Effects of hydrodynamic and initial longitudinal fluctuations on rapidity decorrelation of collective flow

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arXiv:2111.08963

Outline

- Introduction
- Model
- Results
- Summary

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Rapidity decorrelation and fluctuations

Properties of QGP

Dynamics

Longitudinal Dynamics

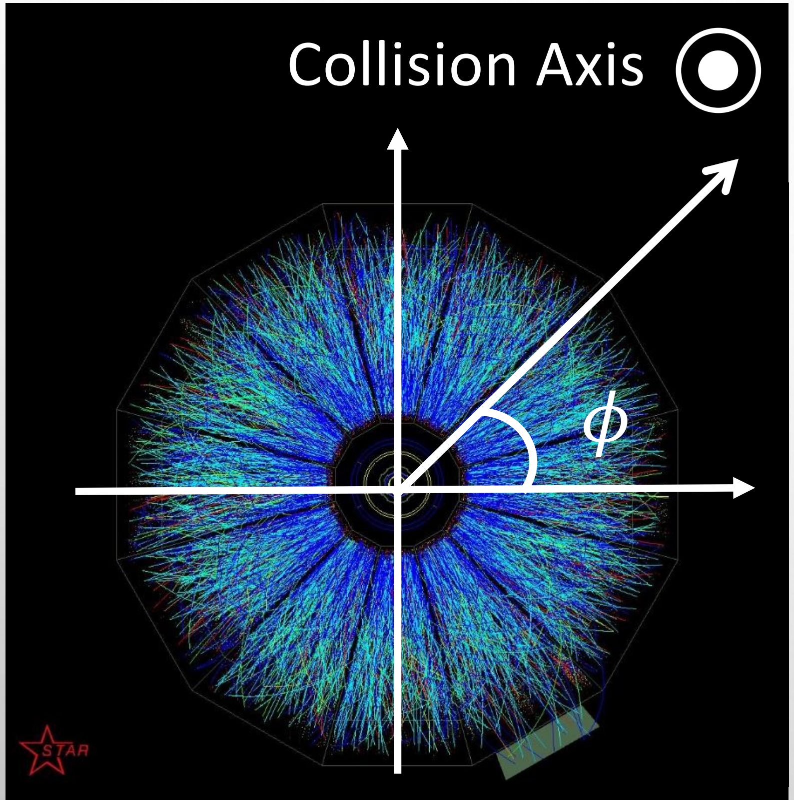
- Hydrodynamic fluctuations
- Initial fluctuations

Observables

Rapidity decorrelation

- Factorization ratio $r_n(\eta^a, \eta^b)$

Observables: Anisotropic flow v_n

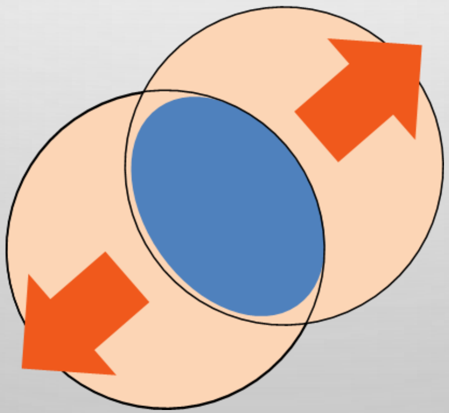


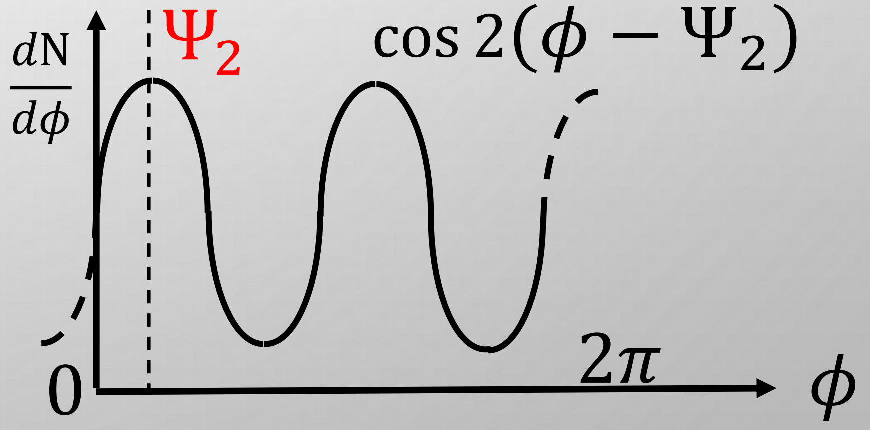
https://www.zmescience.com/science/physics/quark-gluon-plasma-lhc-26052011/

$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos n(\phi - \Psi_n)\right]$$

ϕ: Azimuthal angle of particle
Ψ_n: Azimuthal angle of the event plane
v_n: Anisotropic flow

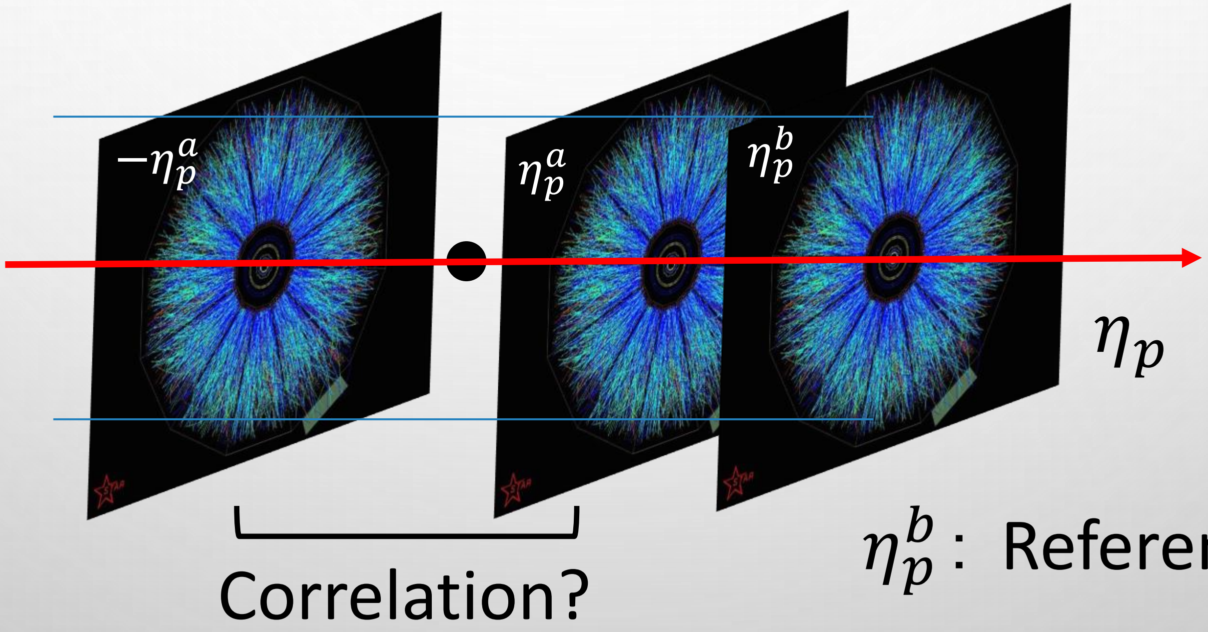
Large elliptic flow v_2 from initial geometry





