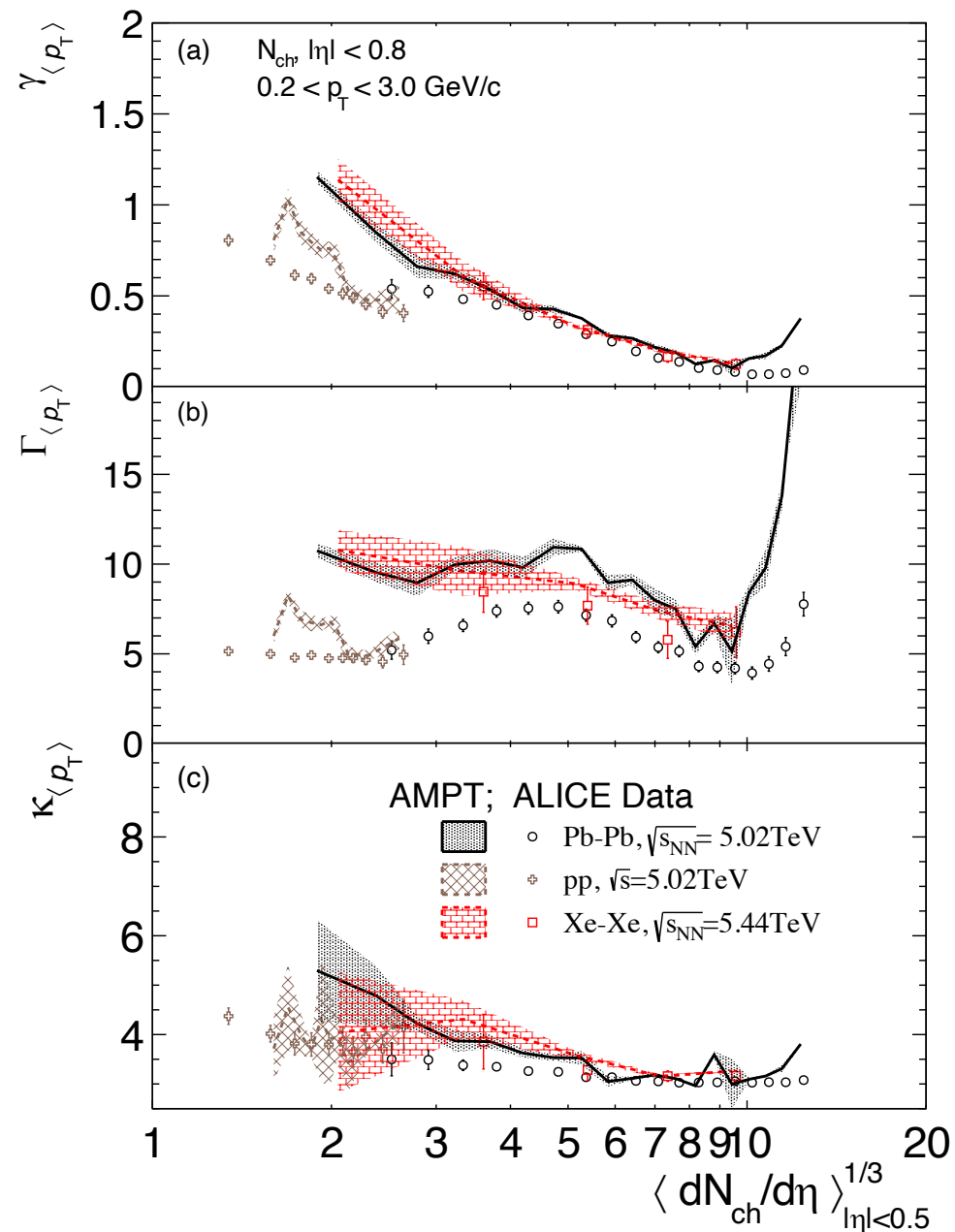
The variance



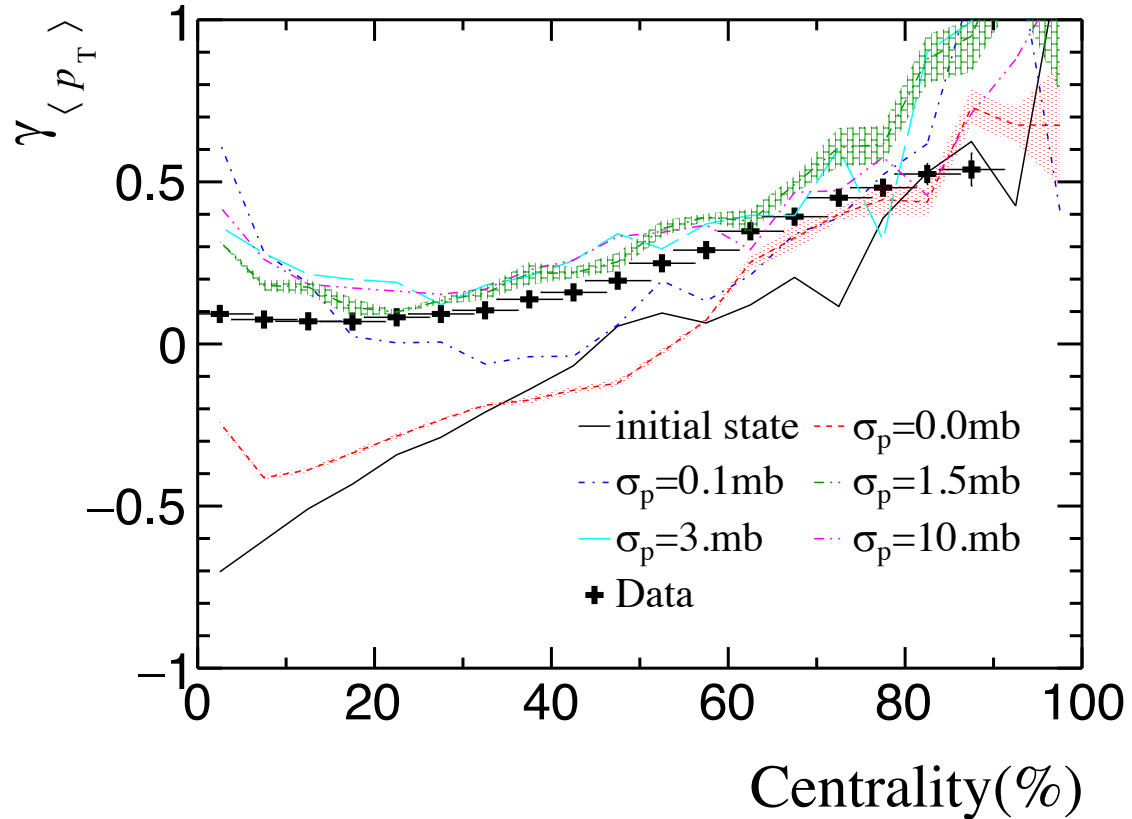
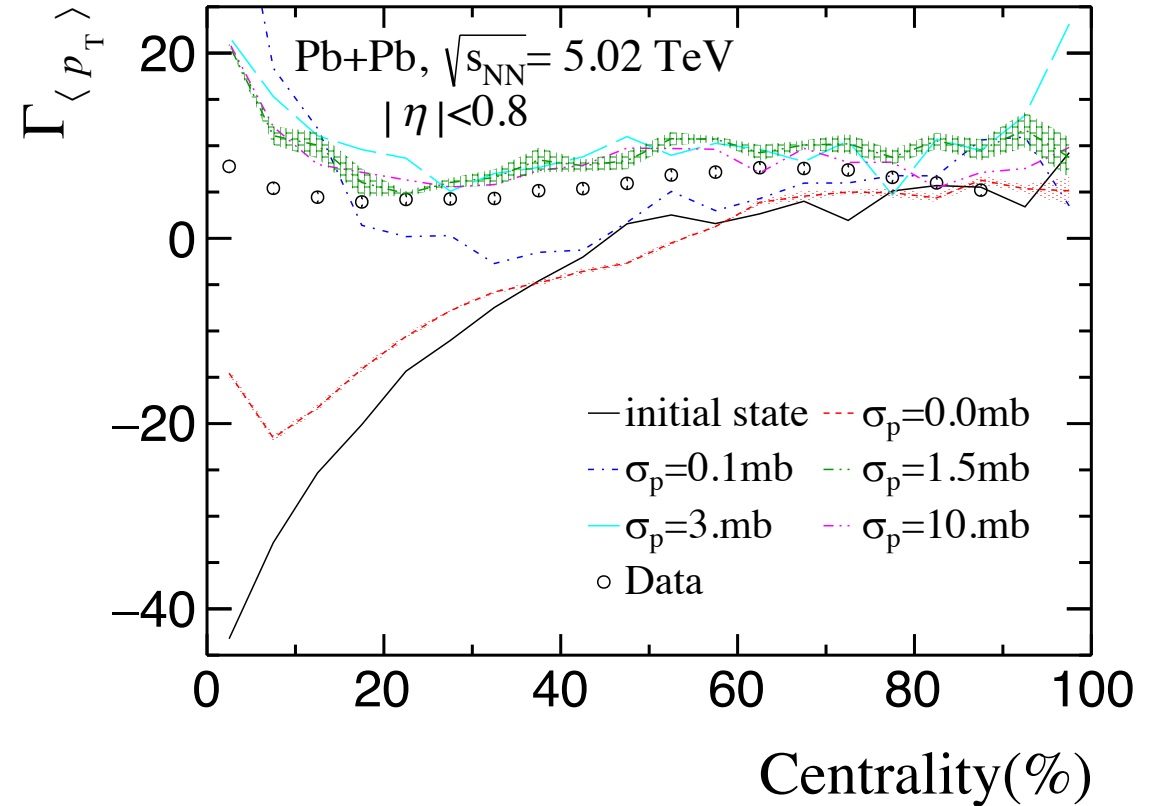
- The AMPT model can reasonably describe the variance of mean transverse momentum fluctuations at LHC.

