Longitudinal de-correlation of anisotropic flow in Pb+Pb collisions

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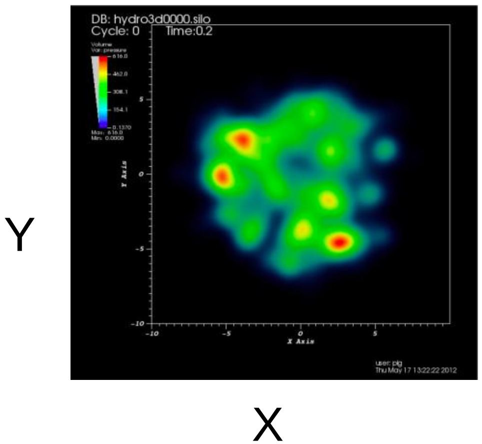
Stiftung/Foundation

Plan of the talk

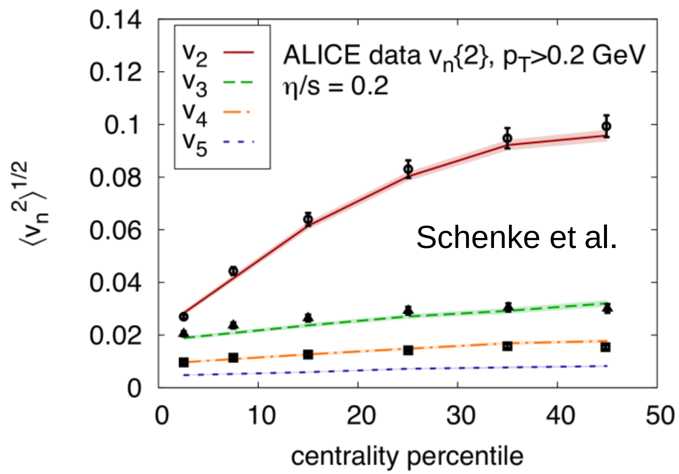
- Motivation
- Dynamical models
  - -3+1 D Ideal Hydro
  - -Transport model AMPT
- Results
- Summary

Motivation: anisotropic flow & initial fluctuation

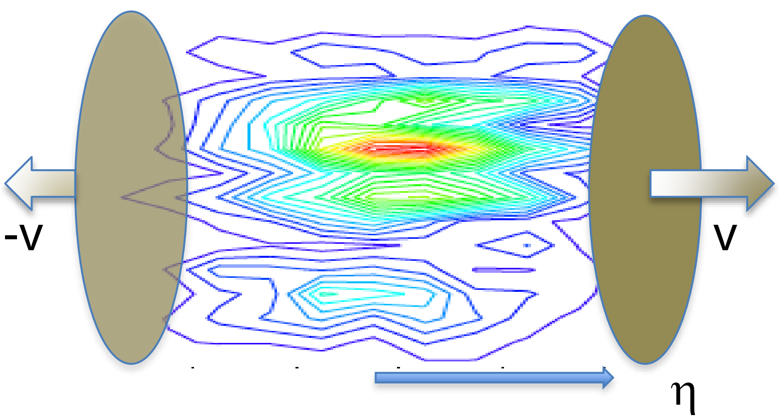
Transverse fluctuation of initial energy density



Non-zero odd flow harmonics



Longitudinal fluctuation of initial energy density



→Hydrodynamic model study:
Anisotropic flow reduces in presence of longitudinal fluctuation.

LG Pang et al
Phys.Rev. C86 (2012) 024911

-What is the effect of longitudinal fluctuation on event plane correlation.

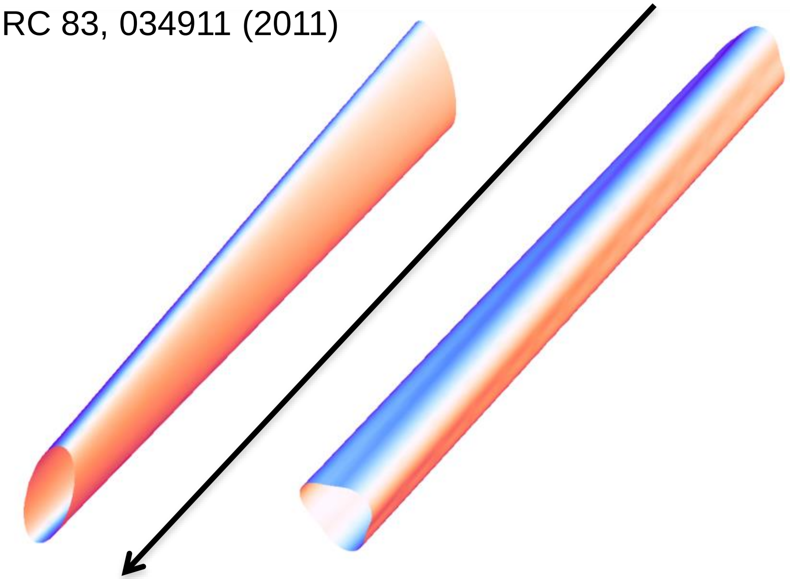
-Any dependency on transport coefficients?

We use a 3+1D ideal Hydro & AMPT model to investigate these questions

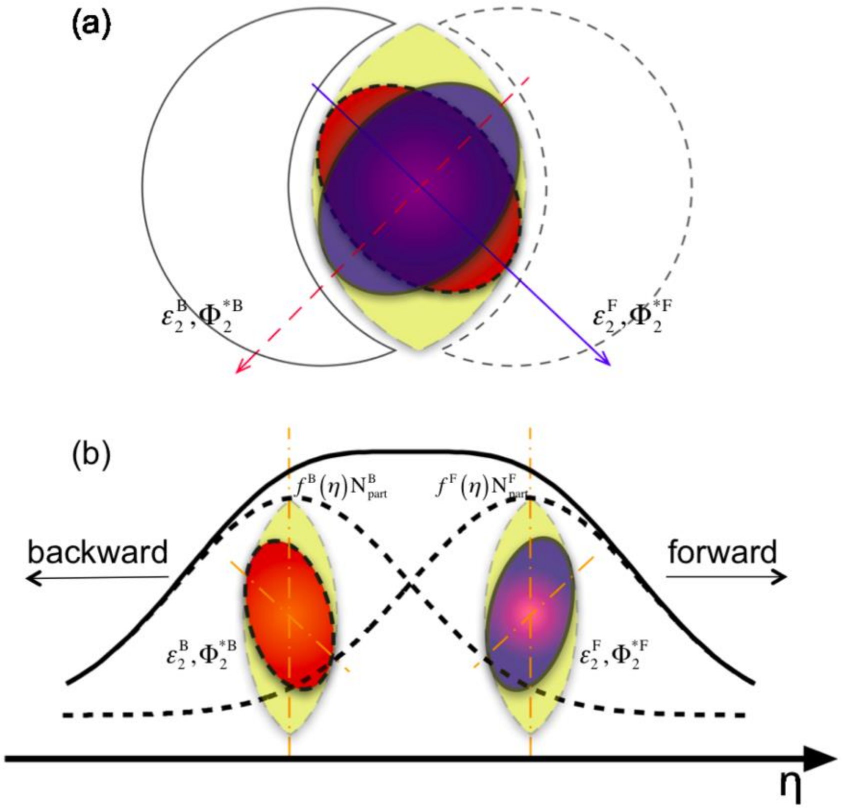
Twist of Event planes

Hydrodynamics , torqued fireball

P Bozek et al,
PRC 83, 034911 (2011)