Observables: Factorization ratio r_n

$$r_n(\eta_p^a, \eta_p^b) = \frac{V_{n\Delta}(-\eta_p^a, \eta_p^b)}{V_{n\Delta}(\eta_p^a, \eta_p^b)}, \quad V_{n\Delta} = \langle \cos[n(\phi^a - \phi^b)] \rangle$$



η_p^b : Reference

CMS Collaboration, Phys. Rev. C 92, 034911 (2015)
F.G. Gardim *et al.*, Phys. Rev . C 87, 031901 (2013)

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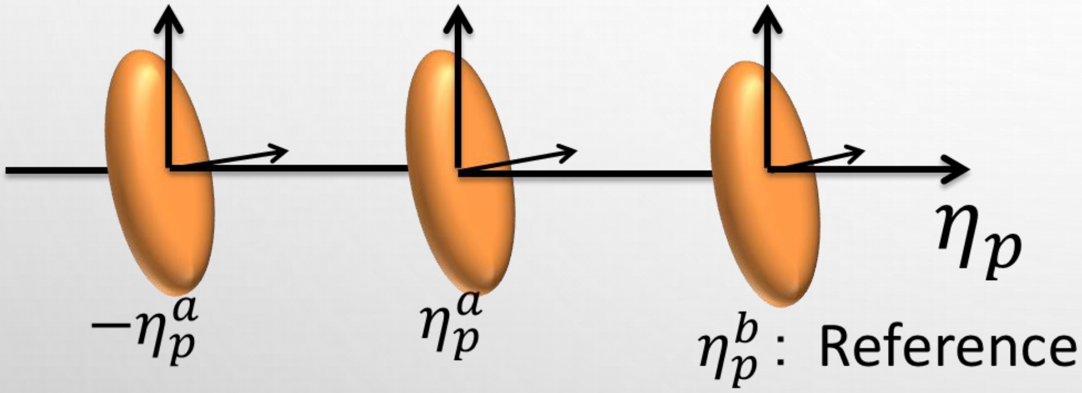
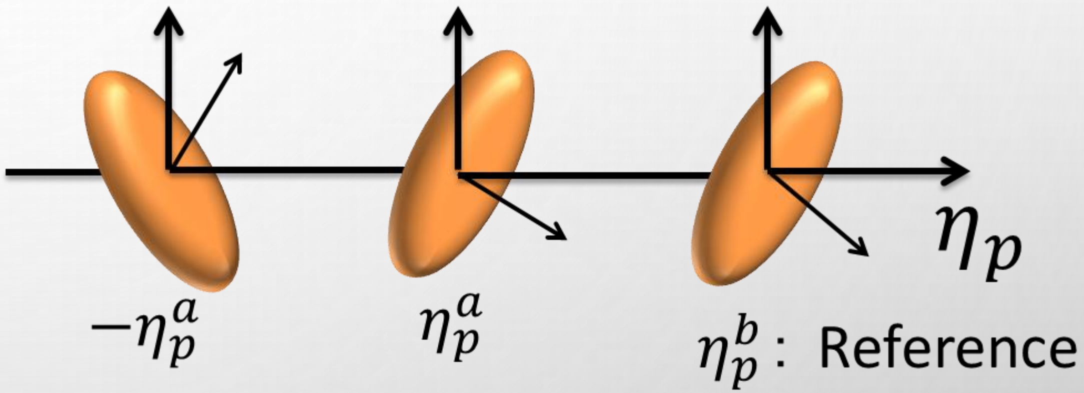




