Flow fluctuation and event plane correlation from E-by-E Hydrodynamics and Transport Model

LongGang Pang[1], Victor Roy[1], Guang-You Qin[1], & Xin-Nian Wang[1,2]

[1] Central China Normal University , [2] Lawrence Berkeley National Laboratory.

Motivation

✧Fluctuating initial condition :

Important for model simulations of Heavy Ion Collisions.
Sources of fluctuation: fluctuating position of nucleons inside colliding nucleus and the quantum fluctuation of parton wave-function inside each nucleons.

✧Fluctuation in transverse plane :

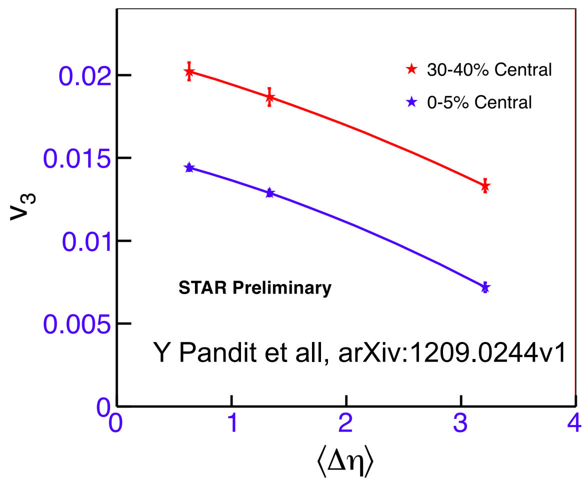
Widely used in model studies. Explain the non-zero odd flow harmonics in hydro.

✧Fluctuation in the longitudinal direction :

*So far less studied, important for understanding observables measured at different rapidities e.g, determination of event planes for flow measurement.**

* See next figure from STAR collaboration

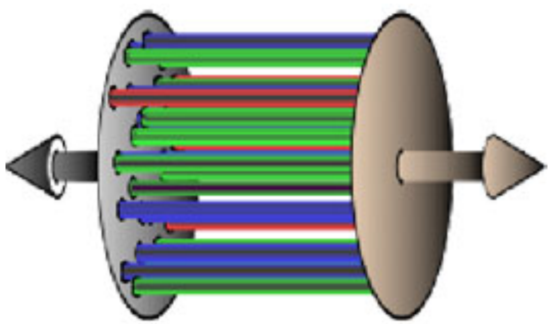
Dependence of third order flow v3 on pseudo-rapidity



longitudinal fluctuation of the initial energy density may be the possible cause of this rapidity dependence

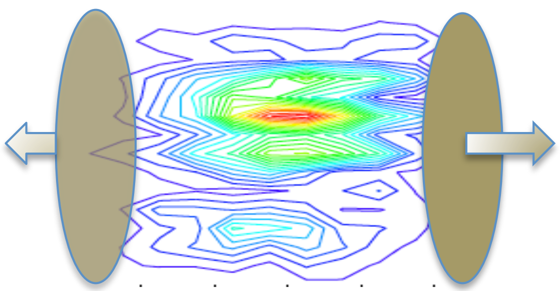
✧Schematic representation of the tube-like and fluctuating initial condition in the longitudinal direction

Tube like (or boost invariant) IC



-No rapidity dependence of initial energy density
Observables at different pseudo-rapidity are expected to be **invariant**.

Longitudinal fluctuation IC



-Initial energy density depends on rapidity and fluctuates from event-by-event
Observables are expected to be **dependent** on the pseudo-rapidity.

We are trying to investigate the effect of longitudinal fluctuation on event plane correlation and also the possible influence of shear viscosity and evolution dynamics on it.

Methodology for studying the event plane correlation

✧We use two dynamical model for studying event plane correlation in the longitudinal (pseudo-rapidity) direction.

1. Ideal 3+1 D hydrodynamics

2. A Multiphase Transport Model (AMPT)

✧Flow chart for the calculation of event plane correlation:

Simulate the Pb+Pb @ 2.76 TeV collisions for multiple events with same initial condition for both AMPT & hydro

↓

Divide the pseudo-rapidity (η_p) range[-5.5 to +5.5] into 11 bins, each of the bin width →1.0 unit. Calculate the flow vector (Q) from positive and negative charged particles using the usual formula**

↓

For each event evaluate the n-th order event plane angel $\Psi_n(\eta_p)$ from the Q vector for positive(+) and negative(-) charged hadrons.