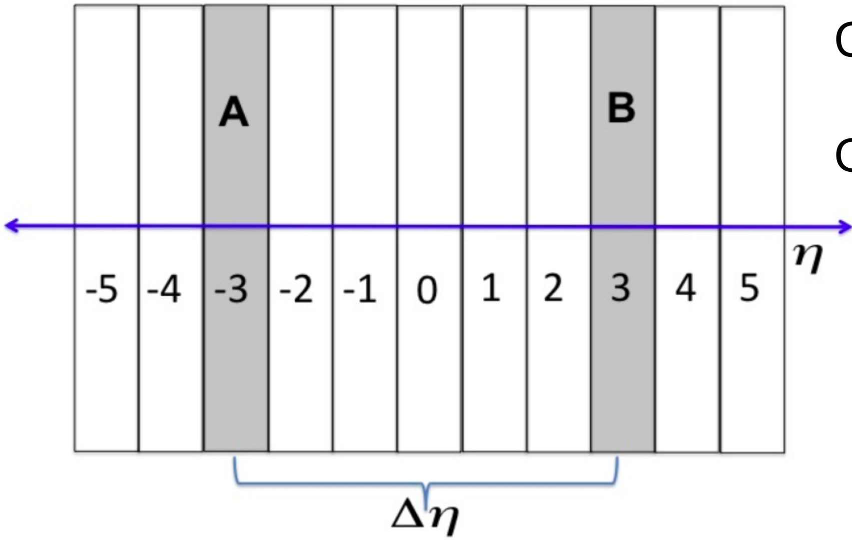
Transport



- Statistical fluctuation in the transverse distribution
- the asymmetry in the emission profiles of forward(backward) moving wounded nucleons

J Jia et al,
PRC 90, 034915 (2014)

Formulation: longitudinal correlation



Correlation of event plane at rapidity “A” and “B”

General Definition :

$$C_n(A,B) = \frac{\langle Q_n(A) \cdot Q_n^*(B) \rangle}{\sqrt{\langle Q_n(A) \cdot Q_n^*(A) \rangle}\sqrt{\langle Q_n(B) \cdot Q_n^*(B) \rangle}}$$

$$\mathrm{Q_n} \equiv Q_n e^{in\Phi_n} = \frac{1}{N}\sum_{j=1}^{N} e^{in\varphi_j}$$ → n-th order Q vector

Specific cases,

(i) Continuous p_T spectra of particles : relevant for hydrodynamic model study

$$C_n(A,B)\big|_{hydro} = \frac{\langle v_n(A) \cdot v_n(B) e^{in(\Phi_n(A)-\Phi_n(B))} \rangle}{\sqrt{\langle v_n(A)^2 \rangle}\sqrt{\langle v_n(B)^2 \rangle}}$$

(ii) Finite multiplicity → sub-event method : relevant our transport model study

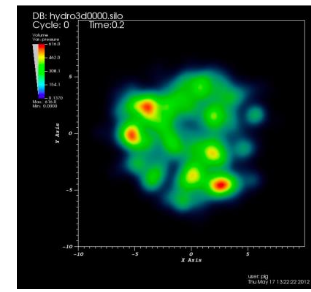
$$C_n(A,B)\big|_{AMPT} = \frac{\frac{1}{4}\sum_{i,j=1}^{2}\langle Q_n(A_i) \cdot Q_n^*(B_j) \rangle}{\sqrt{\langle Q_n(A_1) \cdot Q_n^*(A_2) \rangle}\sqrt{\langle Q_n(B_1) \cdot Q_n^*(B_2) \rangle}}$$

Dynamical Model-1: E-by-E 3+1D ideal hydro

L Pang et al
PhysRevC.86.024911

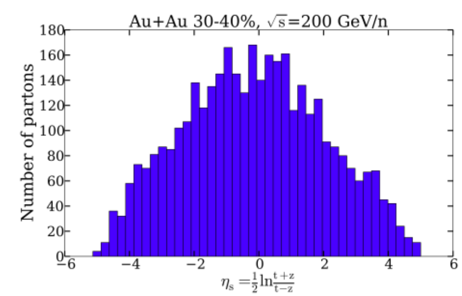
Initial Condition → HIJING (MC Glauber model)

Energy density in XY



Energy Momentum tensor $T^{\mu\nu}$ is calculated from the position and momentum of the initial parton on a fixed proper time surface

$$\partial_\nu T^{\mu\nu} = 0$$



Parton density along spatial-rapidity

TIME ↓

QGP phase

Hadronic Phase

EoS (Lattice QCD+HRG)
Chemical Equilibrium, s95p-v1

P Huovinen et al, Nucl Phys A 837,26

Freeze-out → T_f=137 MeV

Number of event
for each centrality ~1000

Dynamical Model-2: AMPT Monte Carlo

T
I
M
E

Initial condition → HIJING (Glauber model)

Zi wei lin et al
PhysRevC.72.064901

Excited string and mini-jet
fragmented to partons

QGP phase → Zhang's Parton Cascade
two parton collision only

Parton freeze-out ,

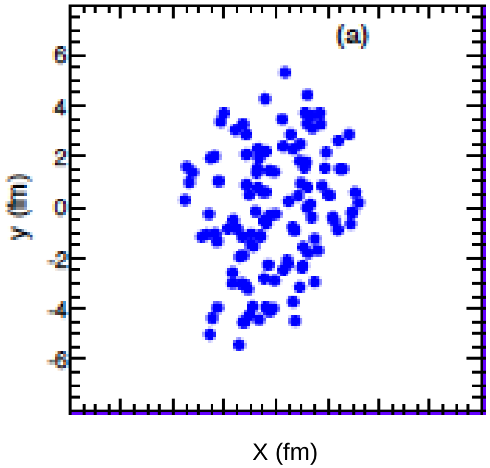
Hadron formation via coalescence

Hadronic phase → A Relativistic Transport
B-B,B-M,M-M elastic and
inelastic processes