$r_n(\eta_p^a, \eta_p^b) \sim 1$

Unique event plane

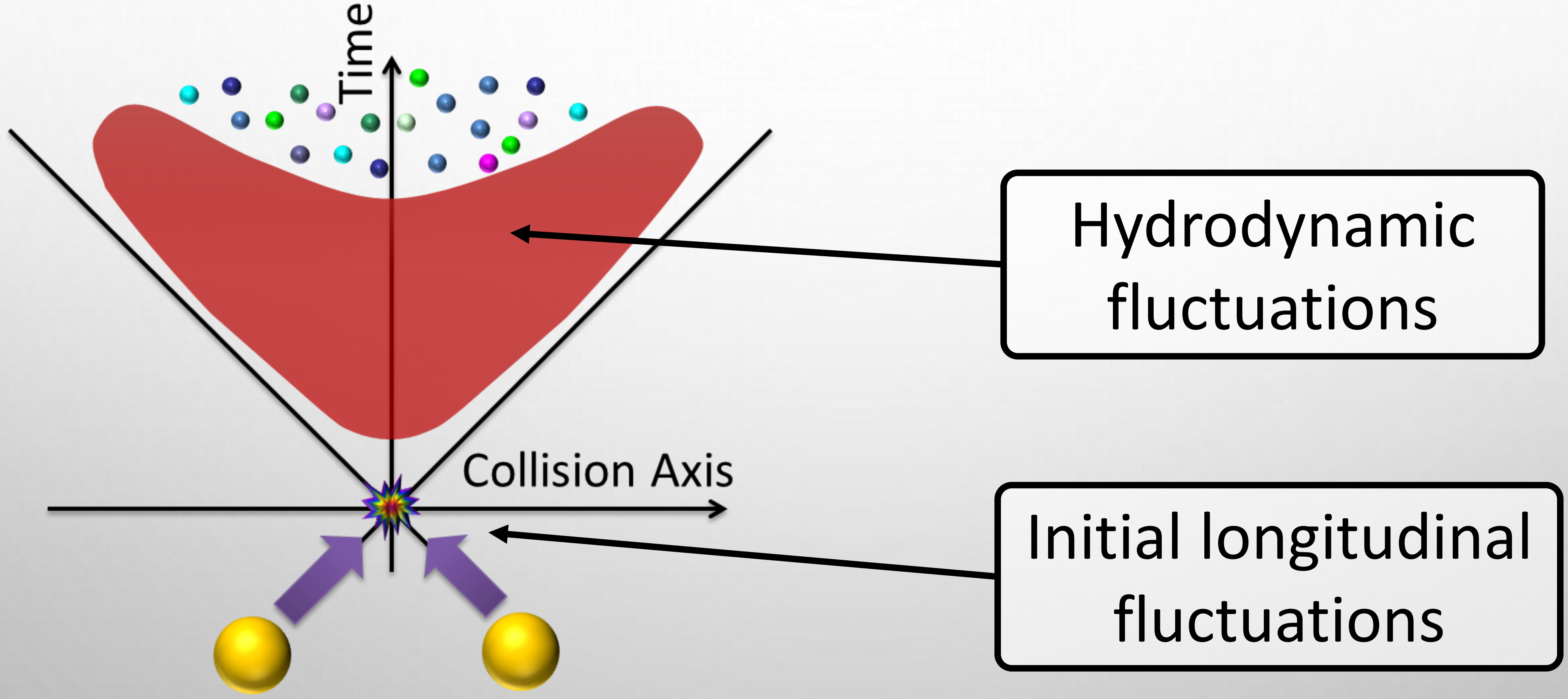
$r_n(\eta_p^a, \eta_p^b) < 1$

Decorrelation

CMS Collaboration, Phys. Rev. C 92, 034911 (2015)

F.G. Gardim *et al.*, Phys. Rev . C 87, 031901 (2013)

Space-time evolution of heavy ion collisions



Purpose of study

Understand QGP longitudinal dynamics by

hydrodynamic fluctuations

+

initial longitudinal fluctuations

Examine the effect by

Rapidity decorrelations

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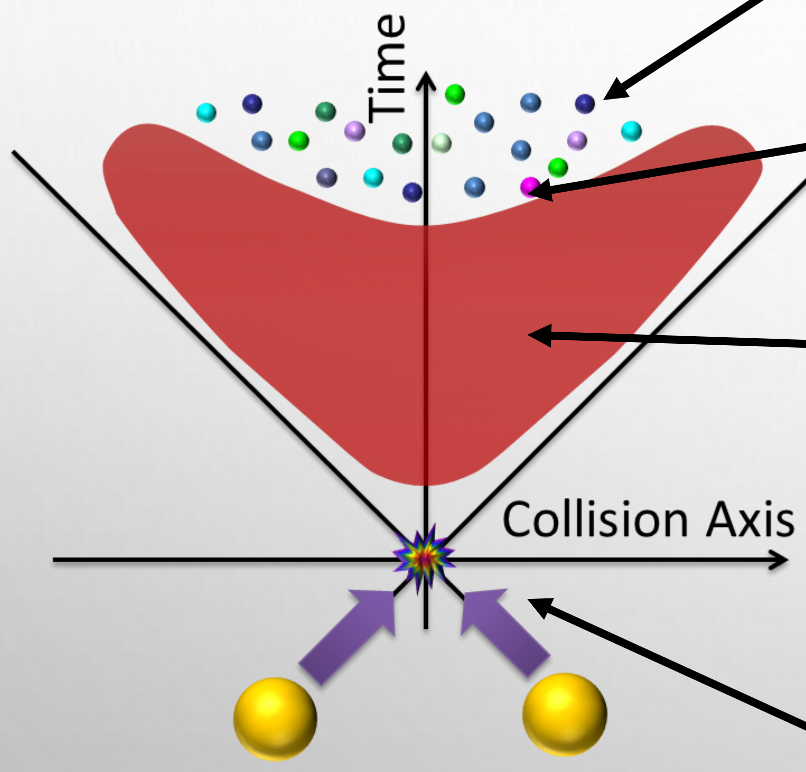
Integrated dynamical model



T.Hirano *et al.*, Prog. Part. Nucl. Phys. 70,108 (2013)

4.Hadron gas

Hadron cascade model (JAM)

3.Particlization

Cooper-Frye formula ($T_{\mathrm{sw}} = 155$ MeV)

2.QGP fluid

Hydrodynamic fluctuations

Full 3D relativistic fluctuating hydrodynamics

EoS: s95p-v1.1 (Lattice QCD+HRG)

Shear viscosity: $\eta/s = 1/4\pi$

K. Murase, Ph. D thesis, The Univ. of Tokyo (2015)

1.Initial state

Longitudinal fluctuations

Longitudinal: PYTHIA x modified BGK

Transverse: MC-Glauber model

M. Okai *et al.*, Phys. Rev. C 95, 054914 (2017)

Hydrodynamic fluctuations

Shear stress tensor (in 1st order for illustration)

Fluctuating hydro

Viscous hydro

$$\boxed{\pi^{\mu\nu}(x) = 2\eta\partial^{\langle\mu}u^{\nu\rangle}} + \delta\pi^{\mu\nu}(x)$$

η: shear viscosity

u^{μ}: four fluid velocity

Thermodynamic force

Hydrodynamic fluctuations

Note: Relaxation term needed in actual simulations

Fluctuation dissipation relation for shear stress tensor

$$\pi^{\mu\nu} = 2\eta\partial^{\langle\mu}u^{\nu\rangle} + \color{red}{\delta\pi^{\mu\nu}}$$

Increase of entropy ⟷ Balance ⟷ Decrease of entropy

Fluctuation dissipation relation
= Stability condition of thermal system

$$\left\langle \delta\pi^{ij}\delta\pi^{ij} \right\rangle \sim 4T\eta\delta^4(x - x')$$

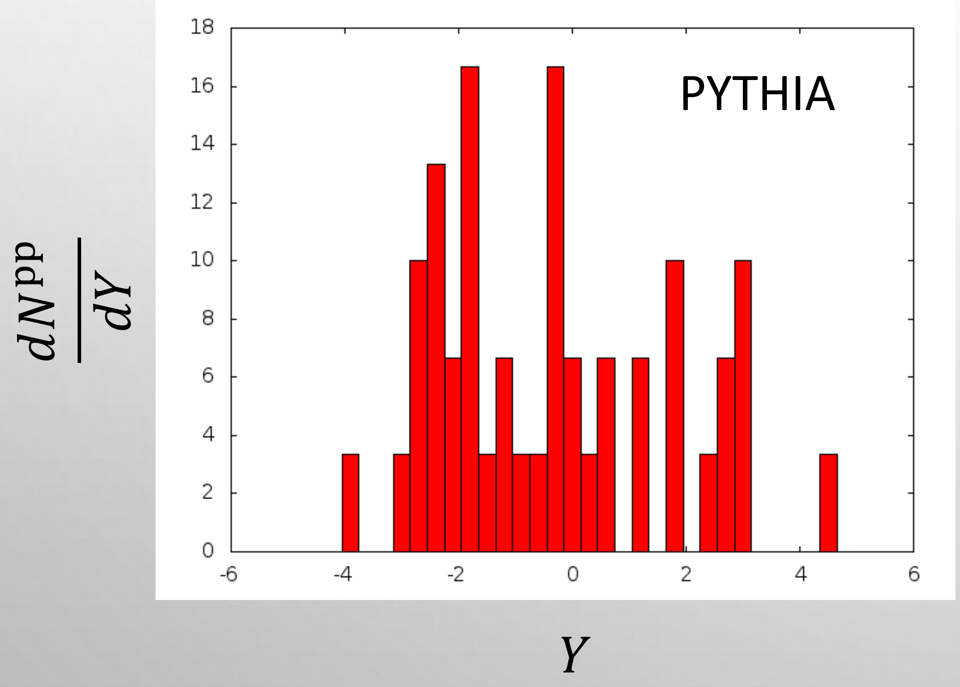
$$\delta^4(x - x') \Rightarrow \frac{1}{\Delta t}\frac{1}{(4\pi\lambda^2)^{\frac{3}{2}}} e^{-\frac{(x-x')^2}{4\lambda^2}}$$