↓

Now calculate the cosine of the difference of event plane angel at $+\eta$ ant and $-\eta$ for same charge Particles. They are defined as $c_n^{(+,+)}(\delta\eta_p) = \cos\left[n\left\{\psi_n^{+}(\eta_p) - \psi_n^{+}(-\eta_p)\right\}\right]$ & $c_n^{(-,-)}(\delta\eta_p) = \cos\left[n\left\{\psi_n^{-}(\eta_p) - \psi_n^{-}(-\eta_p)\right\}\right]$

↓

We calculate the same quantity but in the same rapidity bin between Ψ_n^+ and Ψ_n^-. We defined it

$$c_n^{(+,-)}(0)\Big|_{\eta_p} = \cos\left[n\left\{\psi_n^+(\eta_p) - \psi_n^-(\eta_p)\right\}\right]$$

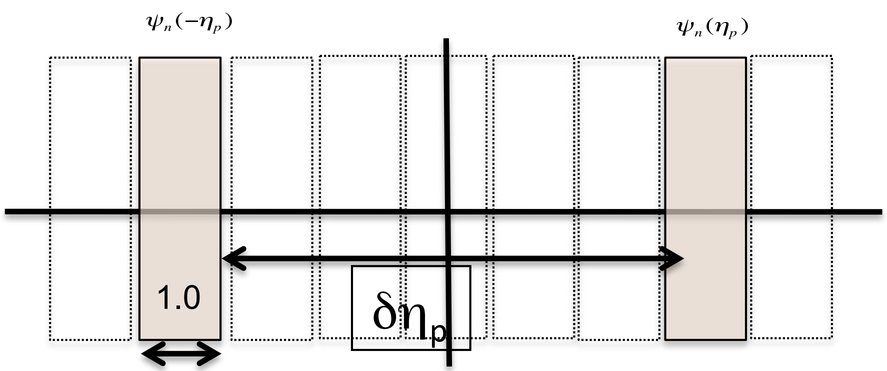
Then, we construct the following quantity as a measure of event plane correlation as a function of pseudo-rapidity gap $\delta\eta_p = \eta_p - (-\eta_p)$

$$C_n^{(+,+)}(\delta\eta_p) = \frac{c_n^{(+,+)}(\delta\eta_p)}{\sqrt{c_n^{(+,-)}(0)\Big|_{\eta_p} \times c_n^{(+,-)}(0)\Big|_{-\eta_p}}} \qquad C_n^{(-,-)}(\delta\eta_p) = \frac{c_n^{(-,-)}(\delta\eta_p)}{\sqrt{c_n^{(+,-)}(0)\Big|_{\eta_p} \times c_n^{(+,-)}(0)\Big|_{-\eta_p}}}$$

Finally we take the event average of the above quantity to plot as a function of $\delta\eta_p$

The above construction is expected to be free from the effect of finite multiplicity on the correlation .

Schematic diagram for rapidity bin



** Definition of Q vector

$$\vec{Q}_n = (Q_x, Q_y) = \left(\frac{1}{N}\sum_{i=1}^{N}\cos(n\varphi_i), \frac{1}{N}\sum_{i=1}^{N}\sin(n\varphi_i),\right)$$

Alternatively $\vec{Q} = |\vec{Q}|e^{in\psi_n}$

DYNAMICAL MODEL : 1

3+1D Ideal hydrodynamics with longitudinal fluctuating initial condition

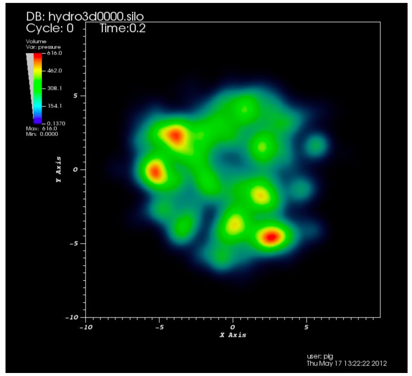
L Pang et al
PhysRevC.86.024911

Initial Condition → HIJING (MC Glauber model)

