De-correlation of anisotropic flow along the longitudinal direction

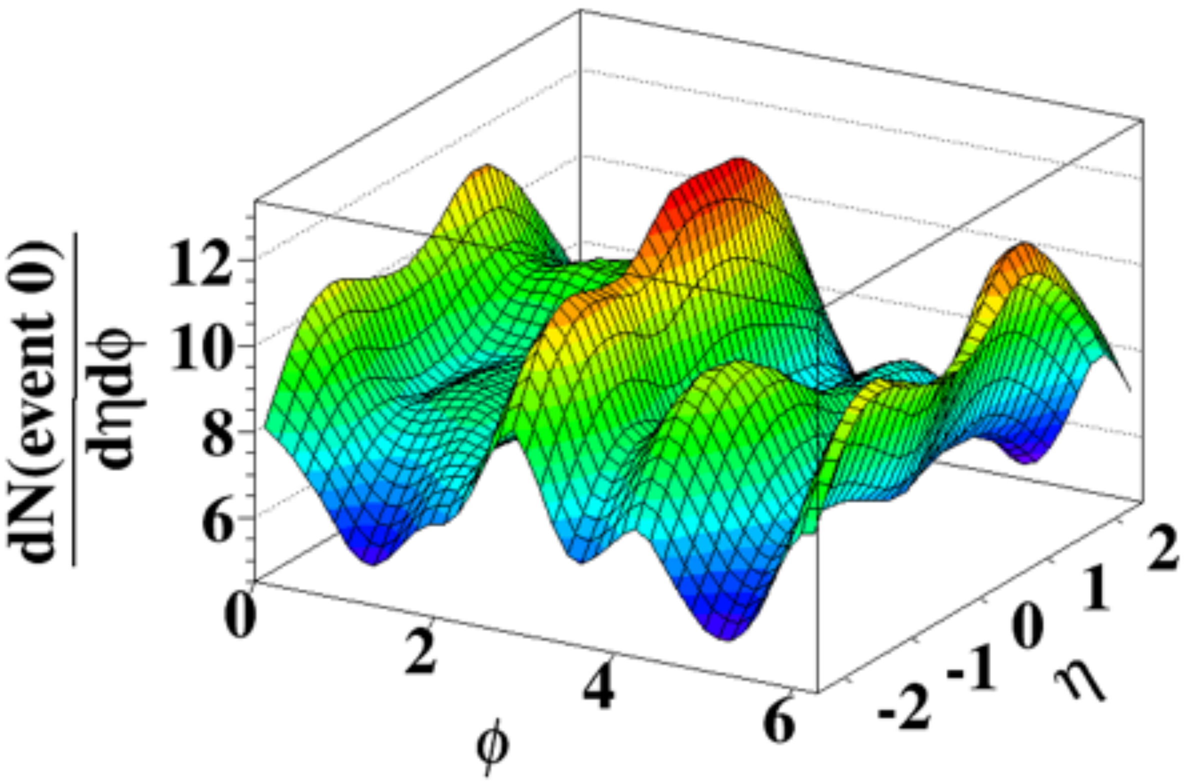
Long-Gang Pang @ FIAS

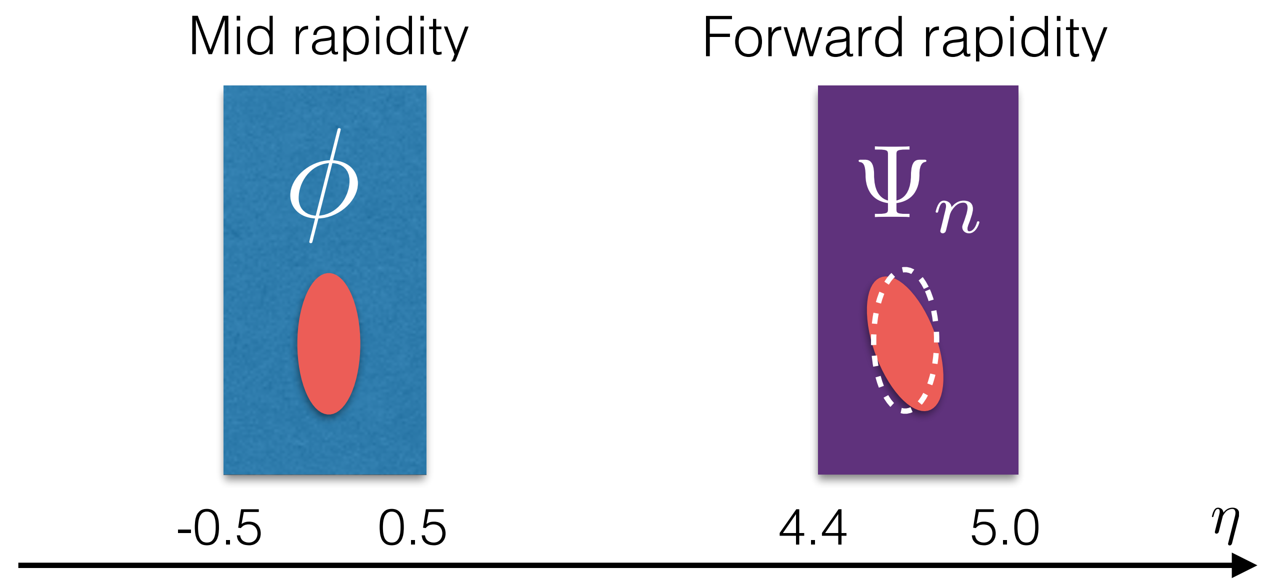
with Hannah Petersen, Guang-You Qin, Victor Roy and Xin-Nian Wang

thanks Pasi for helpful discussions

2015 Sep.29 QM2015

Motivation





$$v_n = \frac{< \cos(n(\phi - \Psi_n)) >}{R}$$

- The flow measurements are questionable when the anisotropic flow (or event plane) de-correlates along the longitudinal direction.

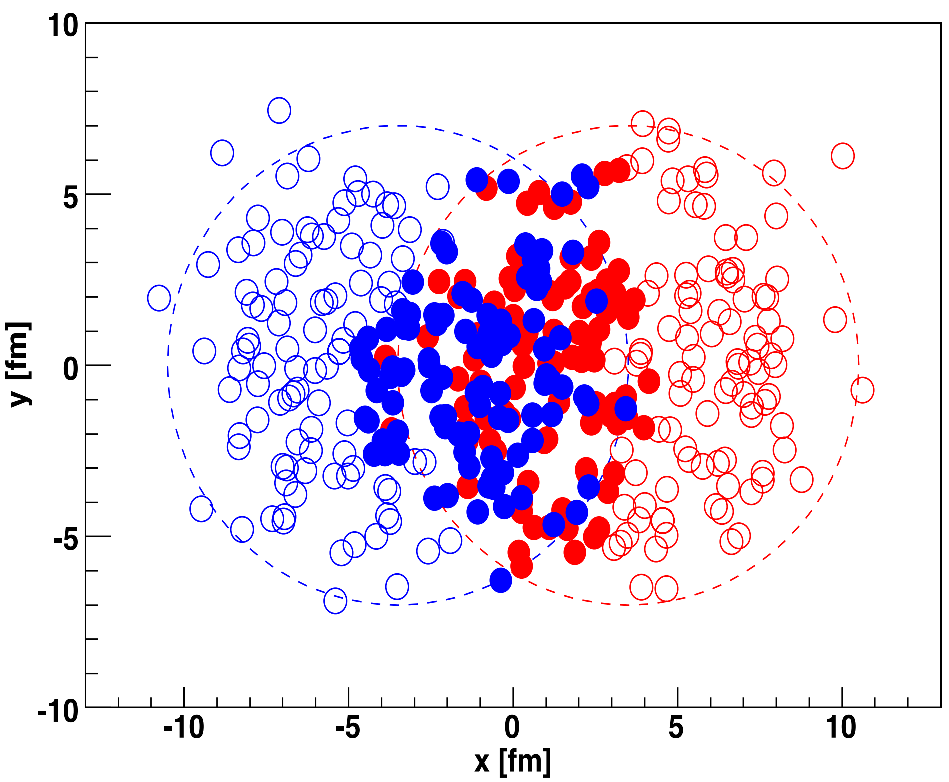
- Adil and Gyulassy PRC 72.034907 (2005); A.Adil, M. Gyulassy and T. Hirano PRD 73, 074006 (2006)
- P.Bozek PRC83, 034911 (2011); arXiv:1506.02817 (2015);
- A. Dumitru , R. Venugopalan PLB 706 (2011) 219-224
- H. Petersen, V. Bhattacharya, S.A. Bass, and C Greiner PRC 84, 054908 (2011)
- L-G. Pang, X-N. Wang and Q. Wang, PRC 86, 024911 (2012);
- K.Xiao, FQ. Wang, F. Liu PRC 87, 011901 (2013)
- J. Jia and P. Huo, PRC 90, 024910 (2014); PRC 90, 034915 (2014)
- L-G.Pang, G-Y.Qin,V.Roy,X-N.Wang, G-L.Ma, PRC 91, 044904 (2015)
- CMS measurements arXiv:1503.01692 (the 4th talk in the same session).