T: temperature
η: shear viscosity
λ: Gaussian width

Initial longitudinal profile

PYTHIA

Rapidity fluctuations
in pp collision at 200 GeV

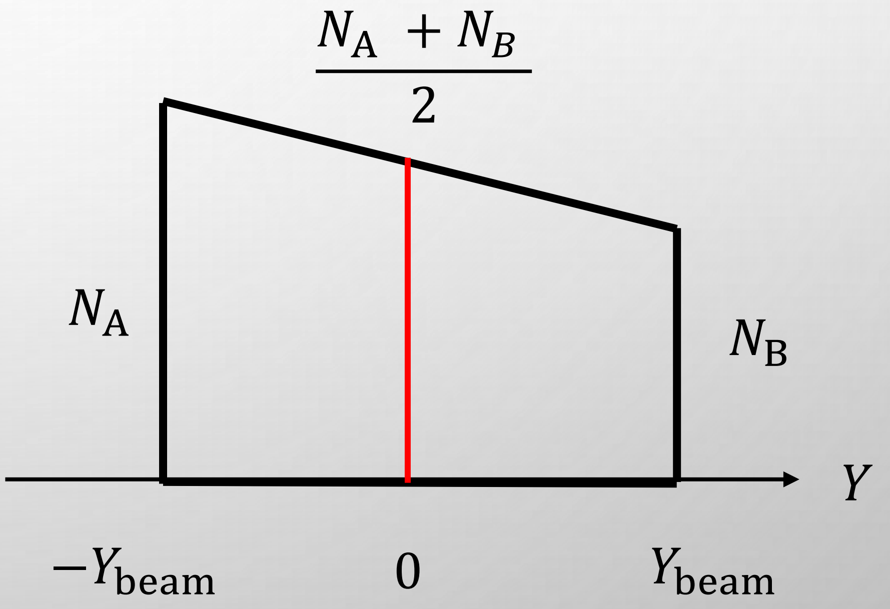


T. Sjöstrand *et al.*, Comput. Phys. Commun. 191, 159 (2015)

Modified BGK

Nuclear effect

N_{part} scaling → twist



M. Okai *et al.*, Phys. Rev. C 95, 054914 (2017)

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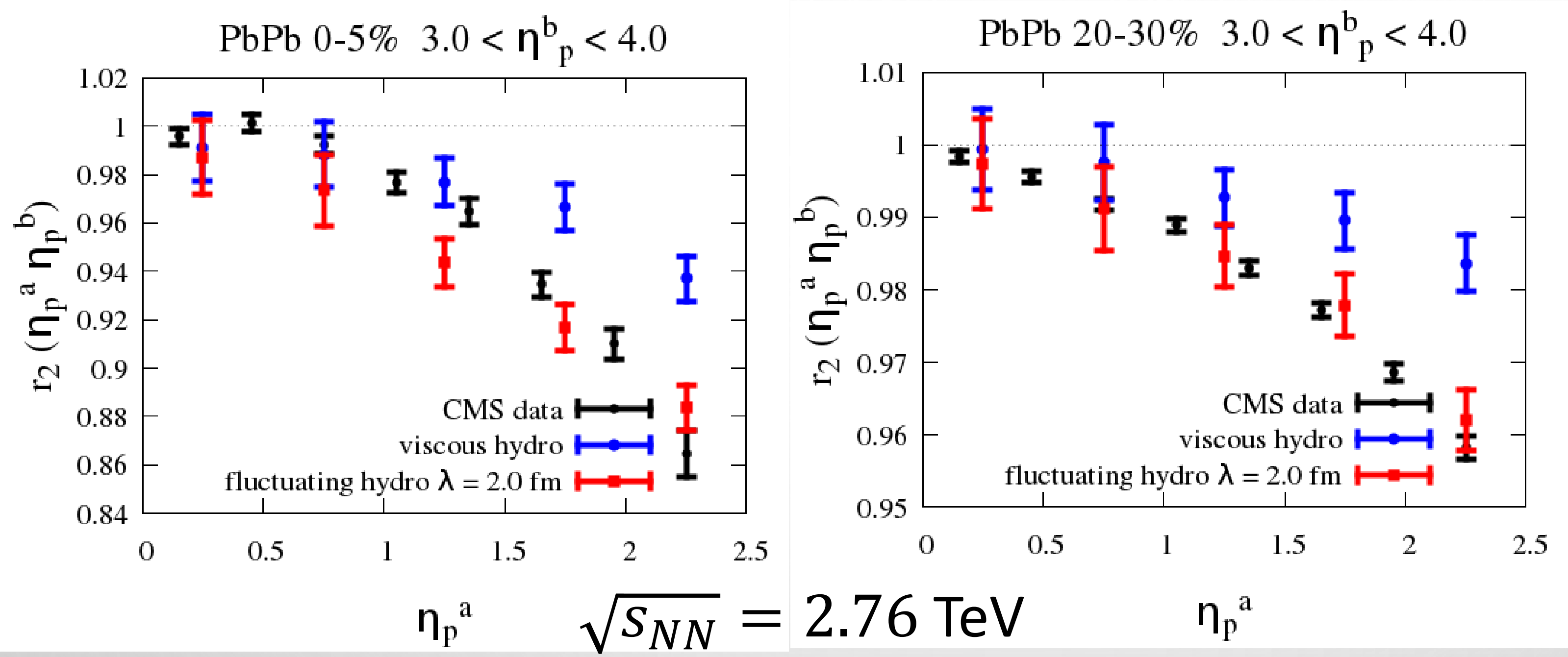
Factorization ratio $r_2(\eta_p^a, \eta_p^b)$

with initial longitudinal fluctuations



$\sqrt{s_{NN}} = 2.76$ TeV

CMS, Phys. Rev. C 92, 034911 (2015)