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

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

Energy density in XY plane



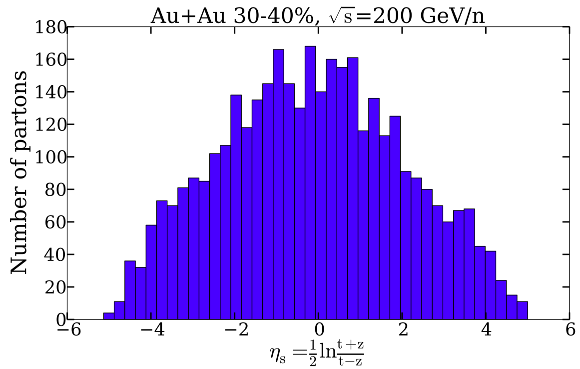
TIME

QGP phase

Hadronic Phase

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

Freeze-out → T_f=137 MeV



Parton density along spatial-rapidity

Number of event
for each centrality ~1000

DYNAMICAL MODEL : 2

A Multiphase Transport Model: AMPT (string melting,2.25t7d)

Zi wei lin et al
PhysRevC.72.064901

T
I
M
E

Initial condition → HIJING (Glauber model)

Excited string and mini-jet
fragmented to partons

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

Parton freeze-out ,

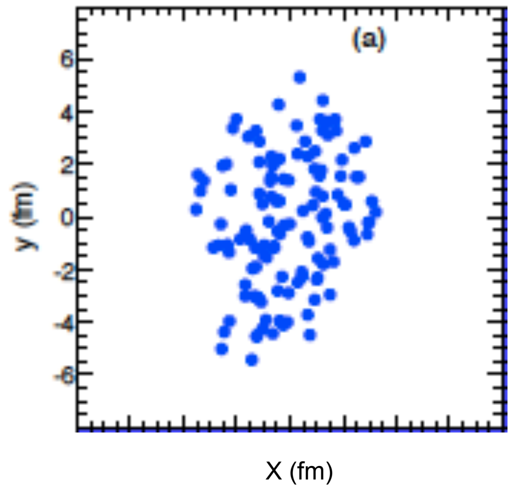
Hadron formation via coalescence

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

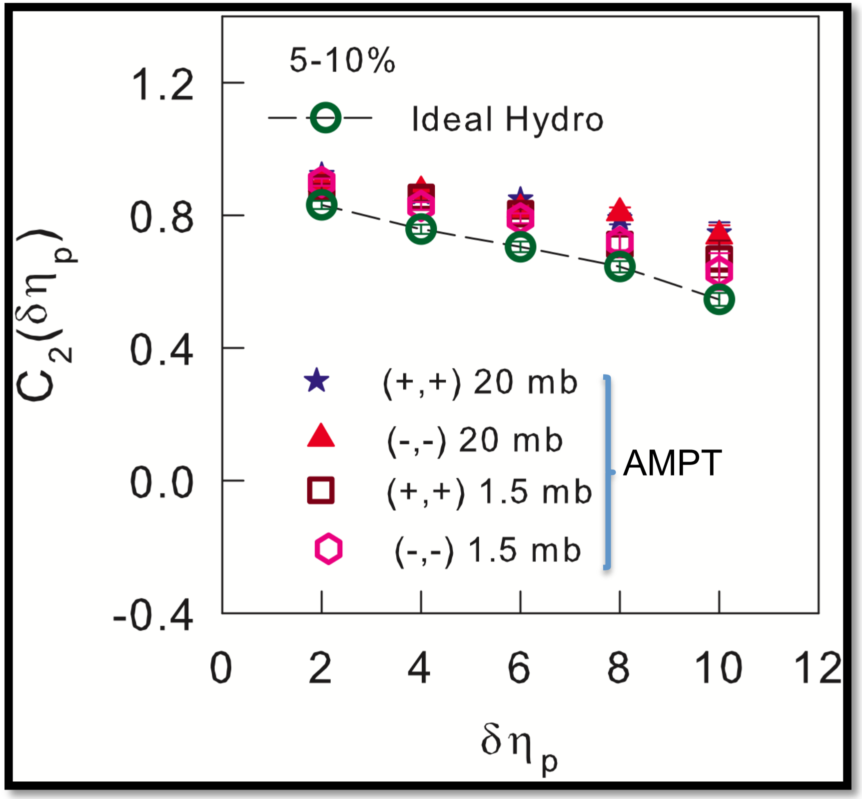


Distribution of participating nucleons
In a typical non-central Au+Au collision.