Longitudinal structure of QGP

$$\rho(\eta, x, y) = f_+(\eta)N_+(x, y) + f_-(\eta)N_-(x, y)$$

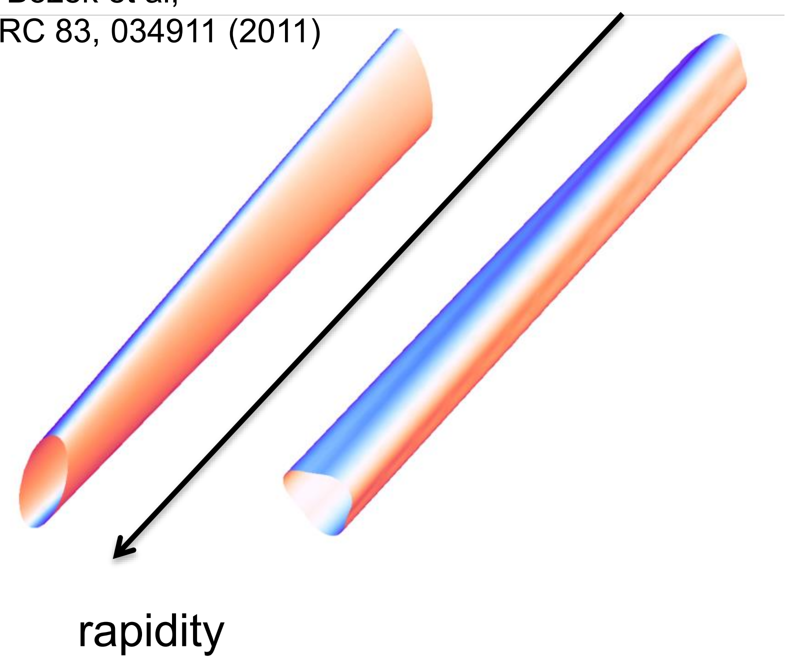
Adil and Gyulassy PRC 72.034907 (2005)

Gluon density is twisted because of the asymmetric distribution of forward and backward going participants.

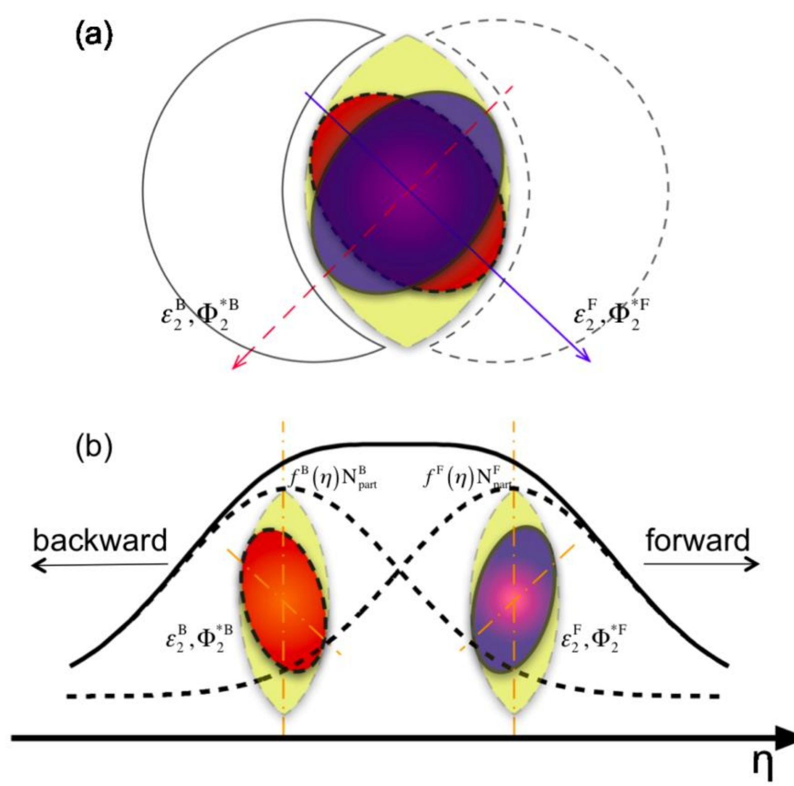


Hydrodynamics , torqued fireball

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

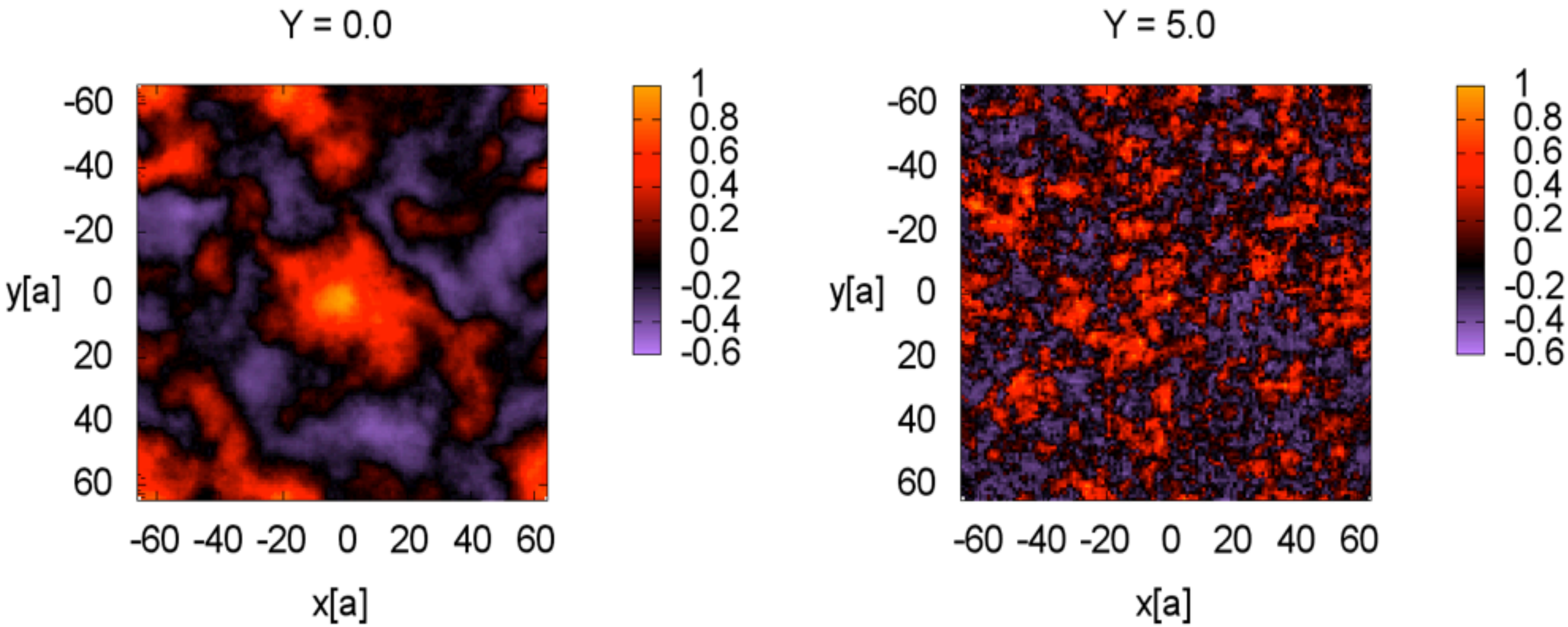


Transport



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

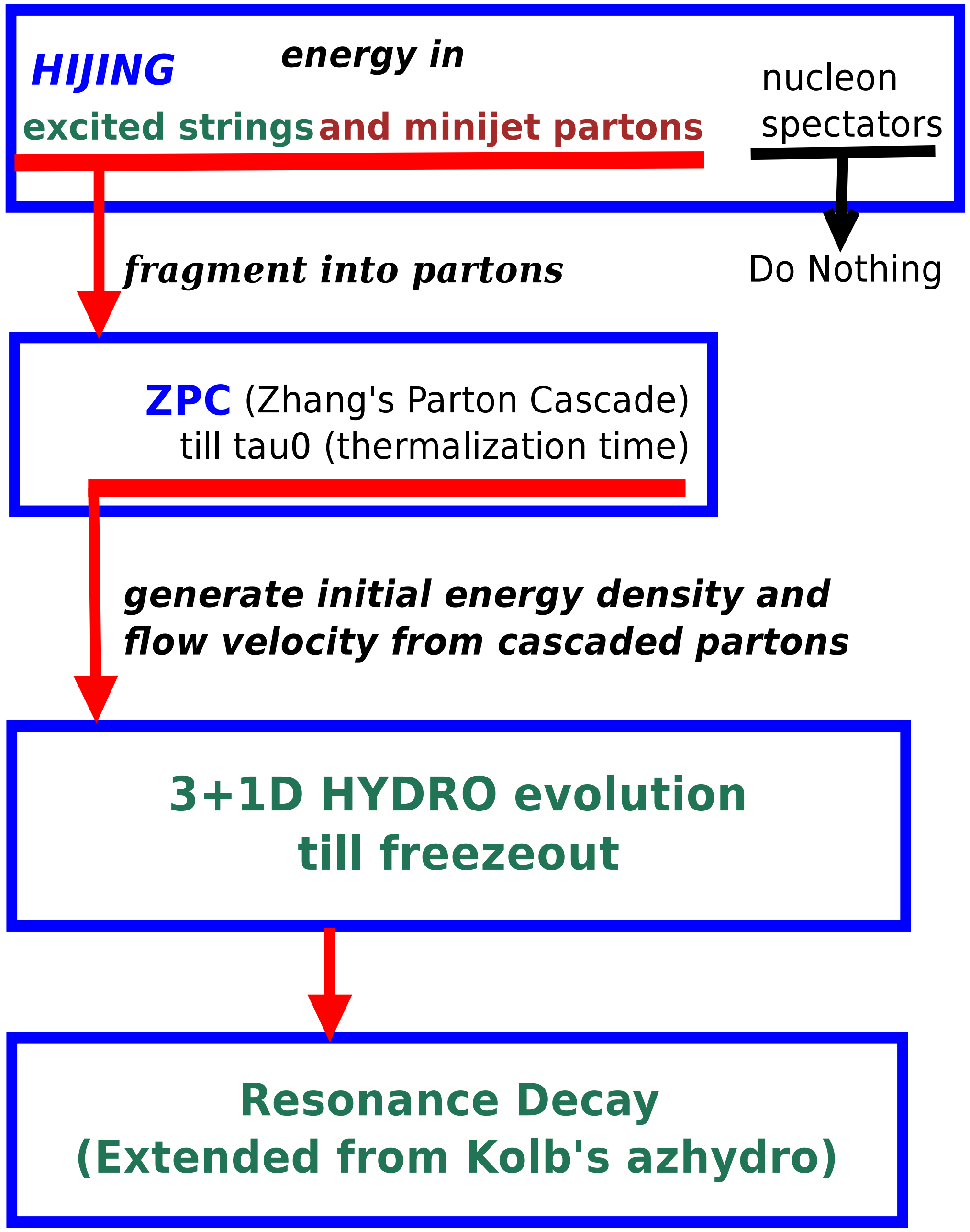
Pure fluctuations in longitudinal direction