1 > Viscous > CMS data ≈ Fluctuating hydro

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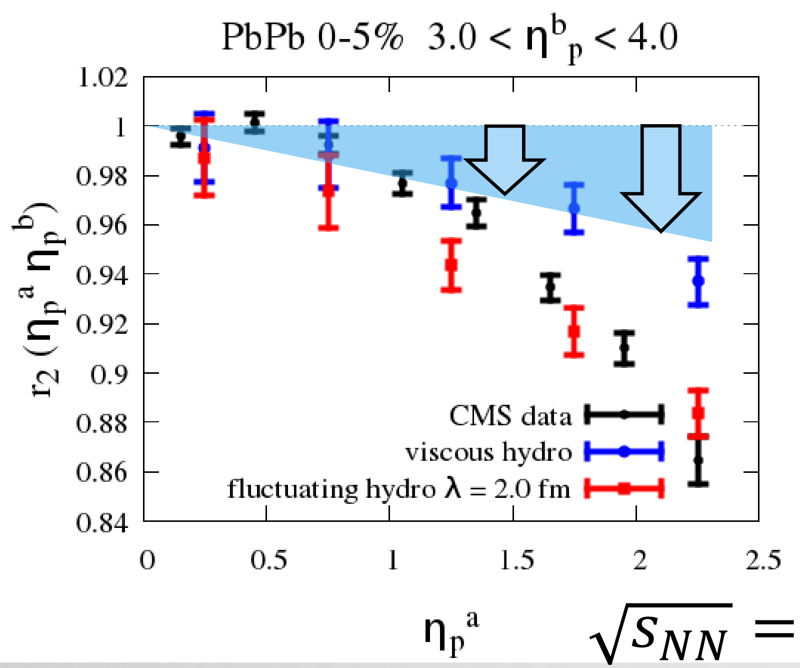

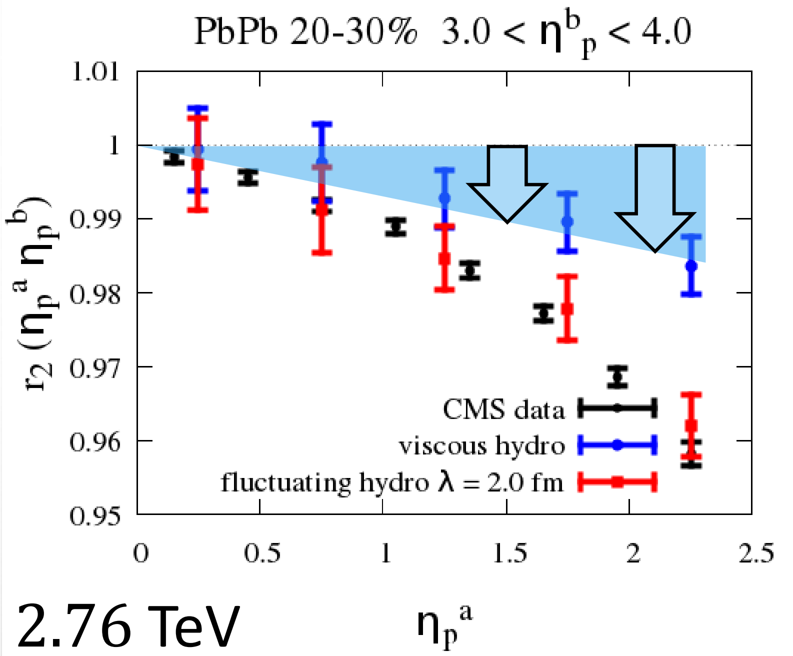

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Initial longitudinal fluctuations

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Initial longitudinal fluctuations ➡ Rapidity decorrelation

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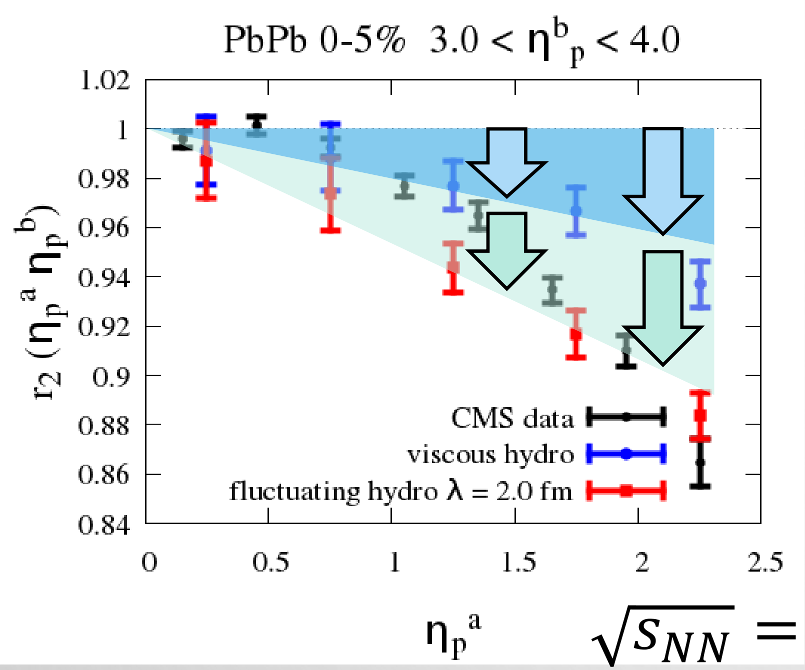

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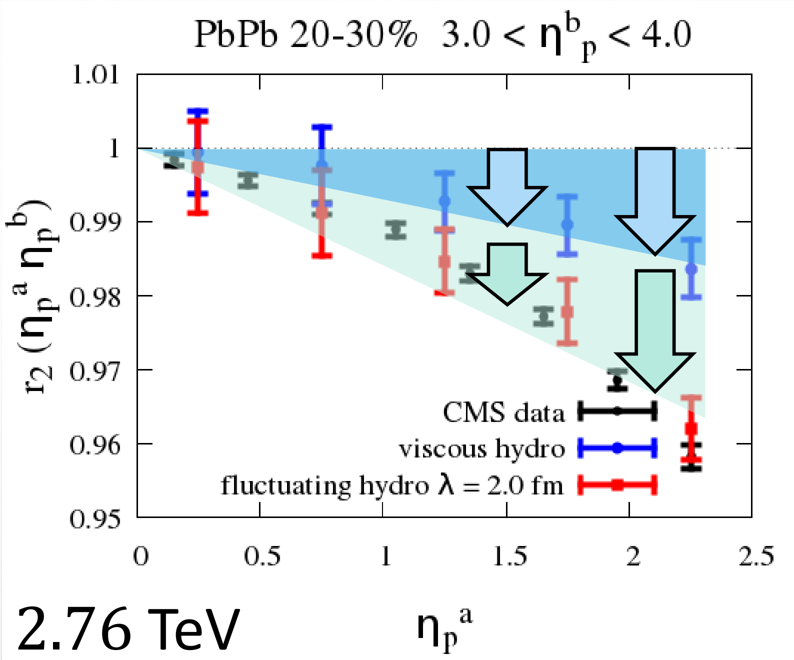