Hadron freeze-out

Number of events for
Each centrality ~ 10000

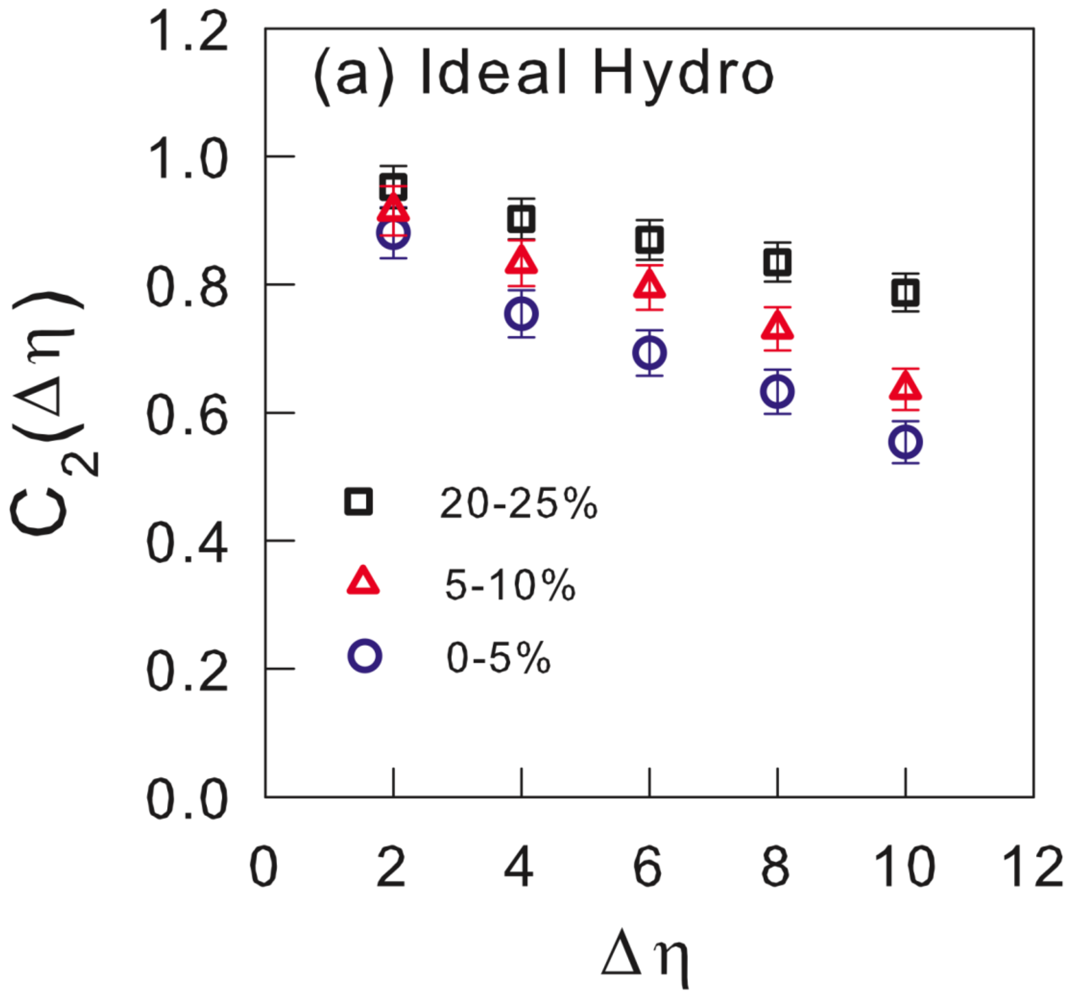
Parton cross section=1.5, 20 mb



Distribution of participating nucleons
In a typical non-central Au+Au collision.

Result: 3+1D Ideal Hydrodynamics

2nd order flow correlation



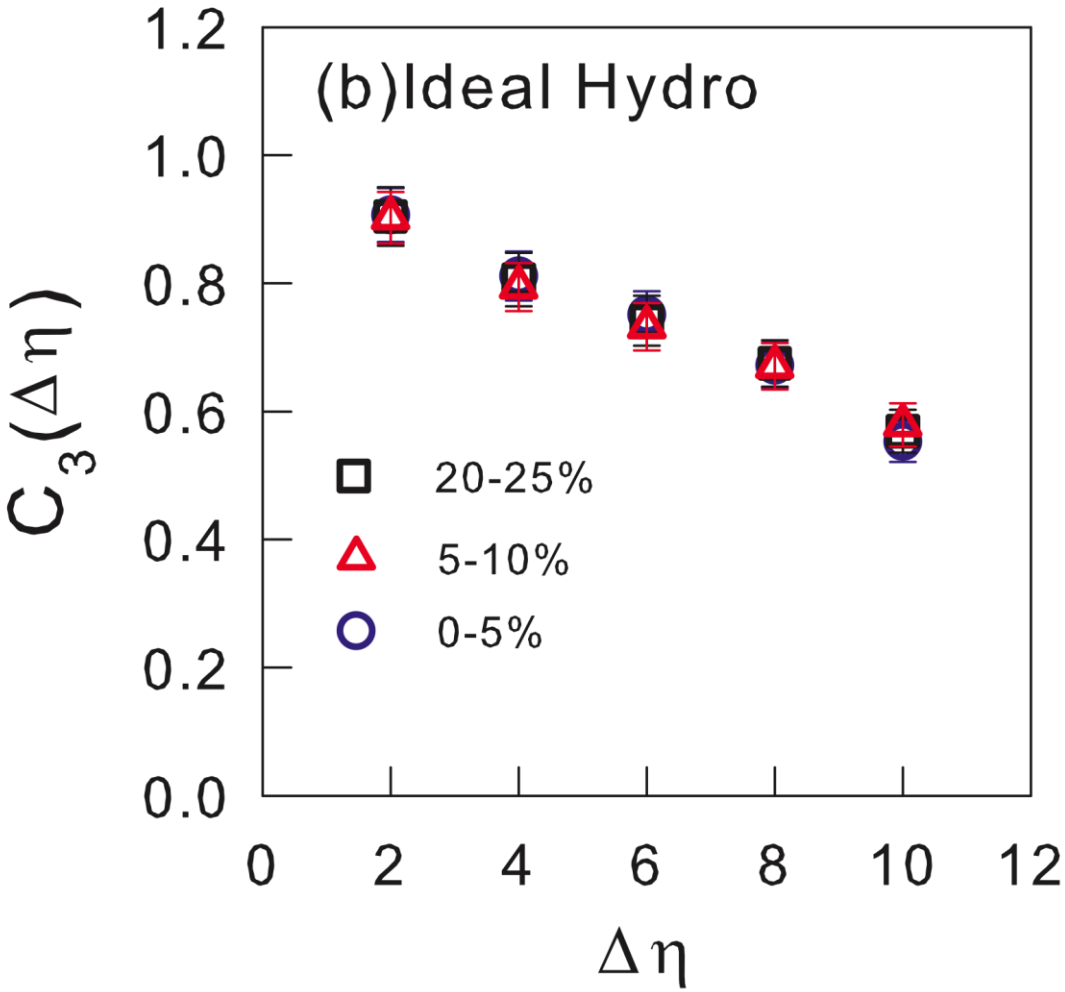
-Decreases with rapidity gap
Twist and/or fluctuation ?
We will come to it later

-Depends on centrality of collision
Role of initial state geometry ?

Answer can be possibly found from third flow harmonics

Result: 3+1D Ideal Hydrodynamics

3rd order flow correlation



-Decreases with rapidity gap

Twist and/or fluctuation ?

We will come to it later in talk

-Doesn't depends on centrality of collision

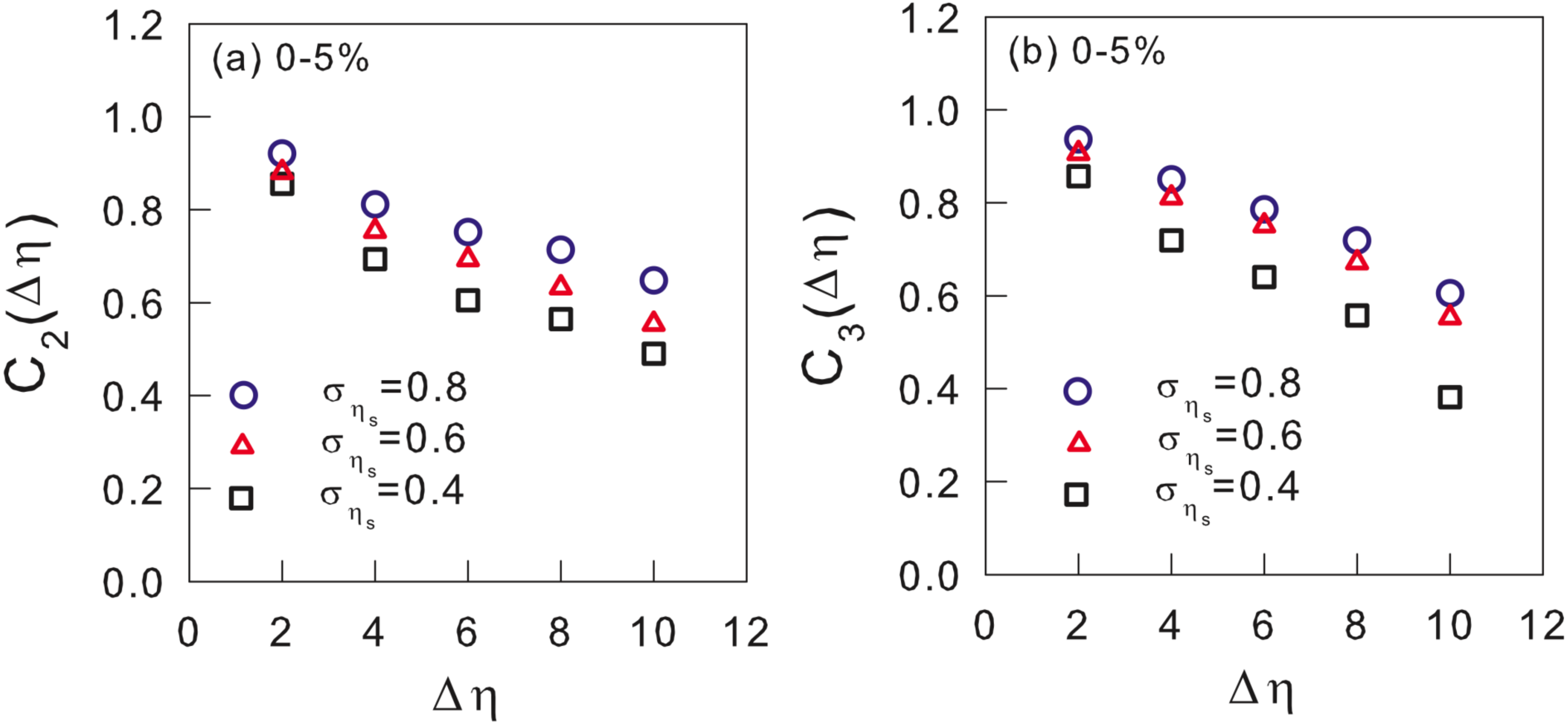
Role of initial state geometry ?