A. Dumitru , R. Venugopalan PLB 706 (2011) 219-224

- The gluon density fluctuates stronger at large rapidity from CGC

Model: AMPT + E-B-E (3+1)D hydro



$$T^{\mu\nu}(\tau_0, x, y, \eta_s) = K \sum_i \frac{p_i^\mu p_i^\nu}{p_i^\tau} \times$$
$$\delta(x - x_i, y - y_i, \eta_s - \eta_{si})$$

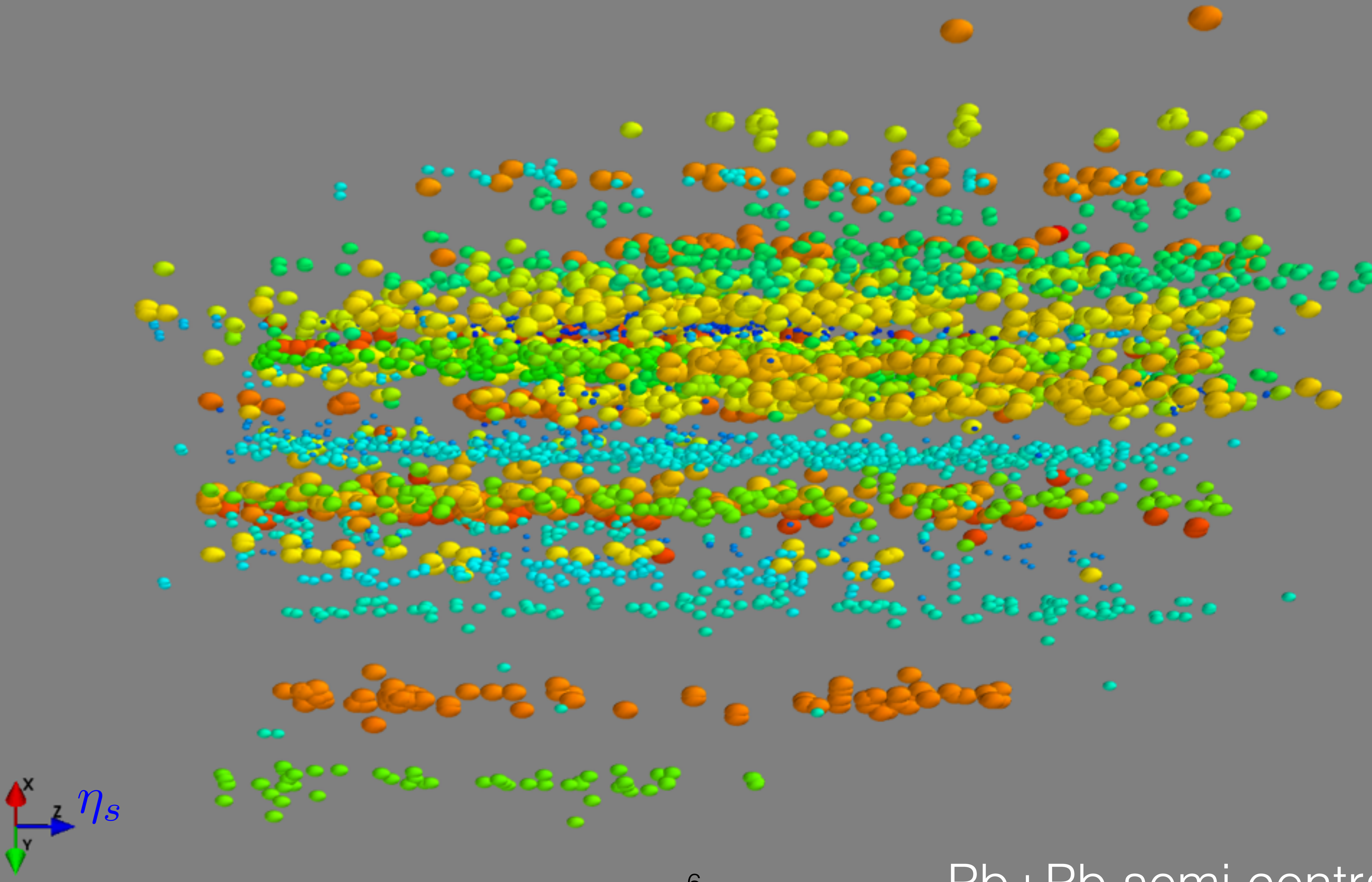
- New developing CLVisc: c++/python, KT algorithm to solve hydrodynamic equations, parallelized on GPU using OpenCL.

L-G Pang, X-N Wang and Q Wang 2012, PRC

L-G Pang, X-N Wang, B-W Xiao, Y. Hatta, 2015 PRD

OpenCL

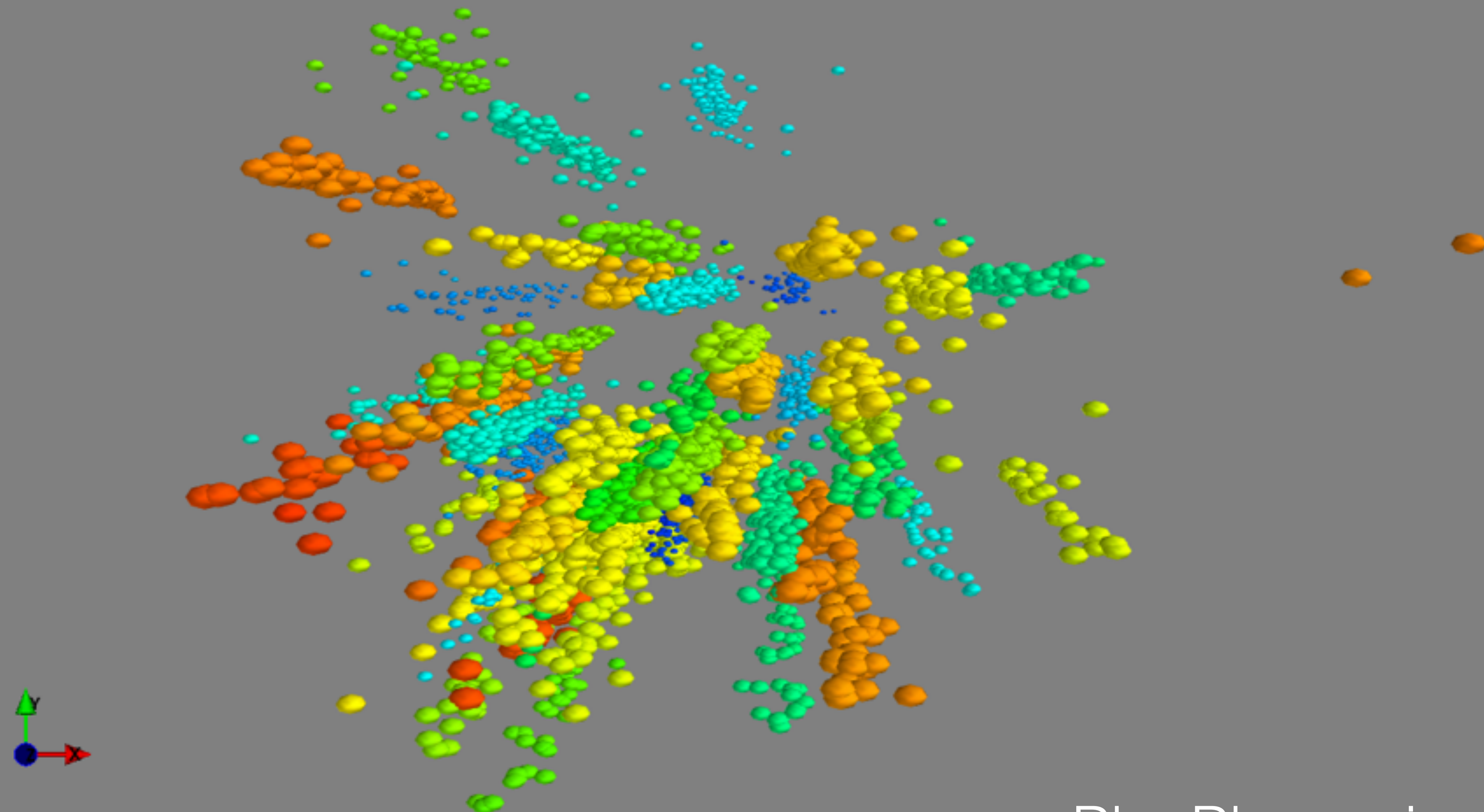
Distribution of initial partons



Pb+Pb semi central

3D view from space-time rapidity

- The initial partons from AMPT look like many strings along space-time rapidity.
- Use k mean method to cluster the partons according to their (x,y) coordinates.
- Partons in the same cluster (string) are plotted with the same color and size.