Initial longitudinal fluctuations

Hydrodynamic fluctuations

CMS, Phys. Rev. C 92, 034911 (2015)

1 > Viscous > CMS data ≈ Fluctuating hydro

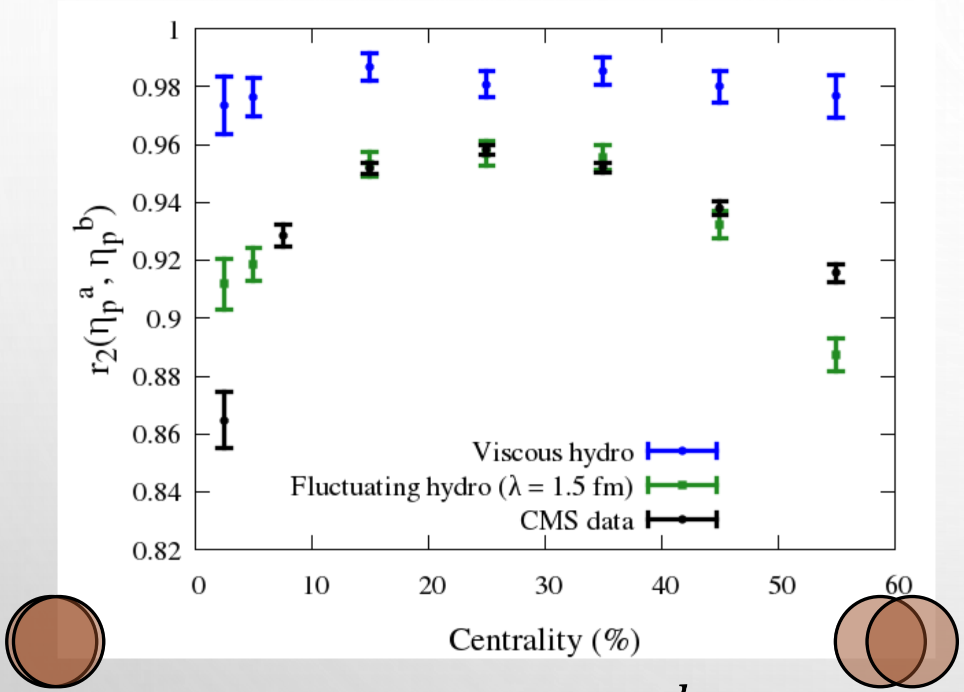
Initial longitudinal fluctuations ➡ Rapidity decorrelation

Hydrodynamic fluctuations + Initial longitudinal fluctuations

➡ Close to experimental data

Centrality dependence of $r_2(\eta_p^a, \eta_p^b)$

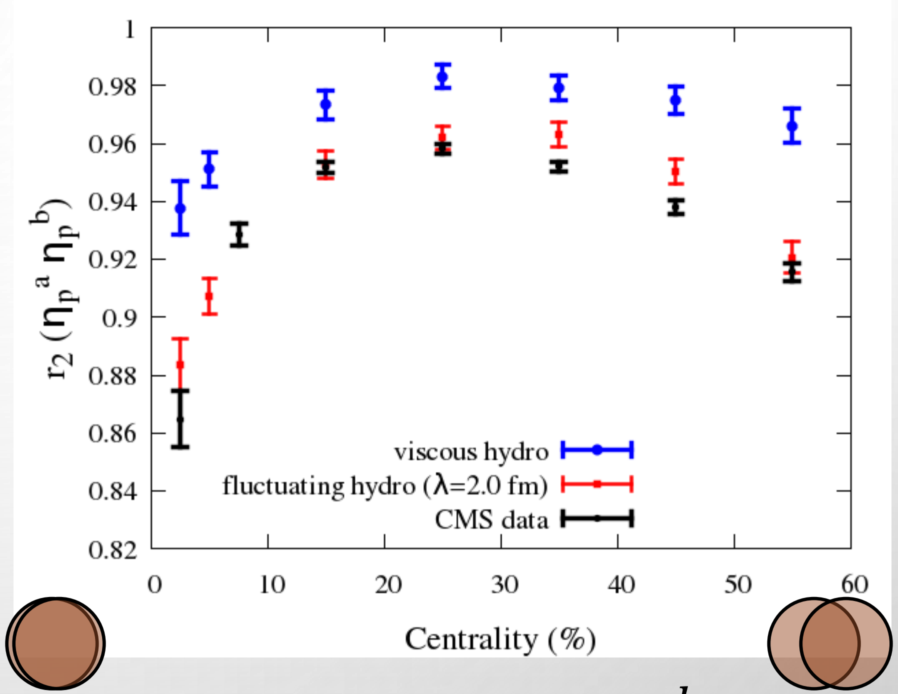
w/o initial longitudinal fluctuations



$2.0 < \eta_p^a < 2.5,\ 3.0 < \eta_p^b < 4.0$

AS, K. Murase and T. Hirano, Phys. Rev. C102, 064903 (2020)

with initial longitudinal fluctuations



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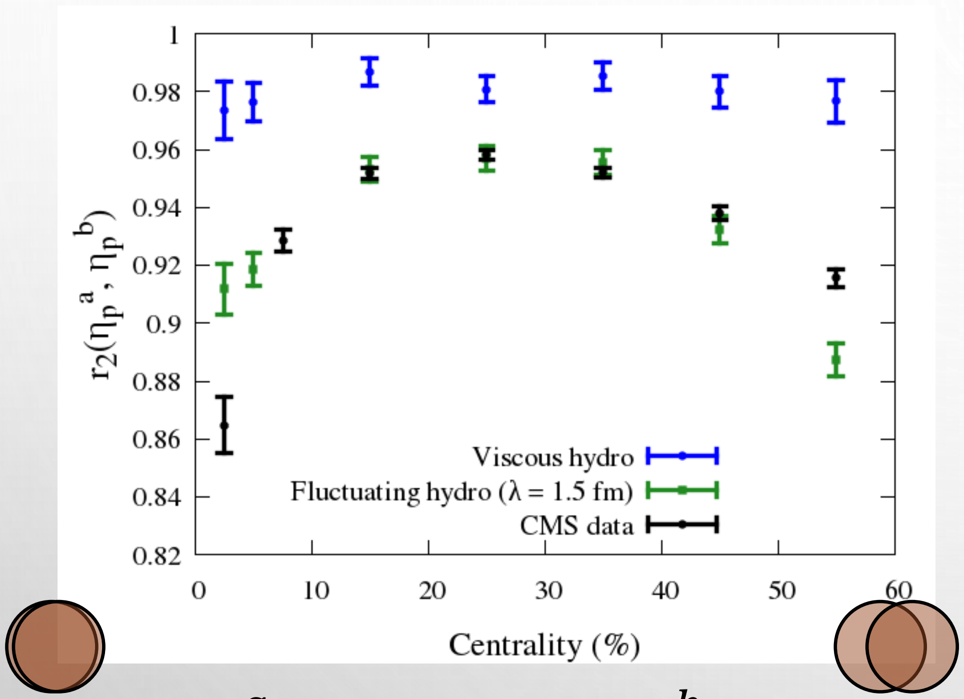
Hydrodynamic fluctuations + Initial longitudinal fluctuations