Indeed geometry plays an important role.

Result: 3+1D Ideal Hydrodynamics

Dependency on the smearing parameter

$$T^{\mu\nu} = K\sum_{i=1}^{N}\frac{p_i^{\mu}p_i^{\nu}}{p_i^{\tau}}\frac{1}{\tau_0 2\pi\sigma_r^2\sqrt{2\pi\sigma_{\eta_s}^2}}\exp\left[-\frac{(x-x_i)^2+(y-y_i)^2}{2\sigma_r^2}-\frac{(\eta_s-\eta_{is})^2}{2\sigma_{\eta_s}^2}\right]$$



Does correlation depends on shear viscosity ?

Possibility of studying Transport coefficients

Bad News : No existing 3+1D viscous hydro code
with longitudinal fluctuating IC

Good News: transport models can be utilized
to study the dependency
by using different parton cross section.

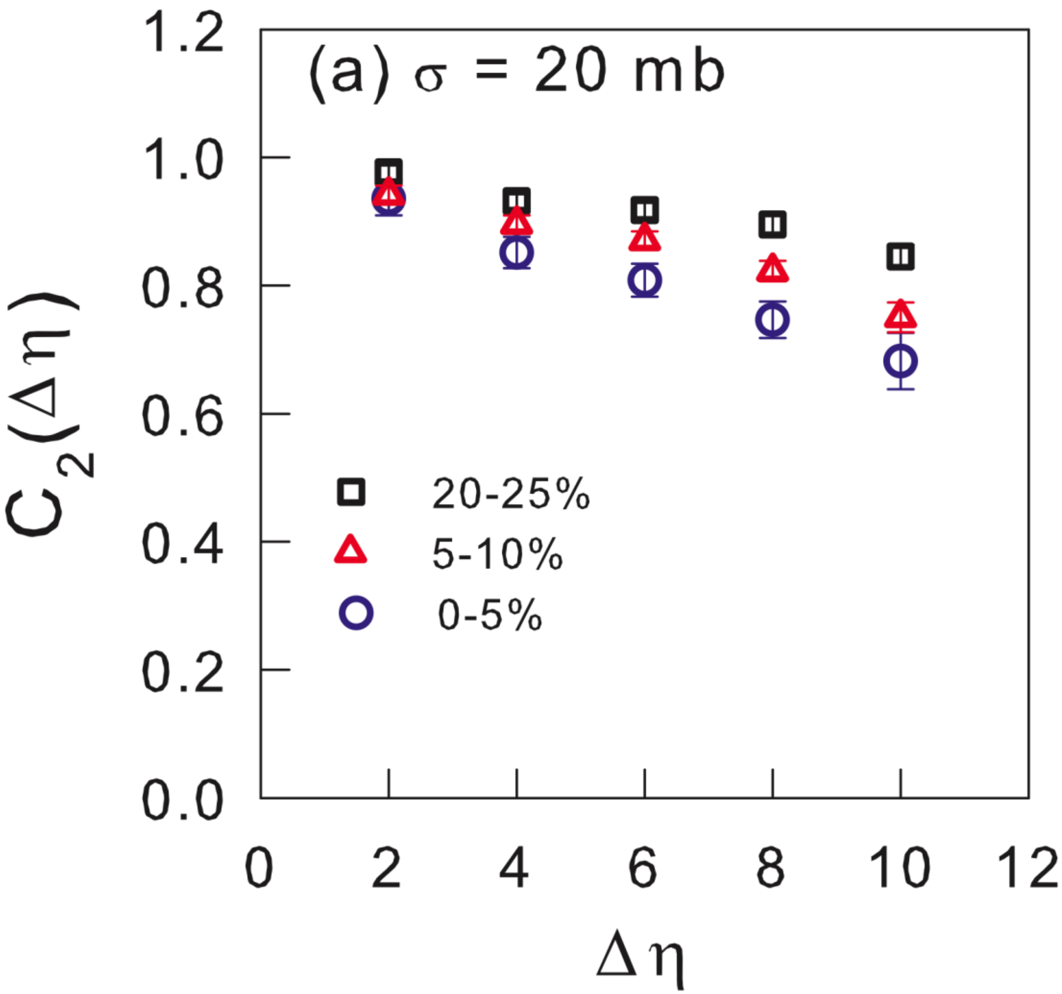
We use: A Multi Phase Transport Model (AMPT)

Advantage : Same initial condition as 3+1D Ideal hydro

Disadvantage : finite hadron multiplicity, larger Stat errors.