Pb+Pb semi central

The longitudinal fluctuations in the model

- MC Glauber model to determine the number of binary collisions and the asymmetric distribution of forward-backward going participants

- String length fluctuates according to the excited mass of the string

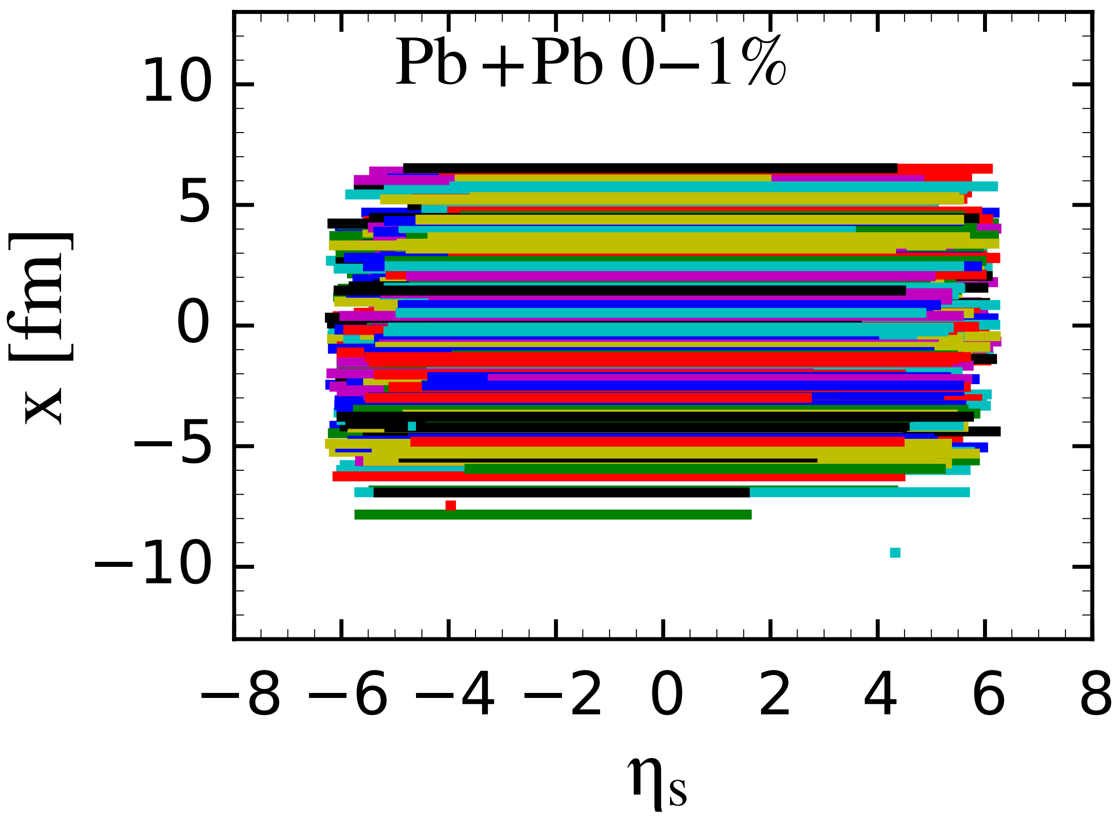
$$M_1^2 = x_-(1-x_+)s - p_T^2$$

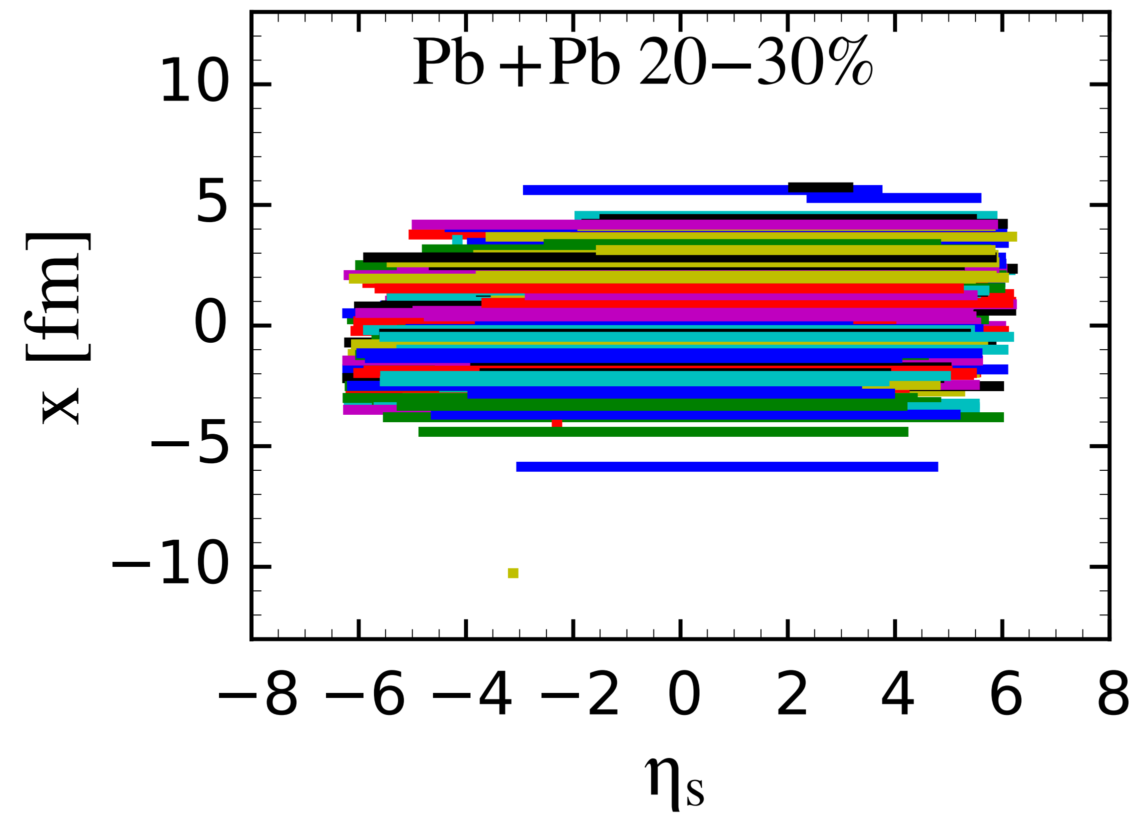
- String position fluctuates due to non-zero net longitudinal momentum

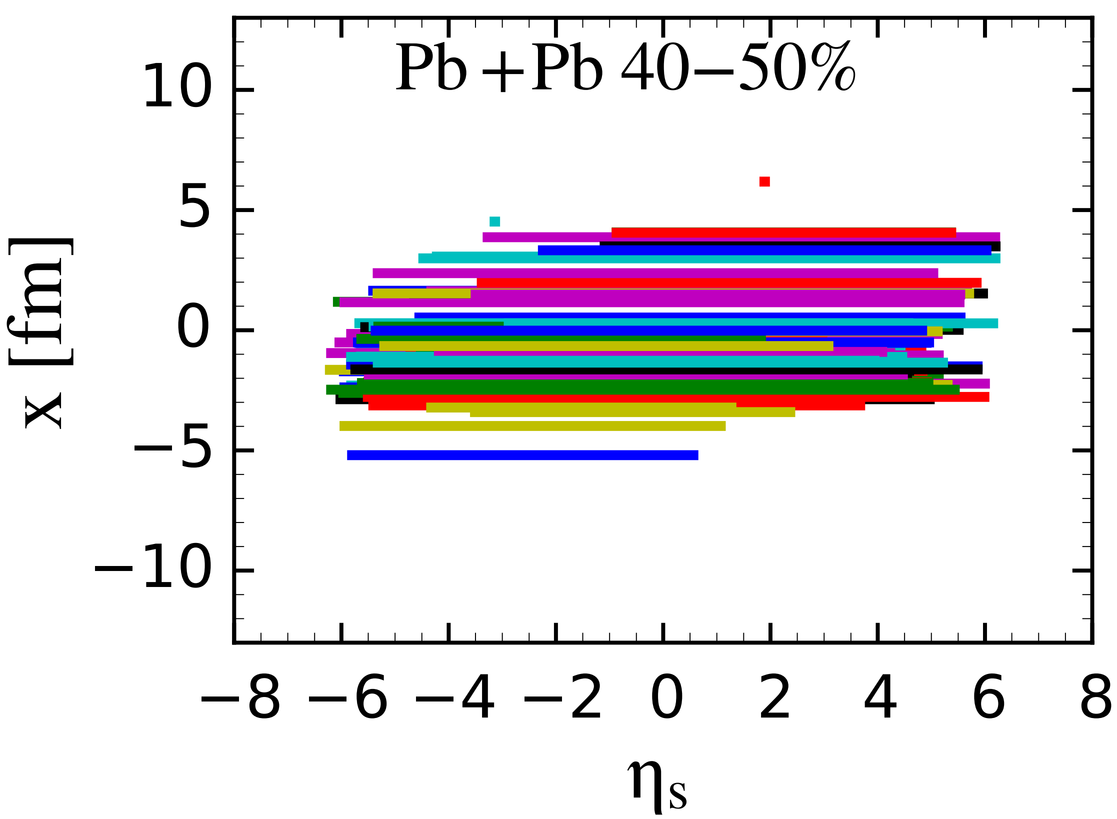
$$x_+ - x_- \neq 0$$

- In the following computing we use string structure in HIJING where number of strings equals to the number of wounded nucleons. Different longitudinal structure (string setting) may give different results.