Results

- Black: Pb+Pb collisions,
Red: Xe+Xe collision,
brown: pp collisions
- Reasonably describe the experimental data; tends to overestimate the $\Gamma_{\langle p_T \rangle}$ for Pb+Pb collisions.
- AMPT model captures the non-monotonic behavior of the $\Gamma_{\langle p_T \rangle}$ as function of centrality.

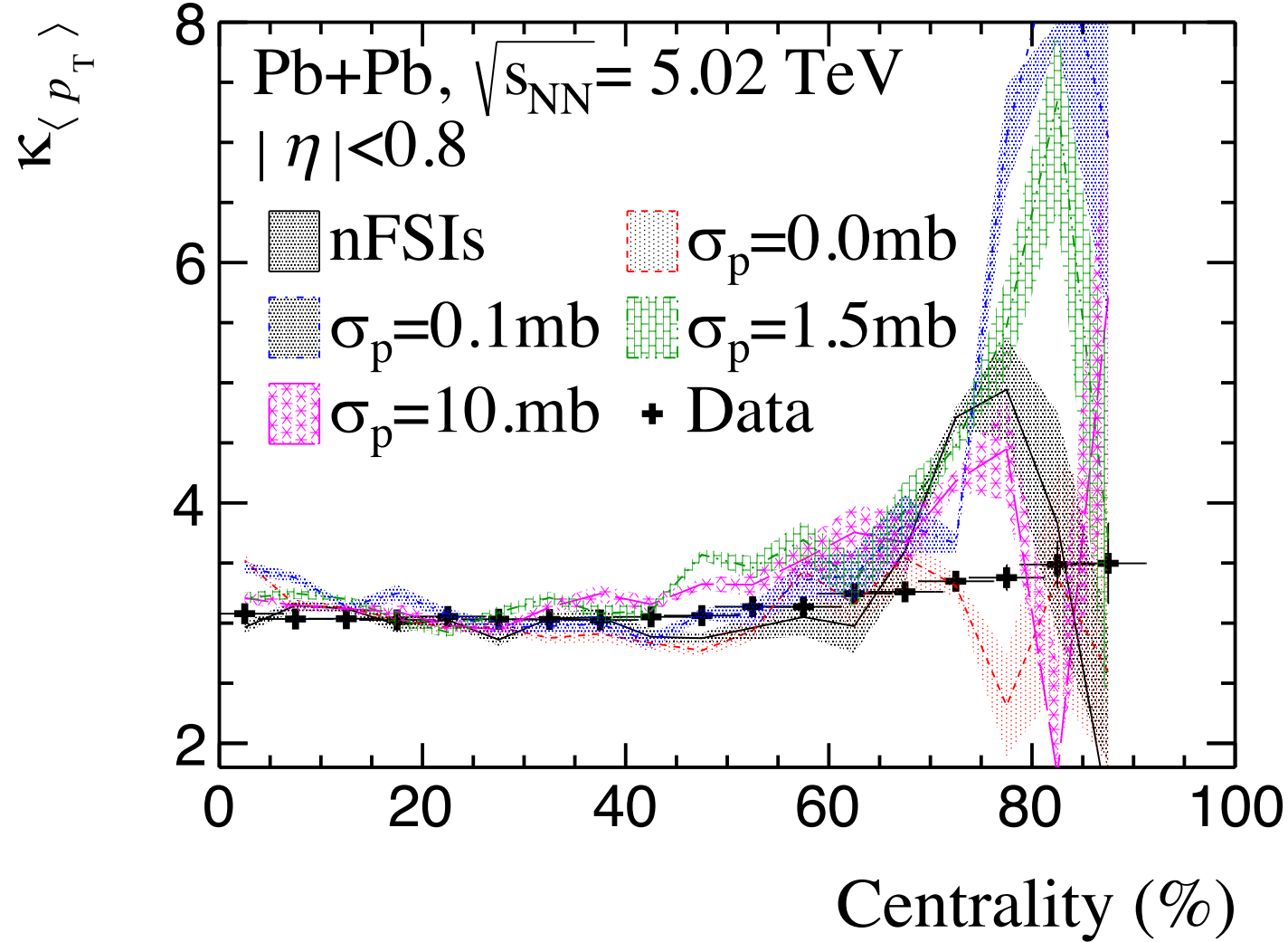


The final state effects



- The initial state: effectively turning off the ZPC and ART
- The FSI leads to the increase of both $\Gamma_{\langle p_T \rangle}$ and $\gamma_{\langle p_T \rangle}$ for most central collision
- A Boltzmann distribution in momentum gives a positive single-particle skewness S_{single} (on the order of 1).

The kurtosis



- The kurtosis: insensitive to the final-state effects, A promising observable for probing initial-state effects

Summary

We have studied the skewness and kurtosis of mean transverse momentum fluctuations in Pb+Pb, Xe+Xe and pp collisions at LHC energies with an improved multi-phase transport model;

The improved AMPT model can provide a reasonable description of the data in all three collision systems;

The final state effect is found important in reproducing the centrality dependence of the skewness.

Outlook

The effect of nuclear structure will be studied in the future.