Result: E-by-E AMPT

2^{nd} order flow correlation



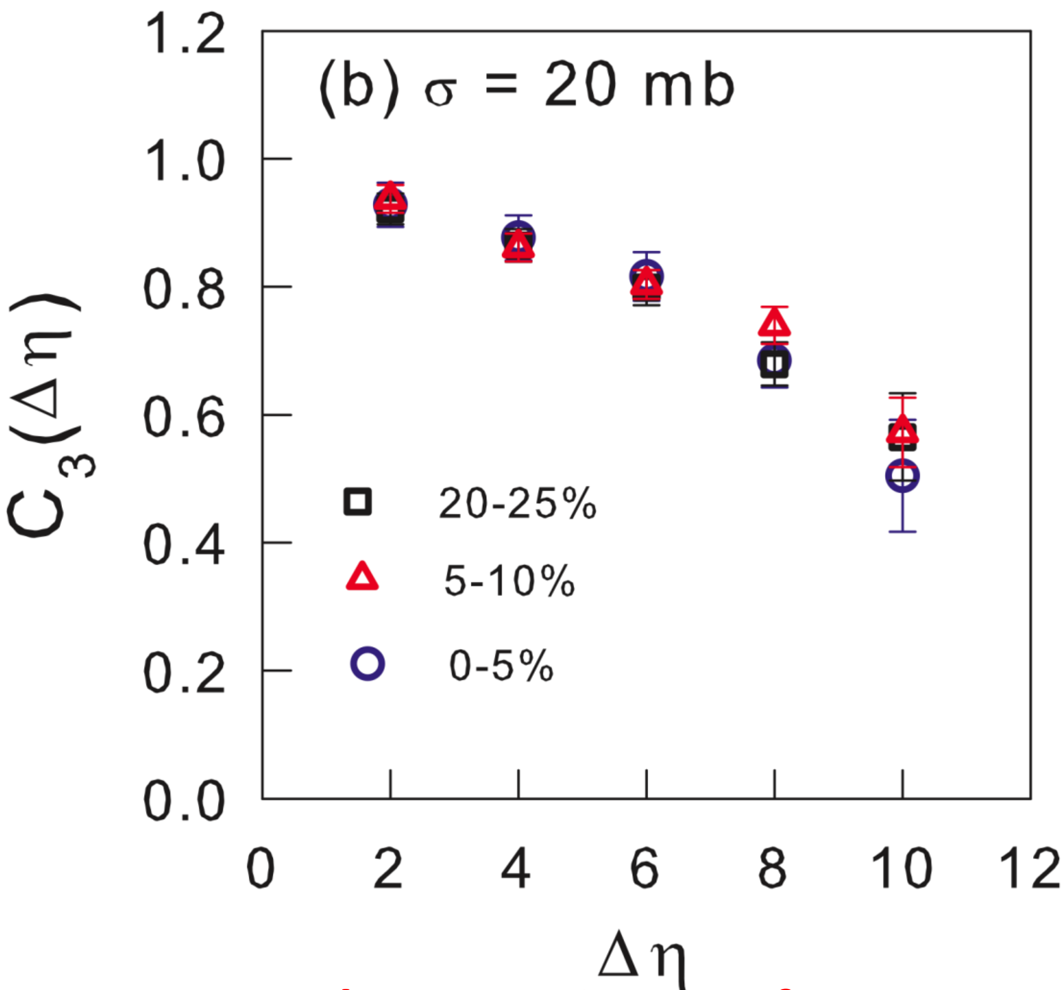
-Decreases with rapidity gap

-Depends on centrality of collision

Similar to the ideal 3+1D hydro

Result: E-by-E AMPT

3rd order flow correlation



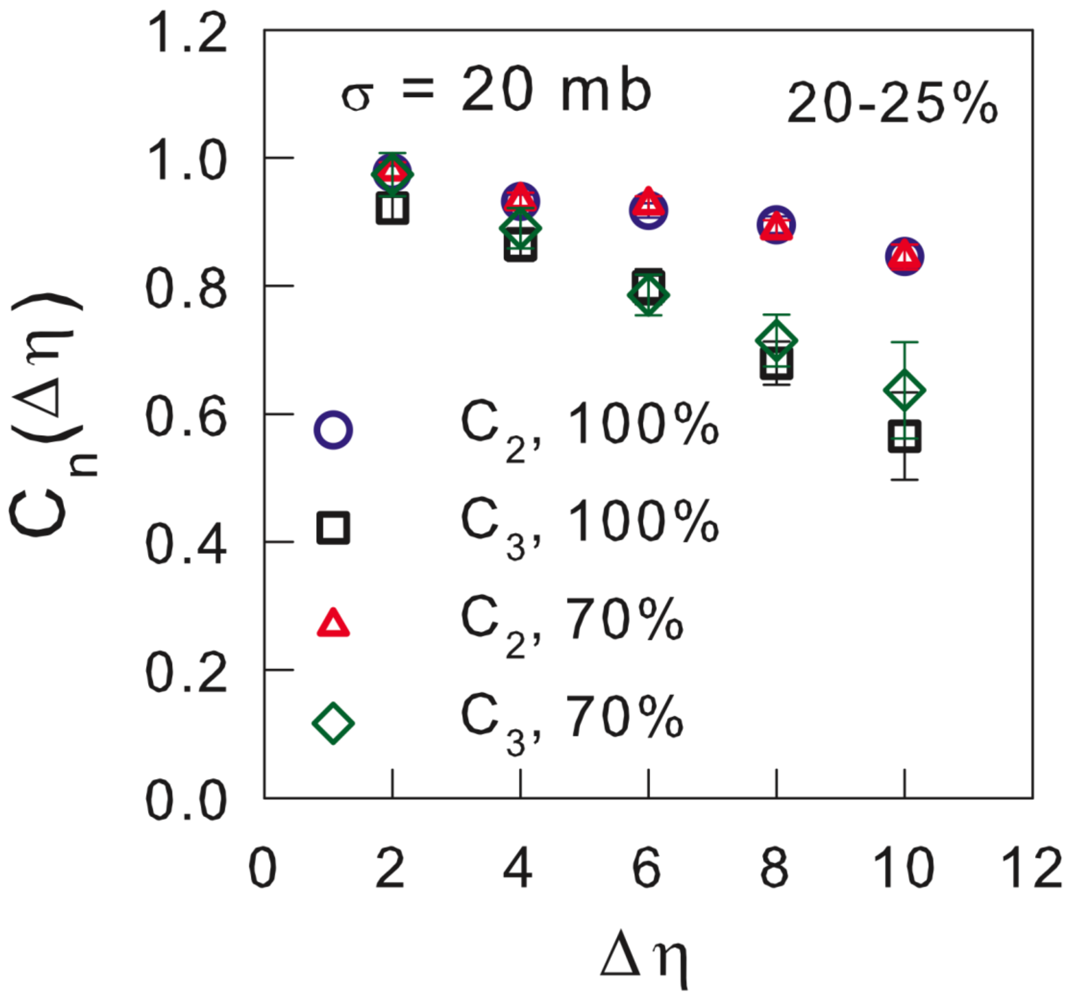
-Decreases with rapidity gap

-Doesn't depends on centrality of collision

Again similar to ideal hydro

How much contamination from Non-Flow and Finite multiplicity ?

Result: E-by-E AMPT finite multiplicity



Two cases:

(1)Correlation obtained from all (100%) particles

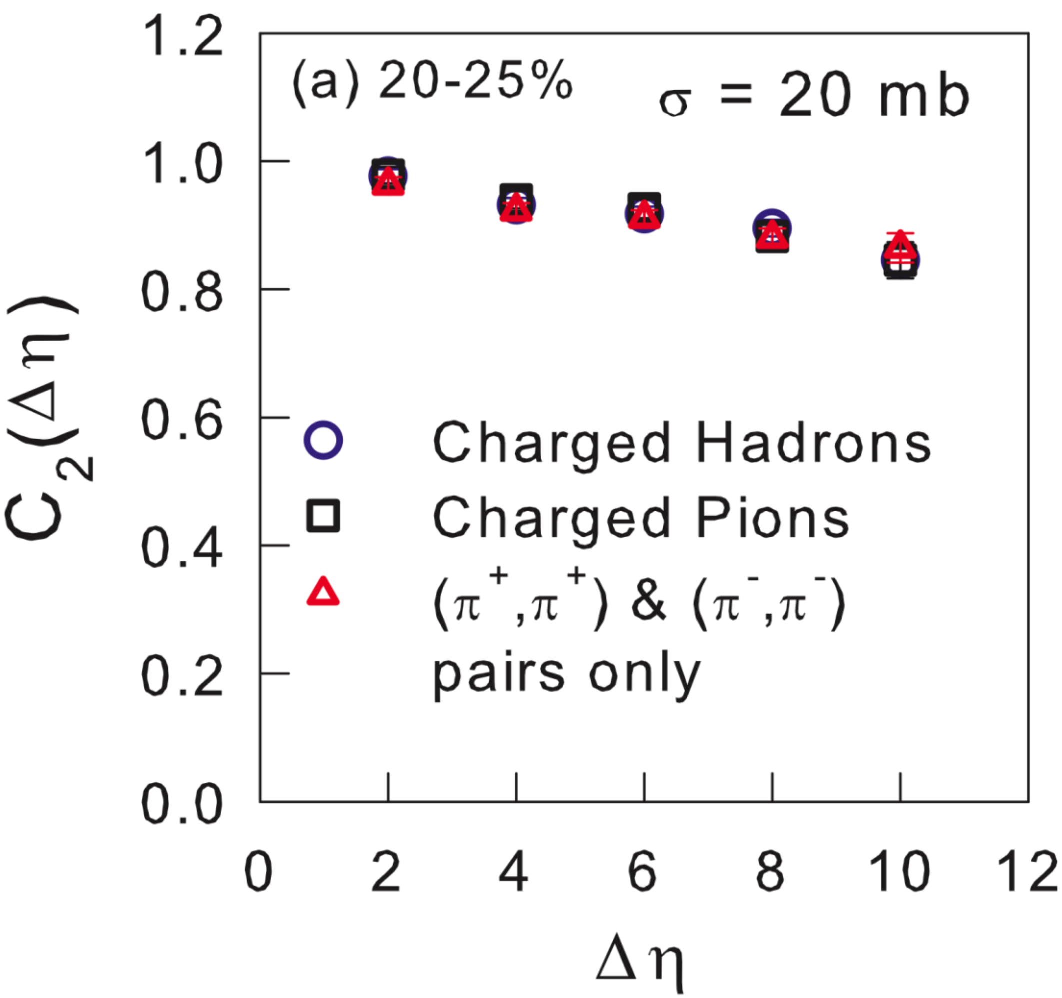
- circles → C_2
- squares → C_3

(2)Correlation from 70% of the total particles

- Triangles → C_2
- Rhombus → C_3

-Very small contribution is observed for finite multiplicity

Result: E-by-E AMPT non-flow



Three cases:

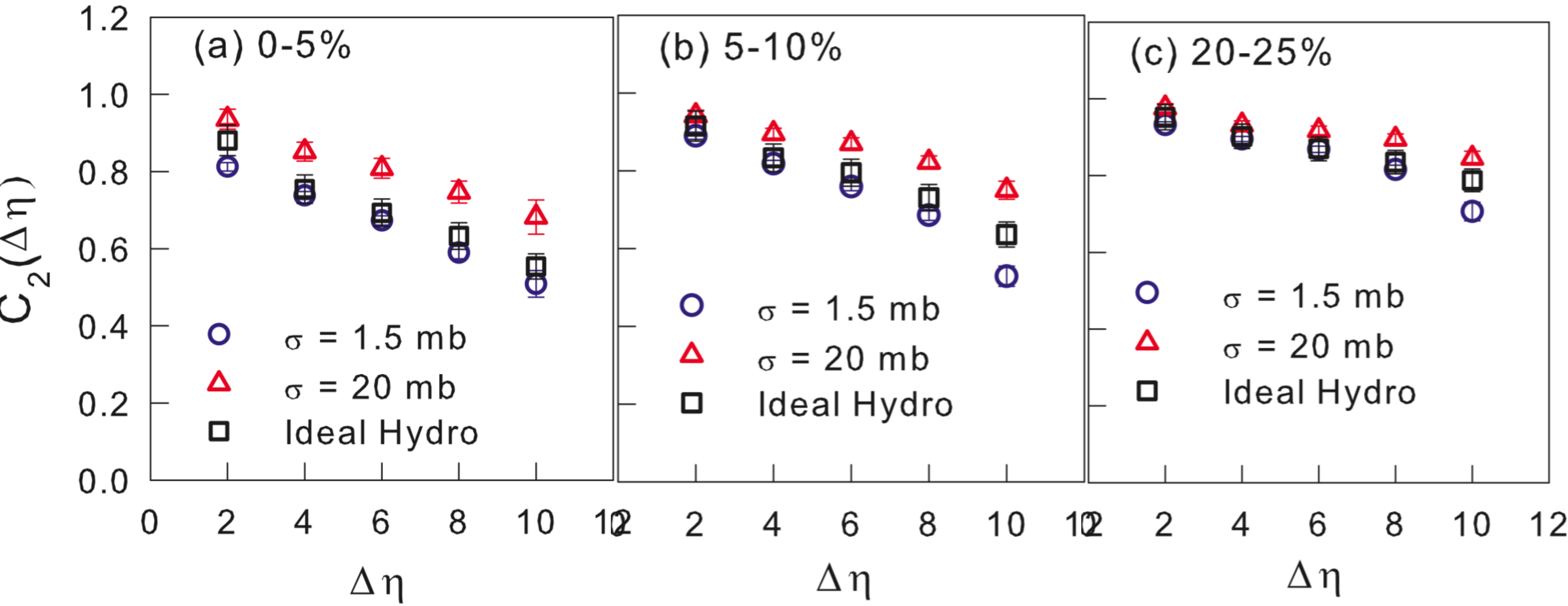
(1)Correlation from all charged hadrons
- circles

(2)Correlation from charged Pions
- Squares

(3)Correlation from the same charged pair of Pions
- Triangles

-Negligible non-flow contribution

Result: C_2, E-by-E AMPT & hydro

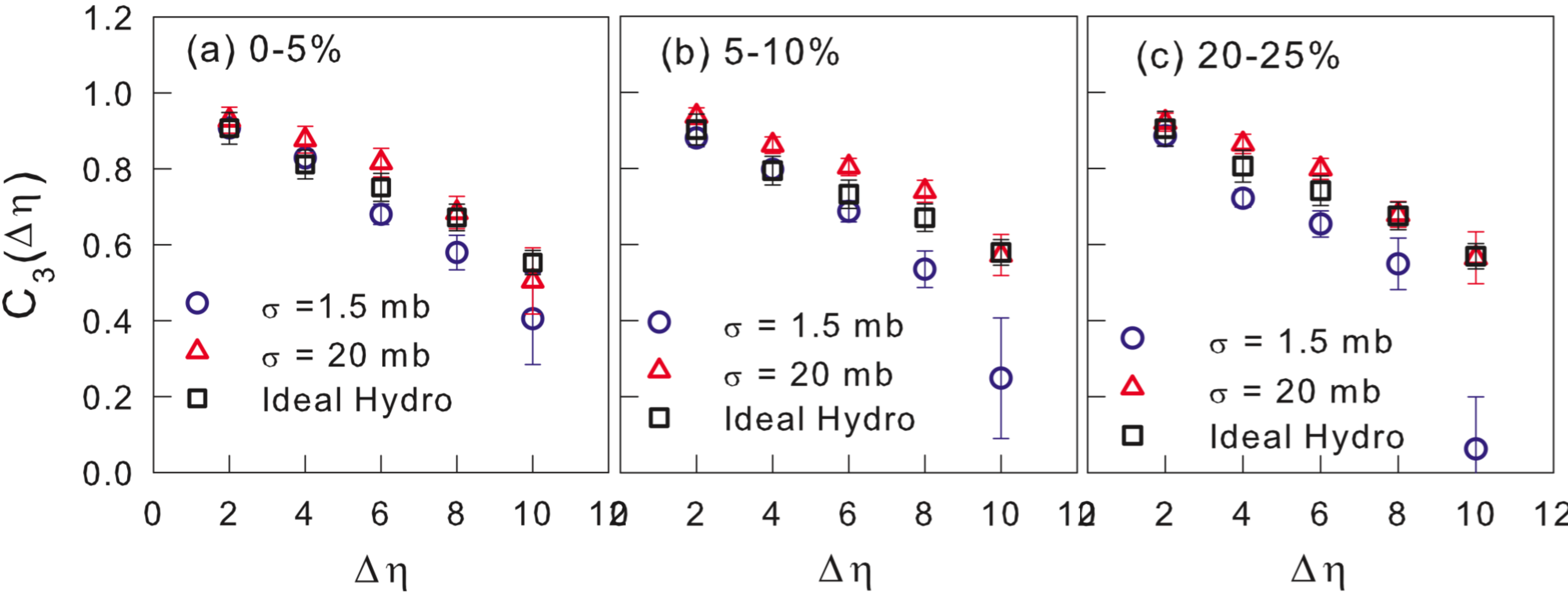


Larger cross section (small shear viscosity) → higher correlation

Expectation : Strong coupling limit ($\sigma \to \infty$) , AMPT → ideal hydro

Possible reasons : different EoS, smearing of initial energy density in hydro among other possibilities.