String length fluctuations vs FB asymmetry

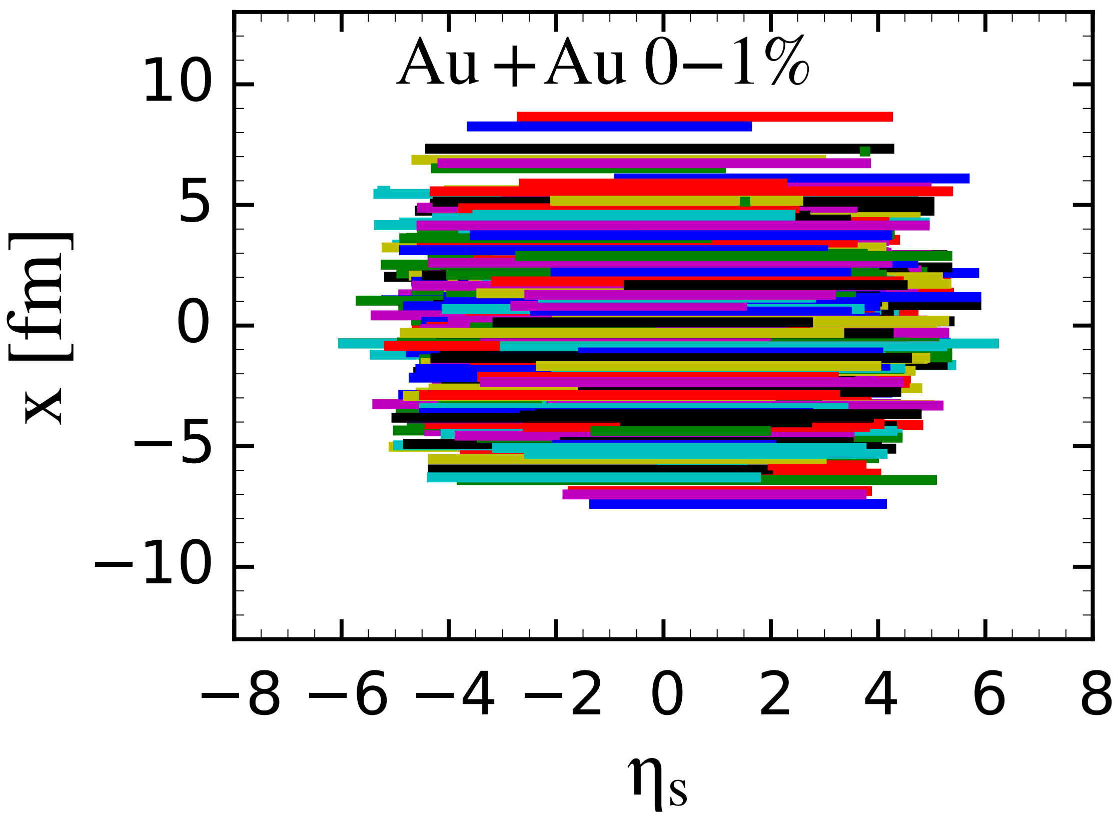


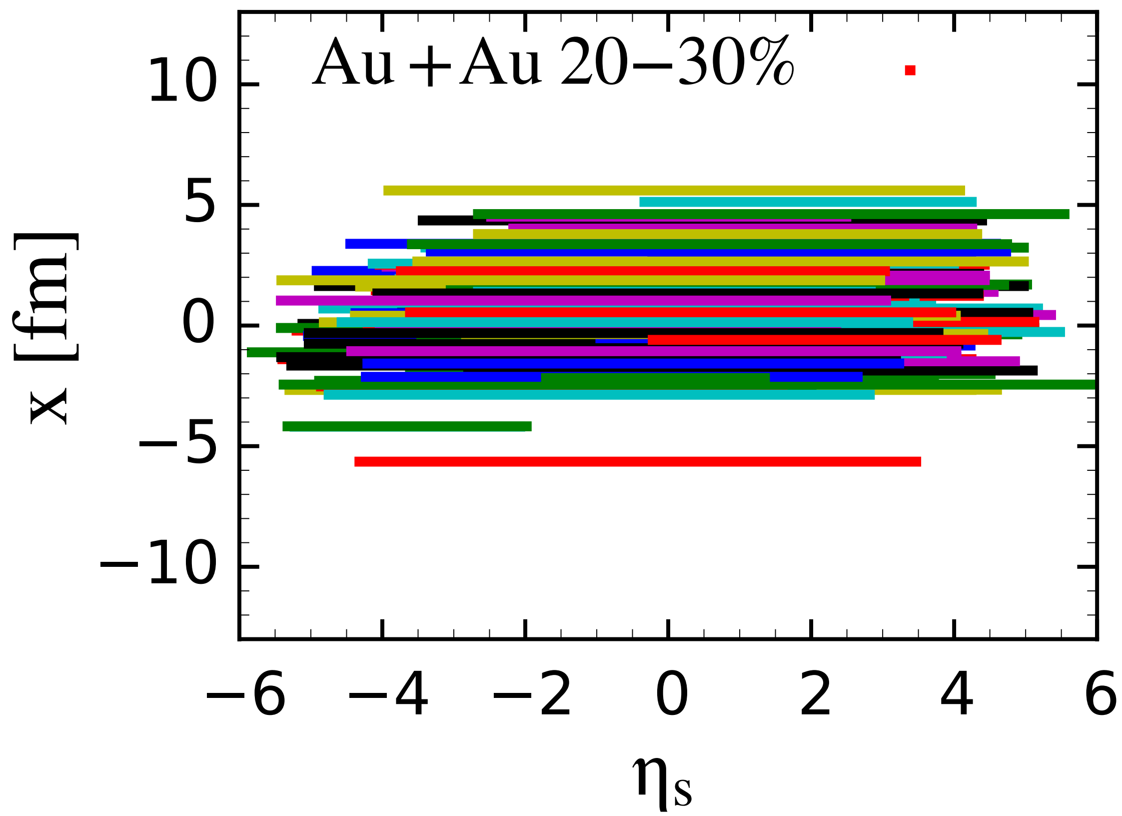


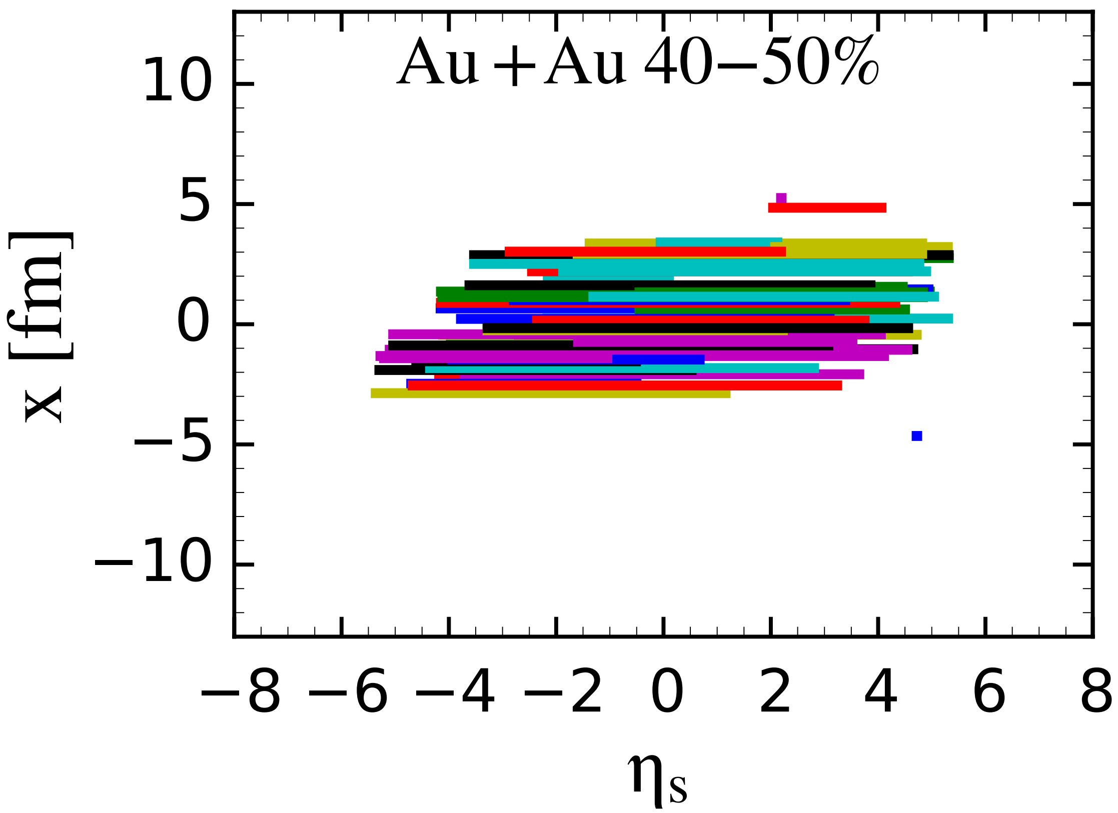


- String length fluctuations are important for most central col.
- Energy density fluctuations are larger at large rapidity than mid rapidity (random fluctuations besides twist).
- FB asymmetry is strong for semi-central and peripheral col.
- num of strings = [400, 189, 70] @ Pb+Pb 2.76 TeV/n