➡ Close to experimental data

Centrality dependence of $r_2(\eta_p^a, \eta_p^b)$

w/o initial longitudinal fluctuations



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AS, K. Murase and T. Hirano, Phys. Rev. C102, 064903 (2020)

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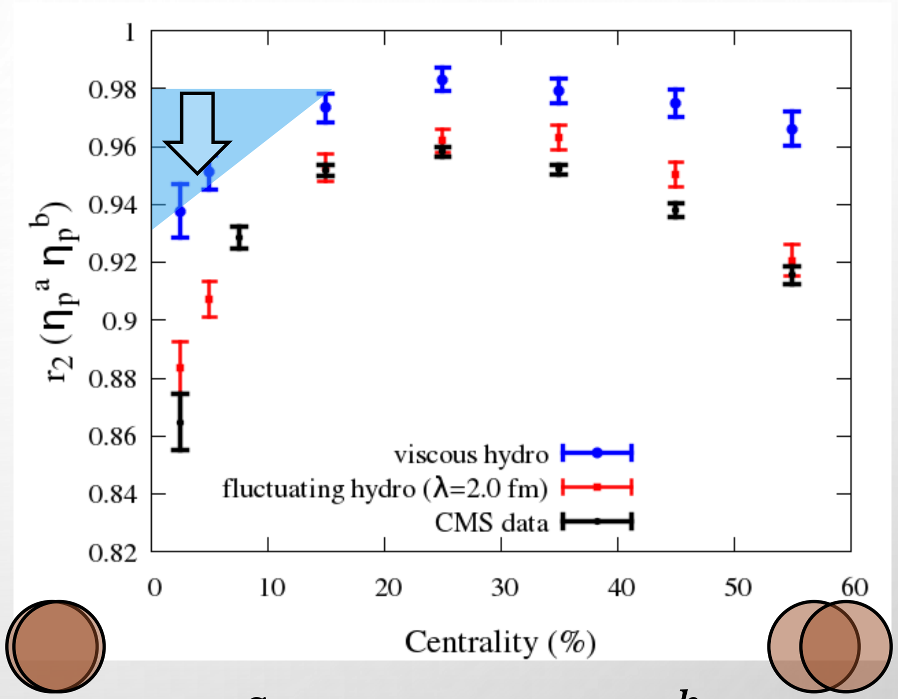

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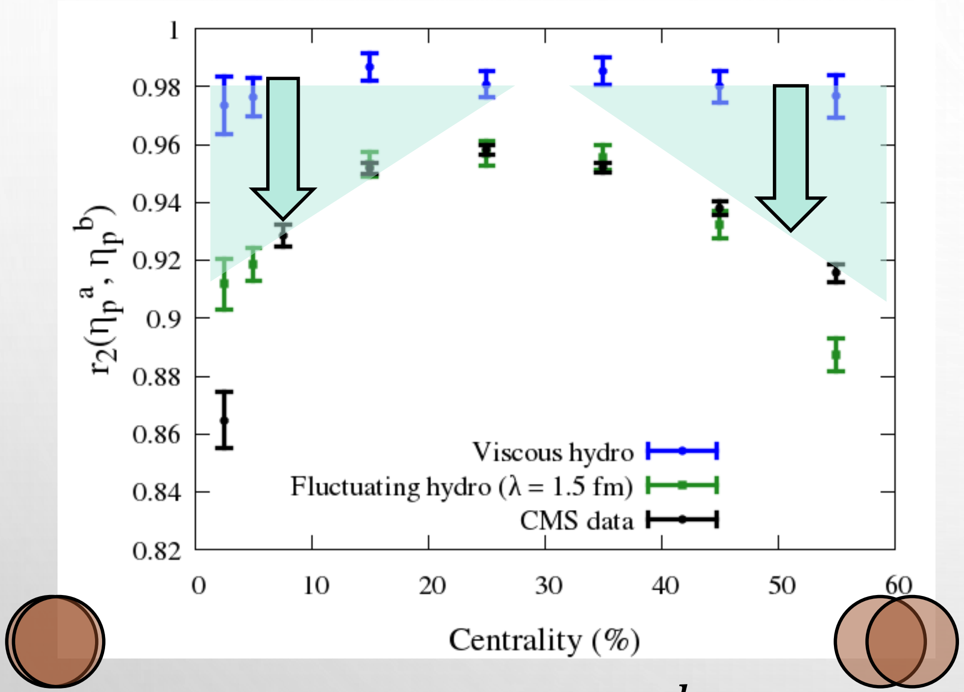
CMS, Phys. Rev. C 92, 034911 (2015).

Initial longitudinal fluctuations ➡ Affects central collisions

Centrality dependence of $r_2(\eta_p^a, \eta_p^b)$

w/o initial longitudinal fluctuations



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AS, K. Murase and T. Hirano, Phys. Rev. C102, 064903 (2020)

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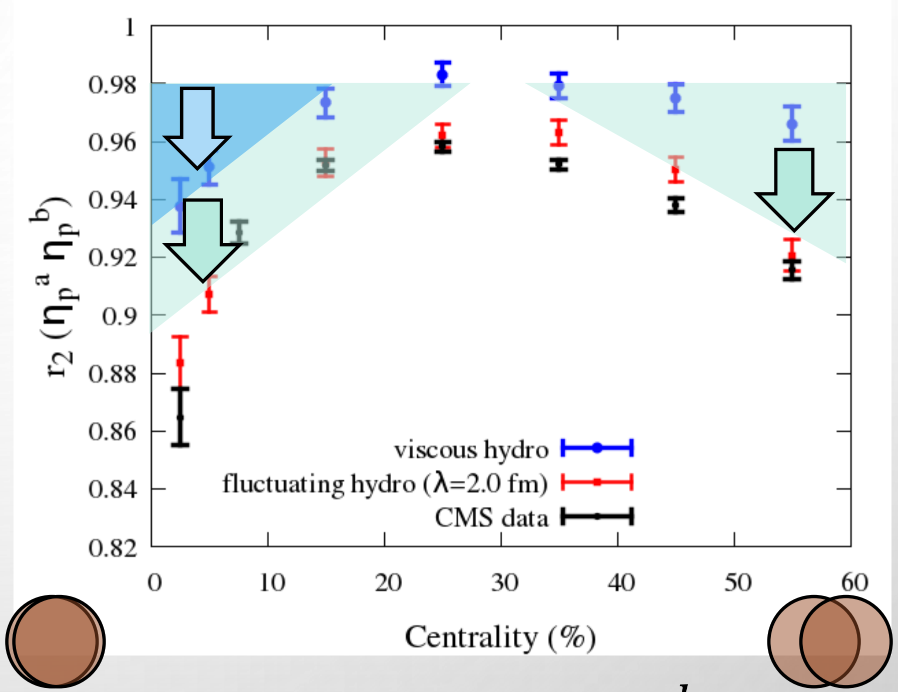