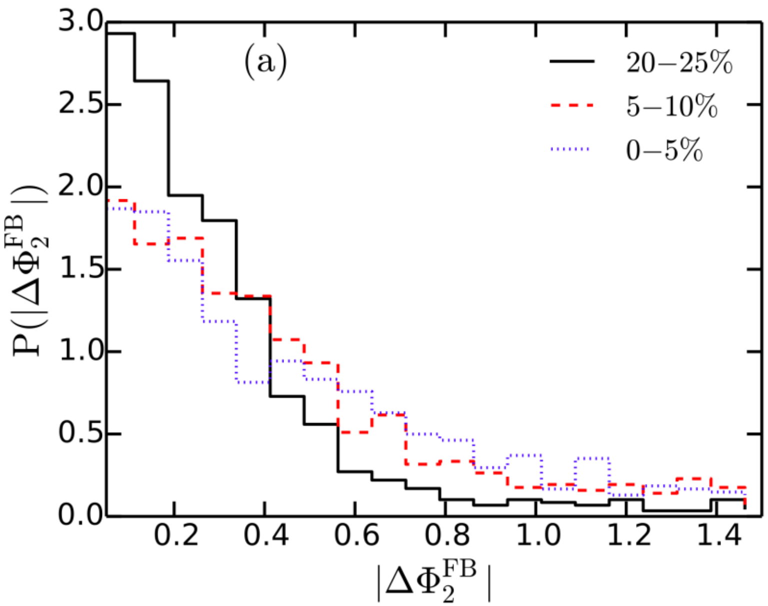
Result: C_3, E-by-E AMPT & hydro

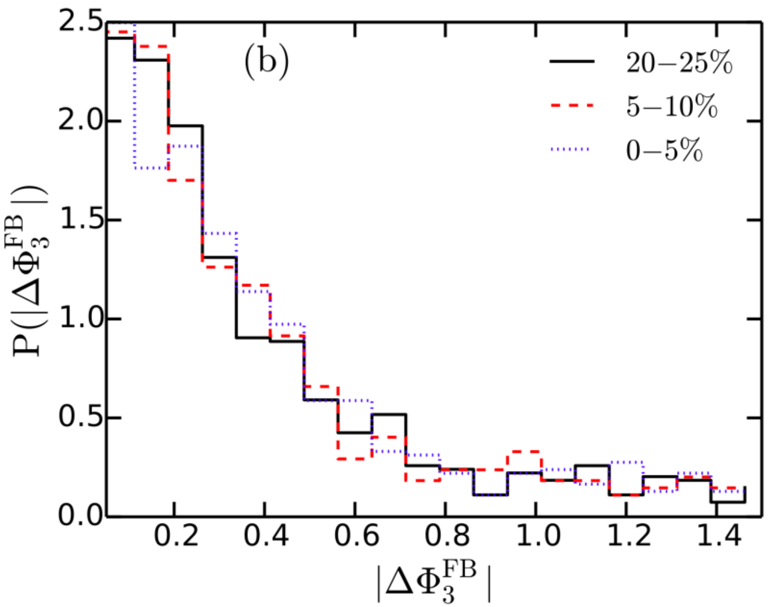


Observation : C_3 independent of collision centrality

C_3 larger for smaller shear viscosity (larger cross section)

Result: Event distribution of twist angel in ideal hydro





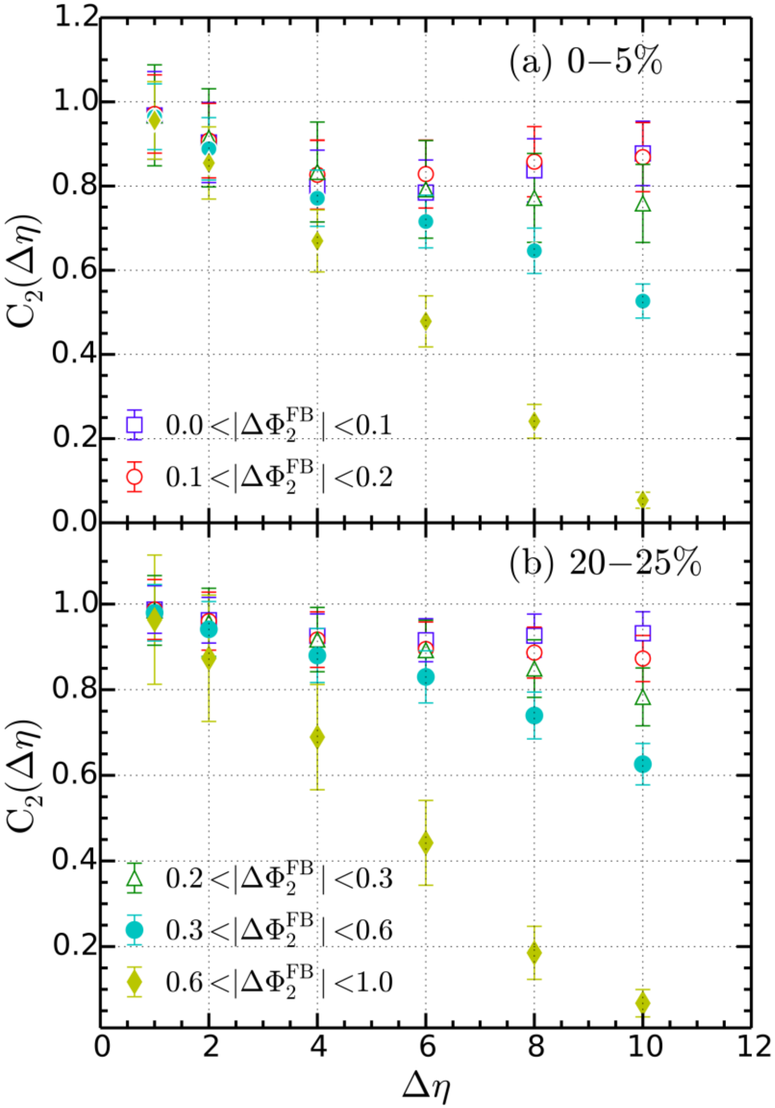
$|\Delta\Phi_2^{FB}|$ →Narrower for 20-25%
→Geometrical contribution