String length fluctuations vs FB asymmetry

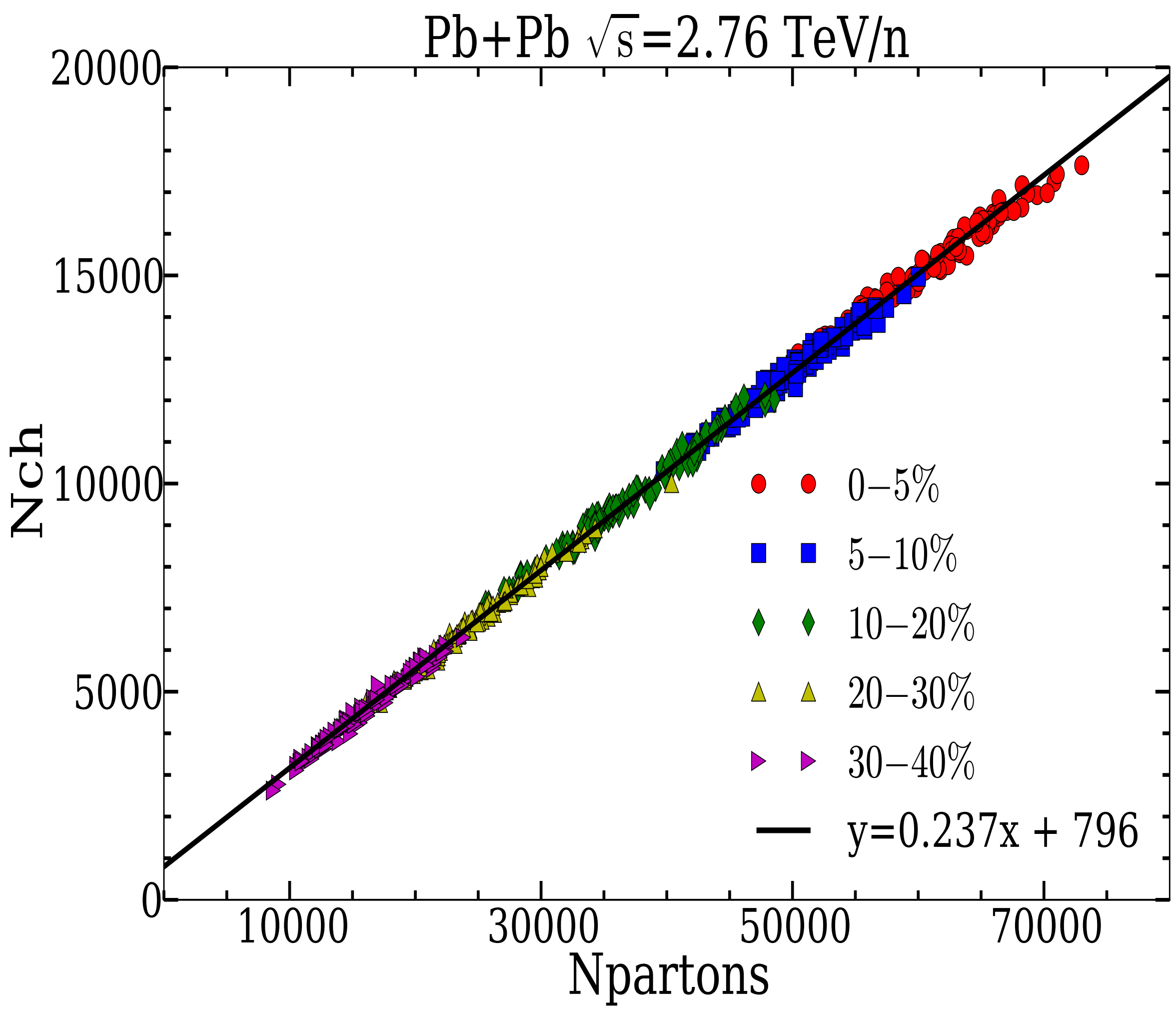


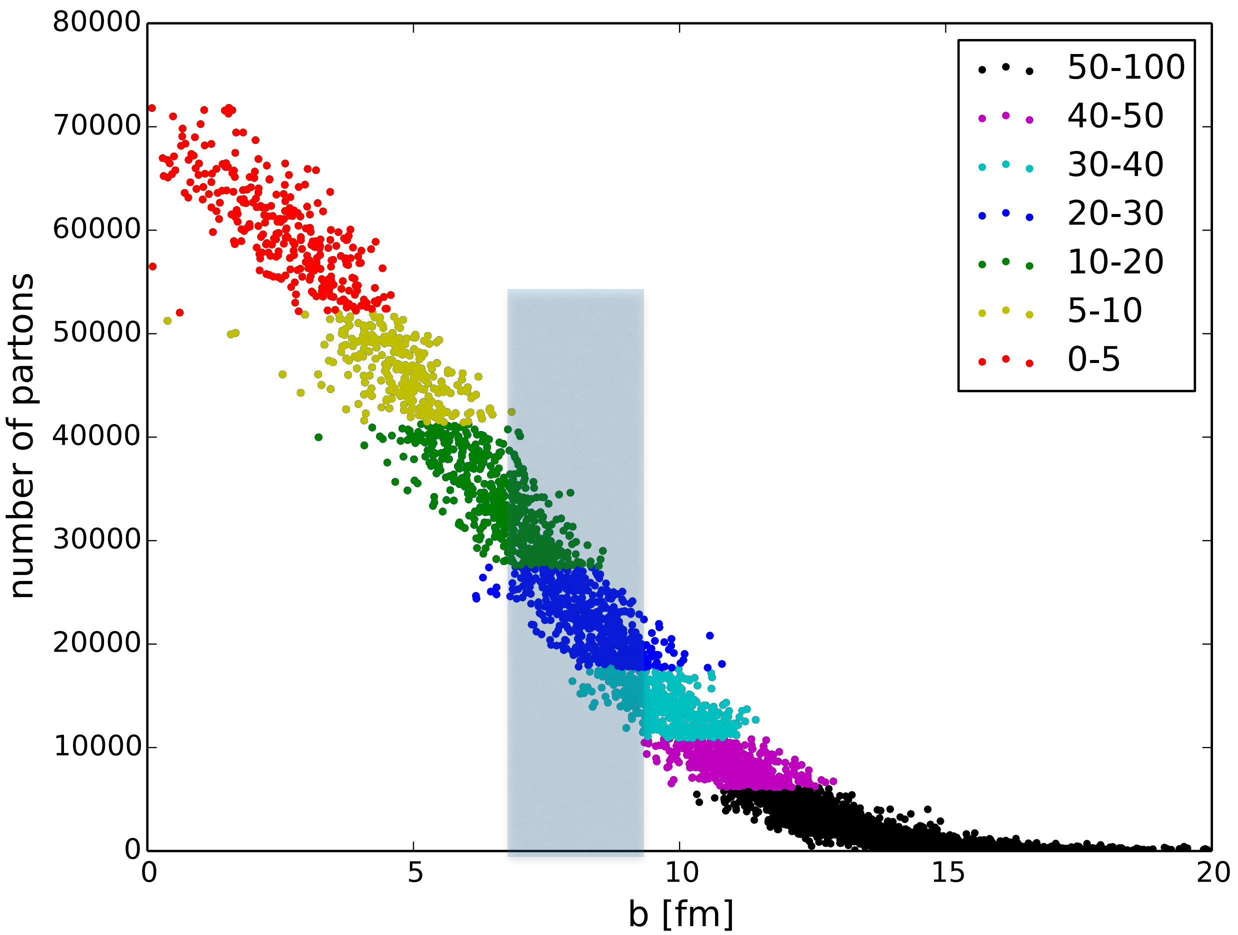




- The average string length is smaller at RHIC energy than LHC energy
- The effect of length fluctuations is larger
- num of strings = [380, 170, 65] @AuAu 200 GeV/n