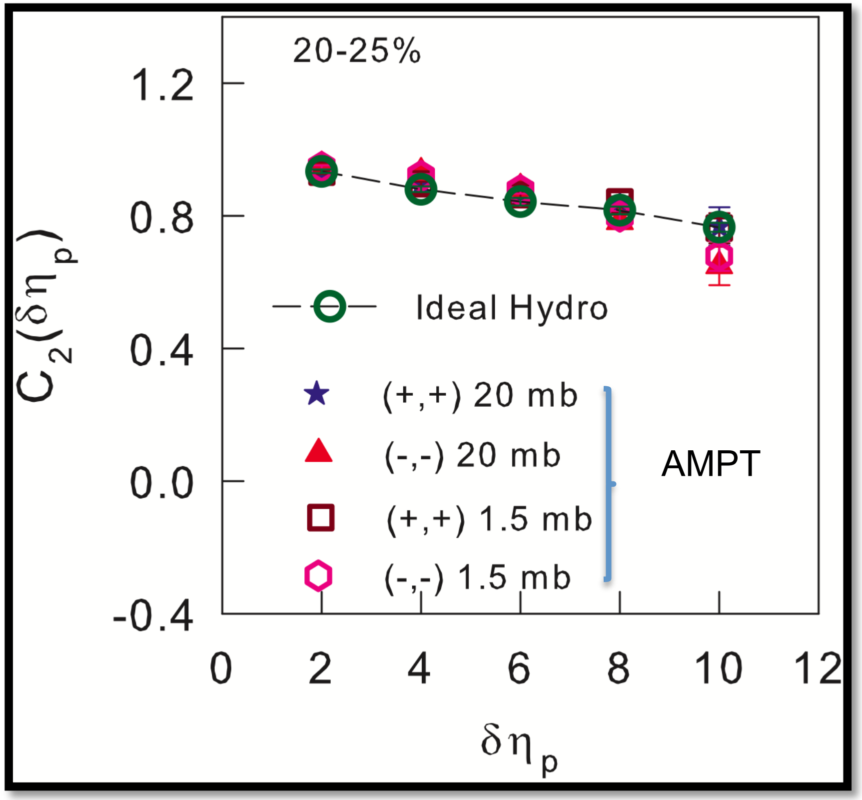
Result

Second order event plane correlation for Pb+Pb @2.76 TeV

5-10%



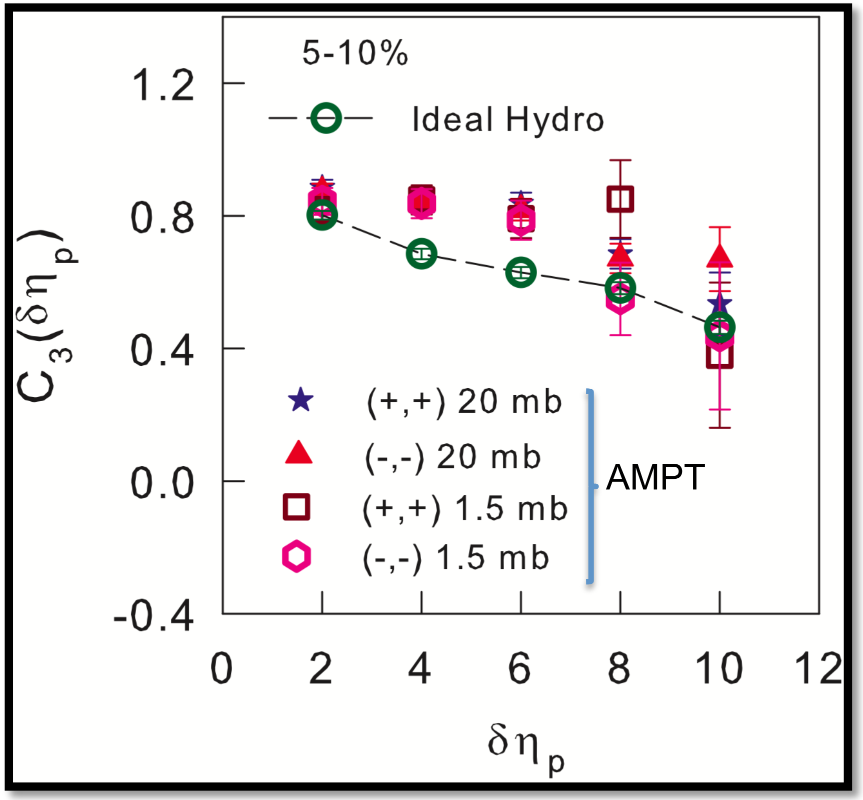
20-25%



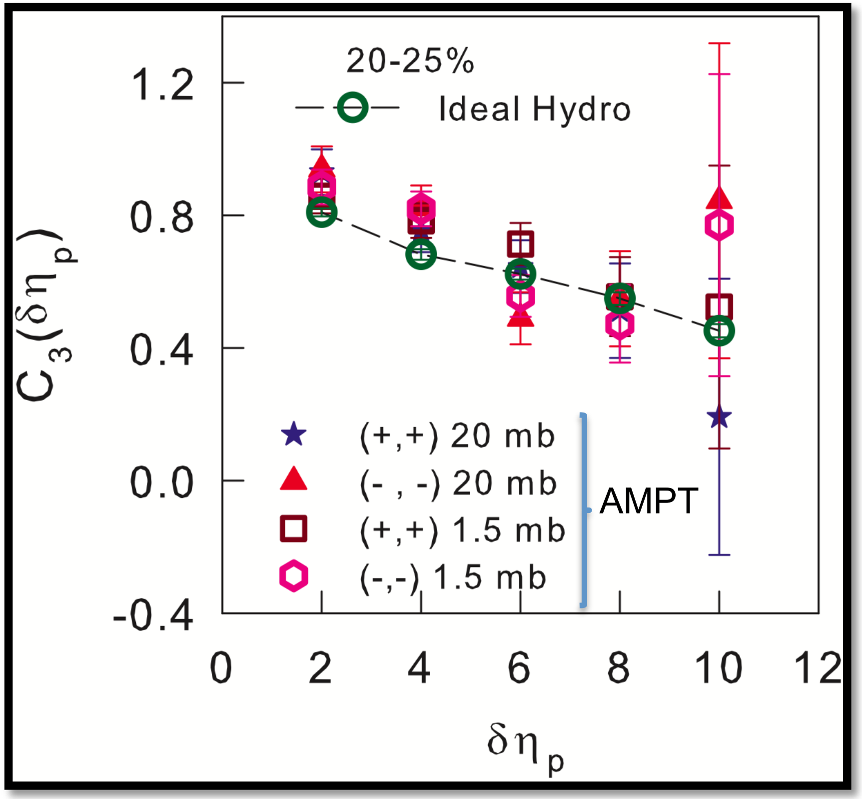
- ✧2nd order event plane (de)correlation is independent of partonic cross section and evolution dynamics
- ✧Central collision (5-10%) stronger de-correlation compared to mid central (20-25%) collisions.

Third order event plane correlation for Pb+Pb @2.76 TeV

5-10%



20-25%



✧3rd order event plane (de)correlation is also independent of partonic cross section and evolution dynamics

✧ De-correlation is similar for central (5-10%) and mid central (20-25%) collisions.

Conclusion

✧Event plane correlation decreases with increasing pseudo-rapidity.

✧2nd order event plane (de)correlation depends on centrality. We believe this arises from the initial overlap geometry of the colliding nucleus and the consequent collective flow resulting from it.

✧ 3rd order event plane (de)correlation is similar for central(5-10%) and mid central (20-25%) collisions. Mainly because the source of the third order flow is the initial fluctuation.

✧The EP de-correlation is almost independent of shear viscosity and evolution dynamics of the system.

The event plane correlation as a function of pseudo-rapidity may serve as a good probe for the initial conditions.
We need more study to arrive at a definitive conclusion