$|\Delta\Phi_3^{FB}|$ →Independent of centrality
→Fluctuating nature of $|\Delta\Phi_3^{FB}|$

$$\Delta\Phi_n^{FB} = \Phi_n(F) - \Phi_n(B)$$

Result: separating de-correlation & twist in ideal hydro

$C_2(\Delta\eta)$



Twist angle between Forward Backward rapidity

$$\Delta\Phi_n^{FB} = \Phi_n(F) - \Phi_n(B)$$

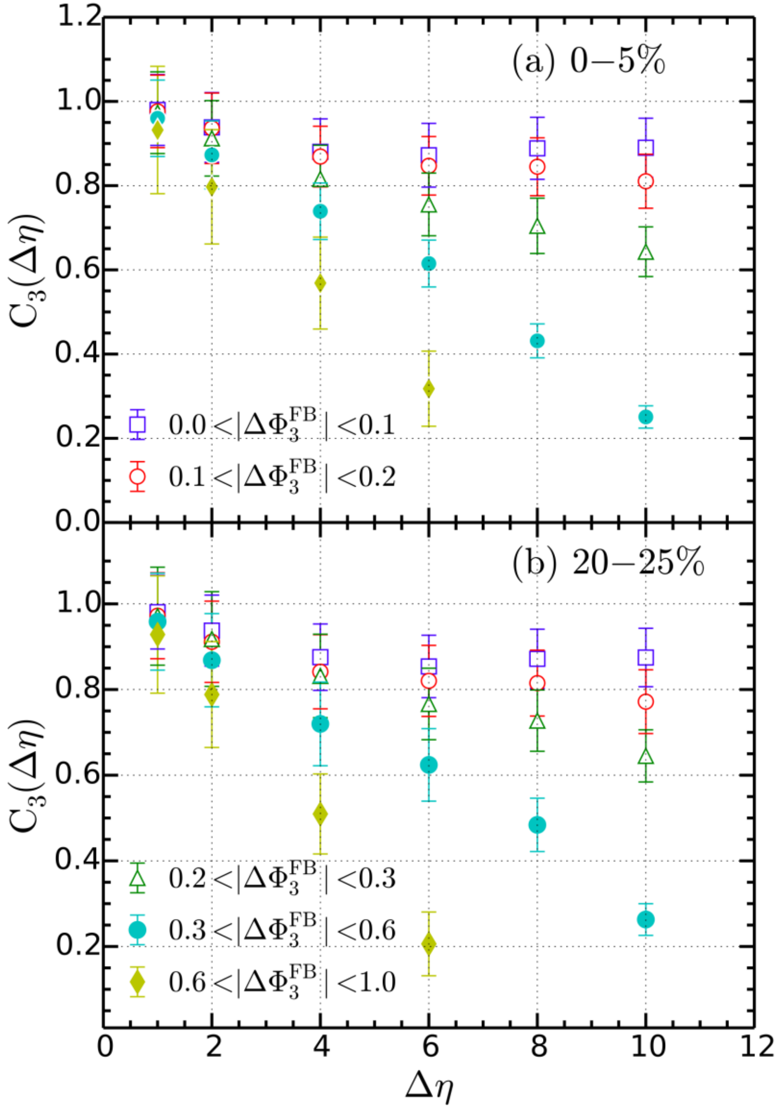
η=+5 η=-5

$$C_n^{FB} = \frac{\langle v_n^F v_n^B \rangle}{\sqrt{\langle {v_n^F}^2 \rangle \langle {v_n^B}^2 \rangle}} \cos(n\Delta\Phi_n^{FB})$$

In the limit $\Delta\Phi_n^{FB} \to 0$ de-correlation is due to pure longitudinal fluctuation.

Result: separating de-correlation & twist in ideal hydro

$C_3(\Delta\eta)$



$$C_n^{FB} = \frac{\langle v_n^F v_n^B \rangle}{\sqrt{\langle {v_n^F}^2 \rangle \langle {v_n^B}^2 \rangle}} \cos(n\Delta\Phi_n^{FB})$$

→ similar correlation for 0-5% & 20-25%

Noticeable contribution in de-correlation due to longitudinal fluctuation!

Conclusions & Outlook

•Anisotropic flows at different pseudo-rapidities are de-correlated due to longitudinal fluctuations in the initial energy density.

•De-correlation is caused by the combination of longitudinal fluctuation & gradual twist of event planes at different rapidities

•Correlation of 2nd order flow → depends on centrality of collisions
3rd order flow → independent of collision centrality

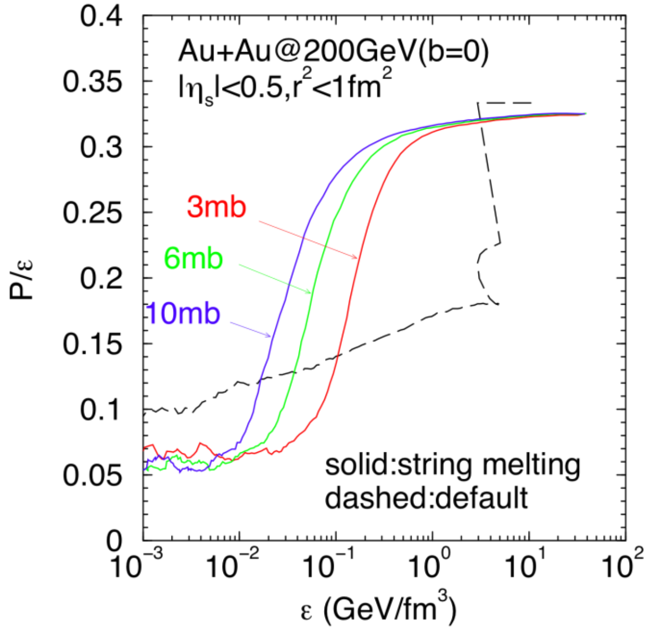
•AMPT model → De-correlation depends on shear viscosity of the early stage but almost insensitive to late stage hadronic evolution.

•Considering longitudinal fluctuation is important for accurate estimation of shear viscosity from hydrodynamic model study

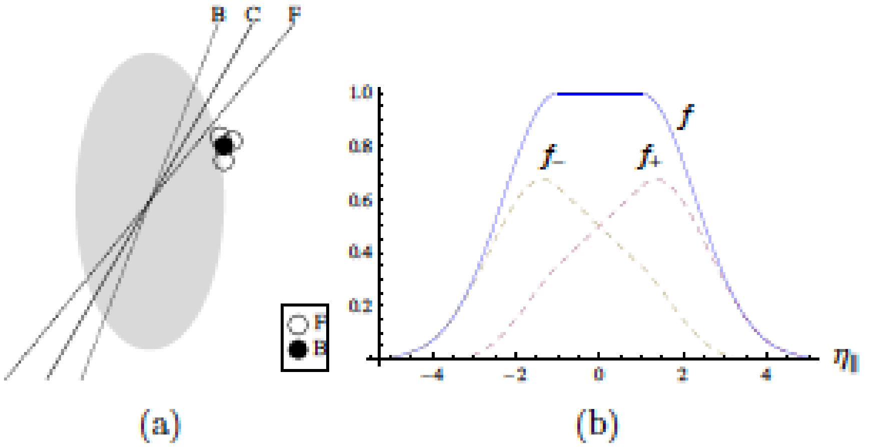
OUTLOOK:
Use of a viscous 3+1D hydrodynamics model to study the dependency on Shear viscosity.

We can also study different systems (p+p, p+Au) and different initial condition with longitudinal fluctuation

Extra



Equation of State in AMPT



(a) (b)

$$F(\eta_\|, x, y) = (1-\alpha)[\rho_+(x,y)f_+(\eta_\|) + \rho_-(x,y)f_-(\eta_\|)] + \alpha\rho_{\rm bin}(x,y)f(\eta_\|),$$

$$f(\eta_\|) = \exp\left(-\frac{(|\eta_\|| - \eta_0)^2}{2\sigma_\eta^2}\theta(|\eta_\|| - \eta_0)\right)$$

$$f_+(\eta_\|) = f_F(\eta_\|)f(\eta_\|),$$

$$f_-(\eta_\|) = f_F(-\eta_\|)f(\eta_\|),$$

with

$$f_F(\eta_\|) = \begin{cases} 0, & \eta_\| \le -\eta_m \\ \frac{\eta_\| + \eta_m}{2\eta_m}, & -\eta_m < \eta_\| < \eta_m \\ 1, & \eta_m \le \eta_\| \end{cases}$$