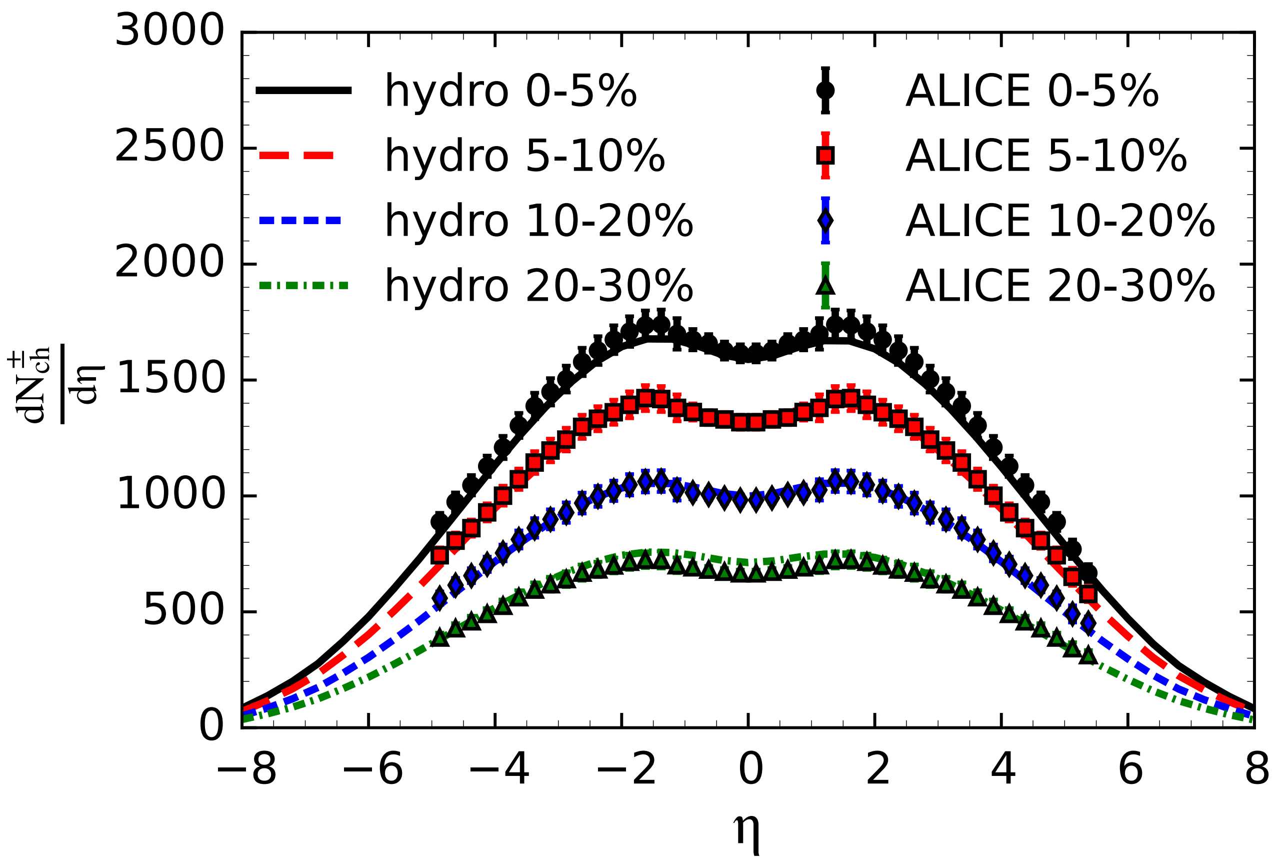
Centrality bins

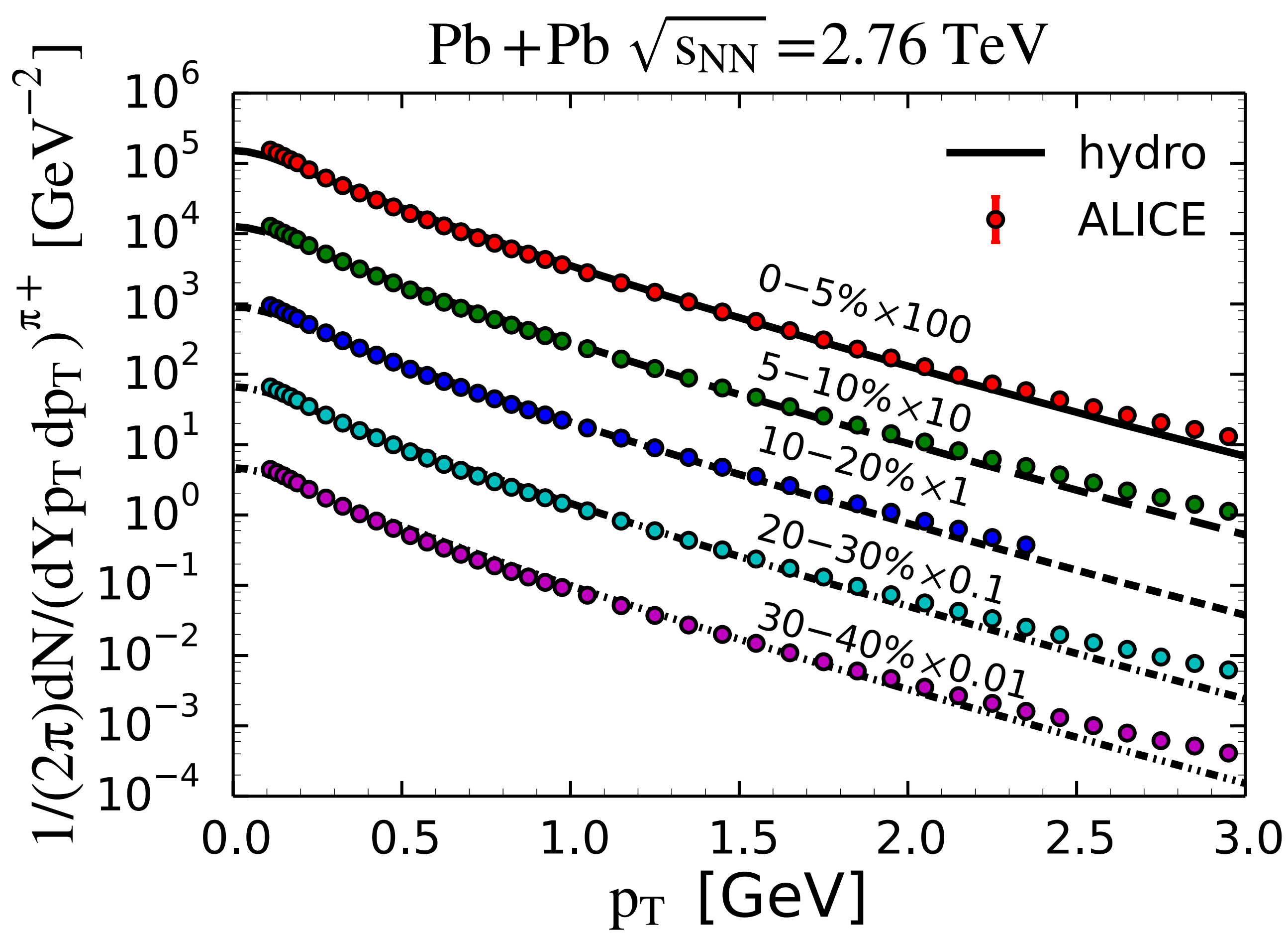




- Linear relationship between the number of partons put in hydro from AMPT and the number of charged hadrons given by hydro.
- The number of partons is used to determine centrality bins

Charged multiplicity (LHC)

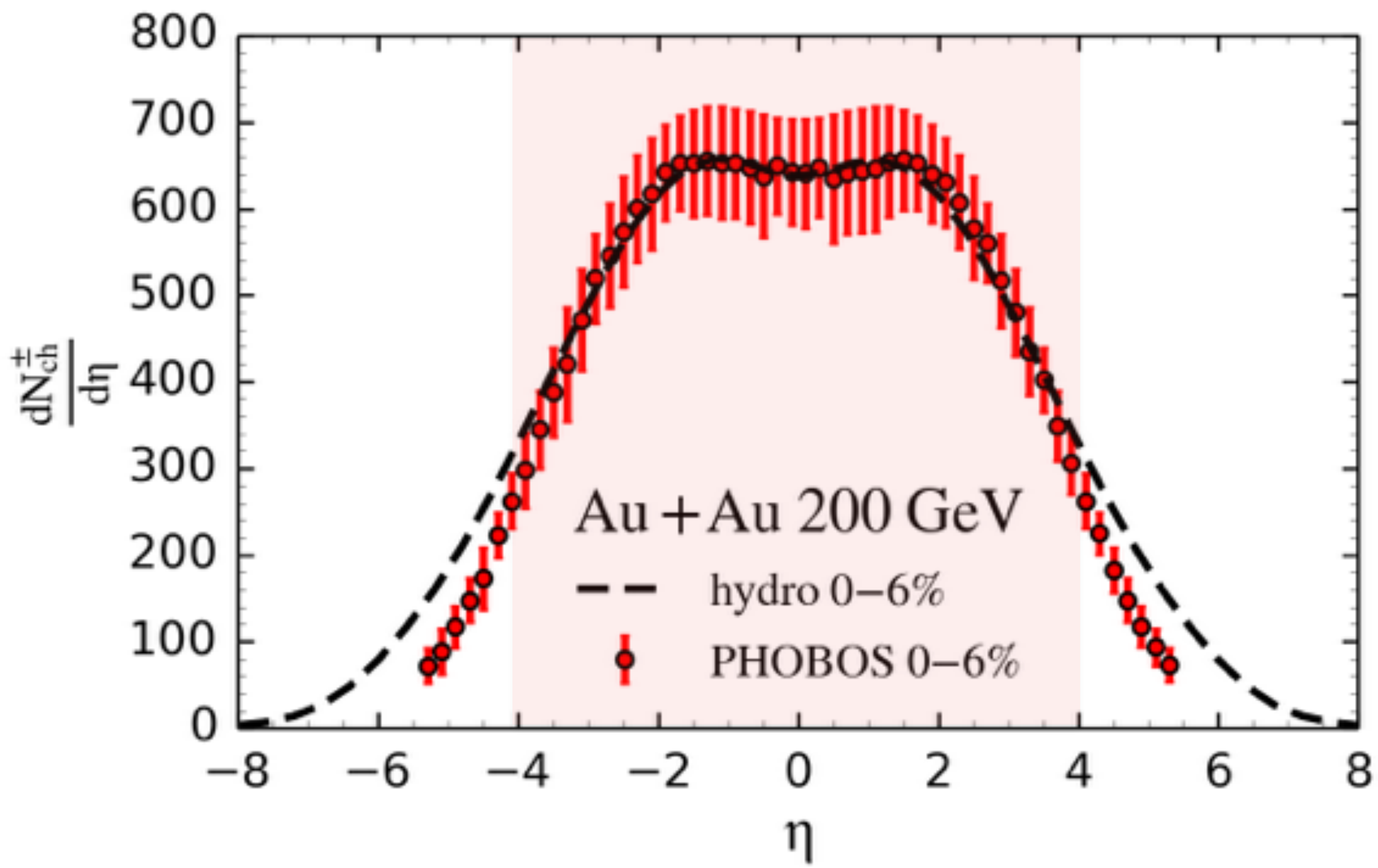




- Charged multiplicity is integrated over transverse momentum and azimuthal angle. Can't see longitudinal fluctuations in event averaged quantities!