$2.0 < \eta_p^a < 2.5,\ 3.0 < \eta_p^b < 4.0$

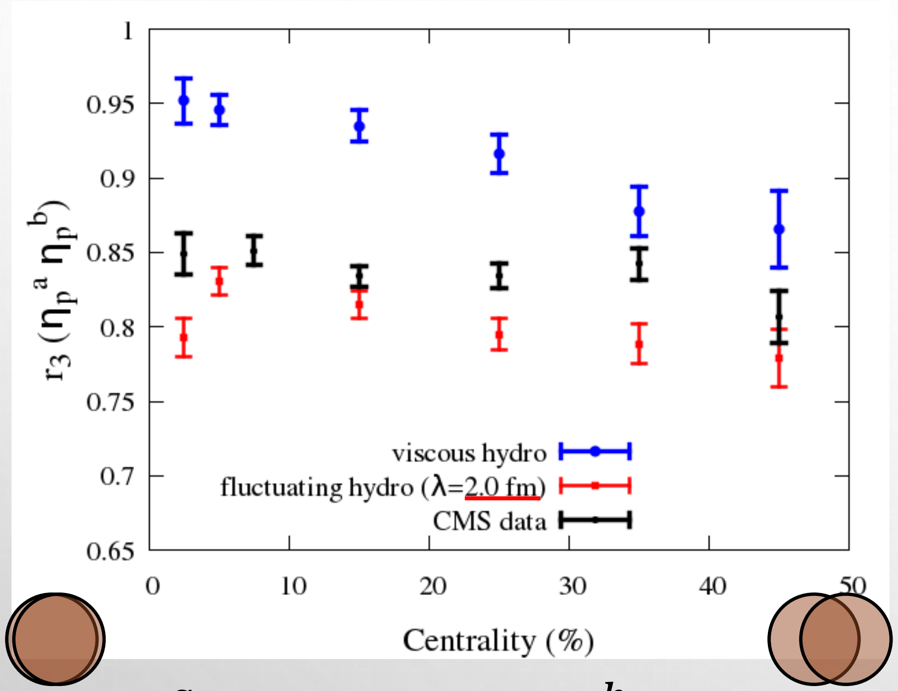
CMS, Phys. Rev. C 92, 034911 (2015).

Initial longitudinal fluctuations ➡ Affects central collisions

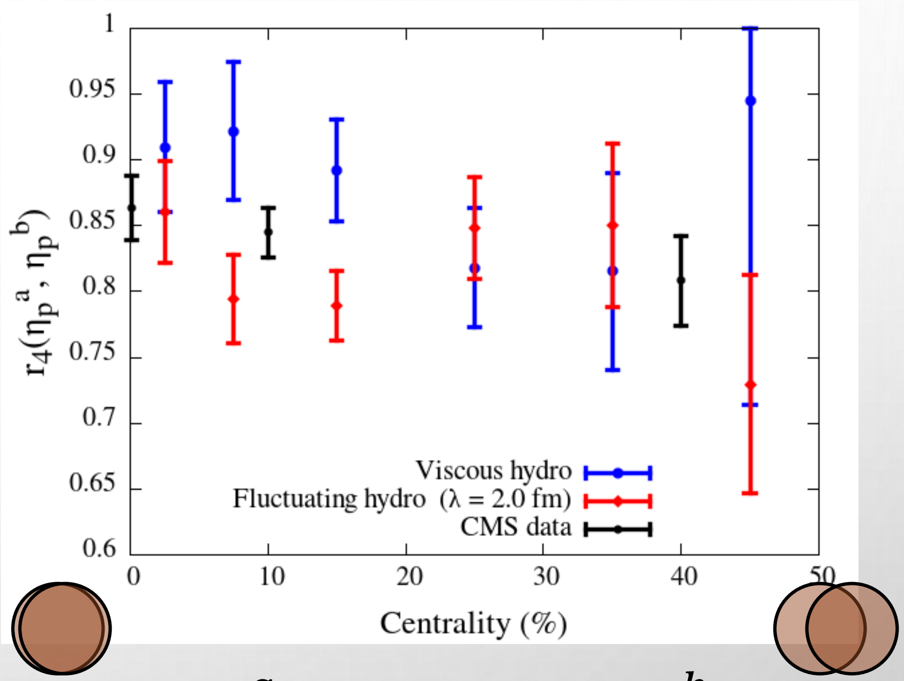
Hydrodynamic fluctuations ➡ Affects central and peripheral collisions

Centrality dependence of $r_3(\eta_p^a, \eta_p^b)$, $r_4(\eta_p^a, \eta_p^b)$

with initial longitudinal fluctuations



$2.0 < \eta_p^a < 2.5,\ 3.0 < \eta_p^b < 4.0$



$2.0 < \eta_p^a < 2.5,\ 3.0 < \eta_p^b < 4.0$

CMS, Phys. Rev. C 92, 034911 (2015).

Hydrodynamic fluctuations + Initial longitudinal fluctuations

➡ $r_3(\eta_p^a, \eta_p^b)$ and $r_4(\eta_p^a, \eta_p^b)$ are close to experimental data

Summary

◆Analyze Pb+Pb 2.76TeV using Integrated dynamical model based on 3D hydrodynamics

- Initial longitudinal fluctuations
- Hydrodynamic fluctuations

◆Factorization ratio $r_n\ (\eta_p^a, \eta_p^b\ )$

- Explain centrality dependence of r_2, r_3, r_4
  - Initial longitudinal fluctuations affects central collisions
  - Hydrodynamic fluctuations affects central and peripheral collisions
- Importance of including both

  hydrodynamic fluctuations and initial longitudinal fluctuations

◆Outlook

- Rapidity decorrelation in Isobar collisions?
- Rapidity decorrelation with nuclear deformation? Talk by Koichi Murase (Tomorrow)