- K=1.5 and $\sigma_r = \sigma_\eta = 0.6$ for CLVisc EOS s95p-PCE-v0.

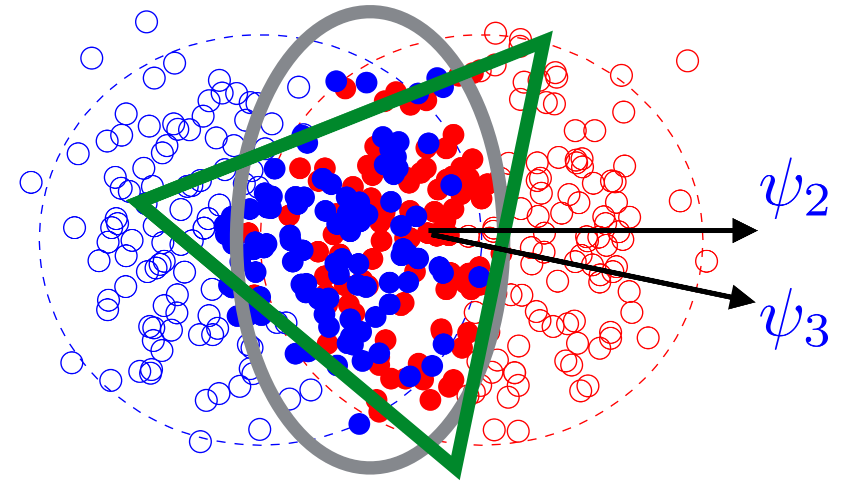
Charged multiplicity (RHIC)



- In the following calculations pseudorapidity range [-4,4] is used for RHIC energy
- Net baryon density may be needed for 3+1D hydro (EOS with finite mu_B) at forward and backward rapidities to describe the data.
- Forward rapidity detector is important to provide more rapidity dependent observables, like vn, event planes, <pt>, net baryon density and its fluctuations to improve the 3+1D hydrodynamics.

How to measure the longitudinal fluctuations

Two ways to measure:



1. The rapidity-dependent event planes $\Psi_n(\eta)$
2. The rapidity-dependent Qn vectors which capture both magnitude and orientation angle of the anisotropic flow.

$$\mathbf{Q}_n(\eta) = v_n(\eta)\exp(in\Psi_n(\eta)) = \frac{1}{N}\sum_i^N \exp(in\phi_i)$$

The intuitive but problematic way:

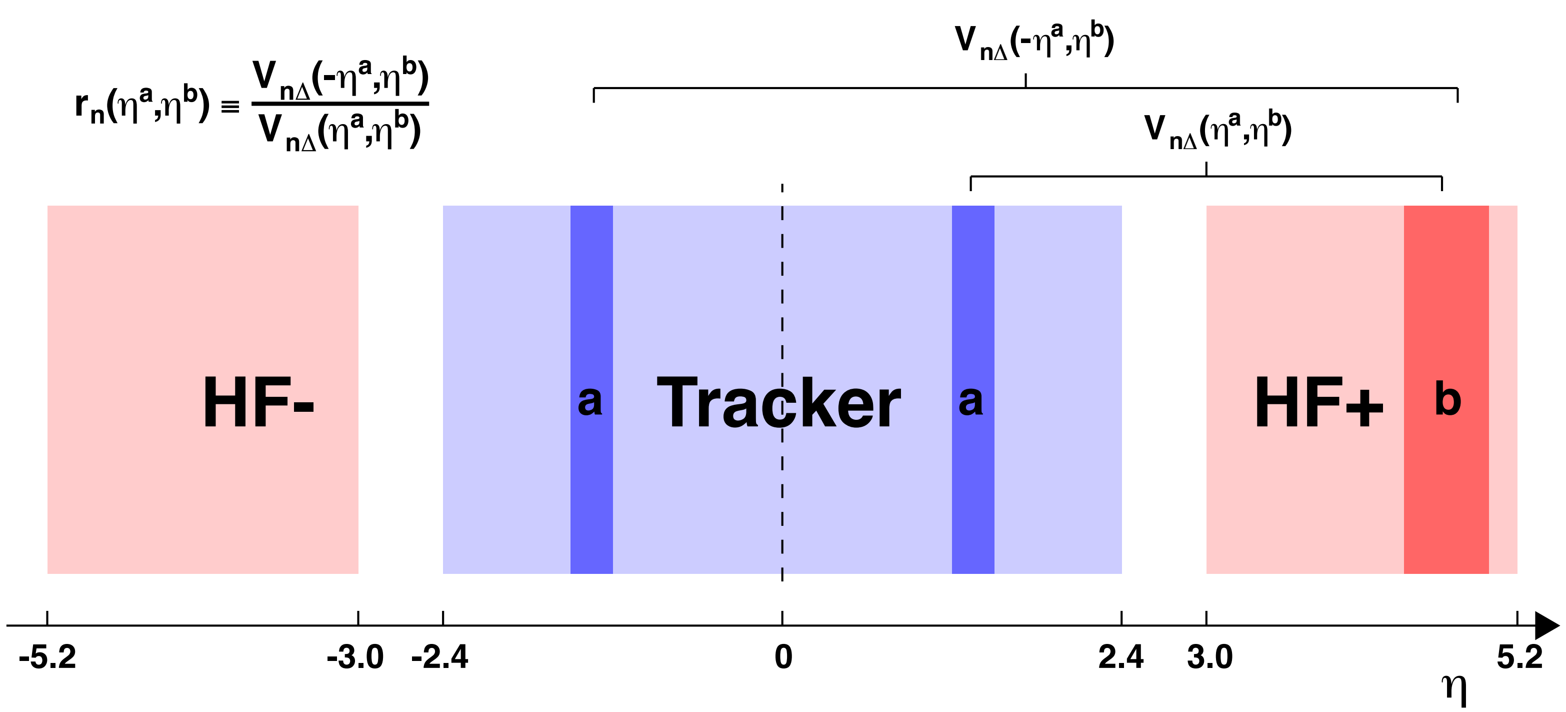
- L-G.Pang, G-Y.Qin,V.Roy,X-N.Wang, G-L.Ma, PRC 91, 044904 (2015)

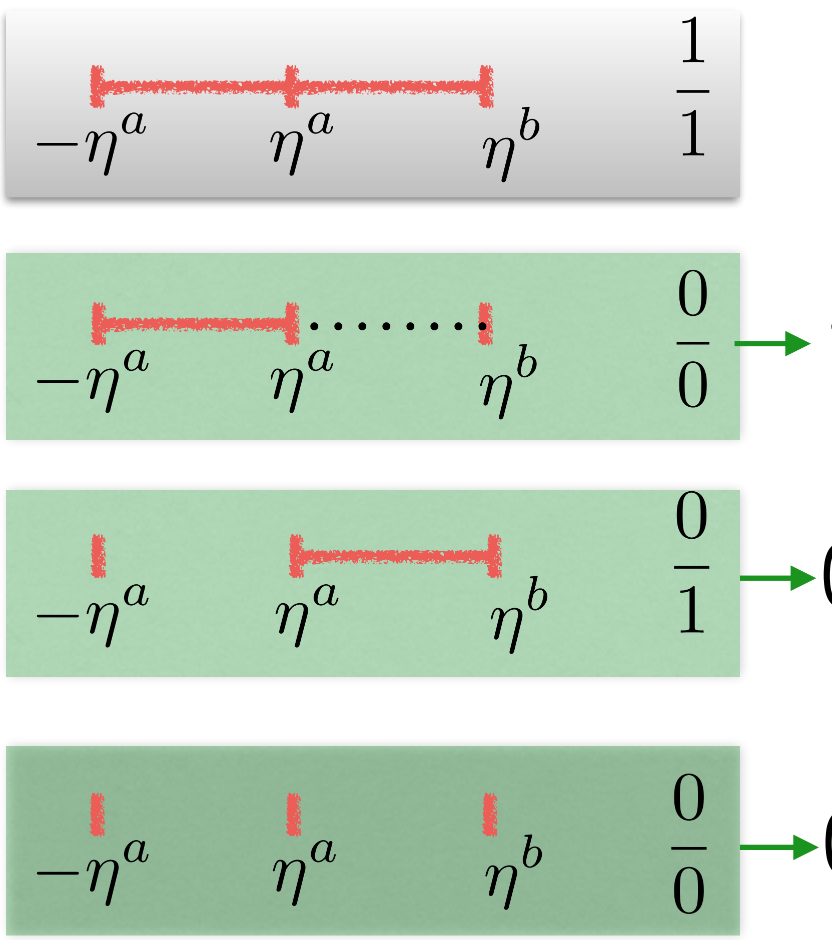
$$r_n(\Delta\eta = 2\eta) = \frac{< \mathbf{Q}_n(\eta)\mathbf{Q}_n(-\eta) >}{\sqrt{< \mathbf{Q}_n^2(\eta) >}\sqrt{< \mathbf{Q}_n^2(-\eta) >}}$$

De-correlation of anisotropic flow by CMS

(CMS 2015 ARXIV:1503.01692)

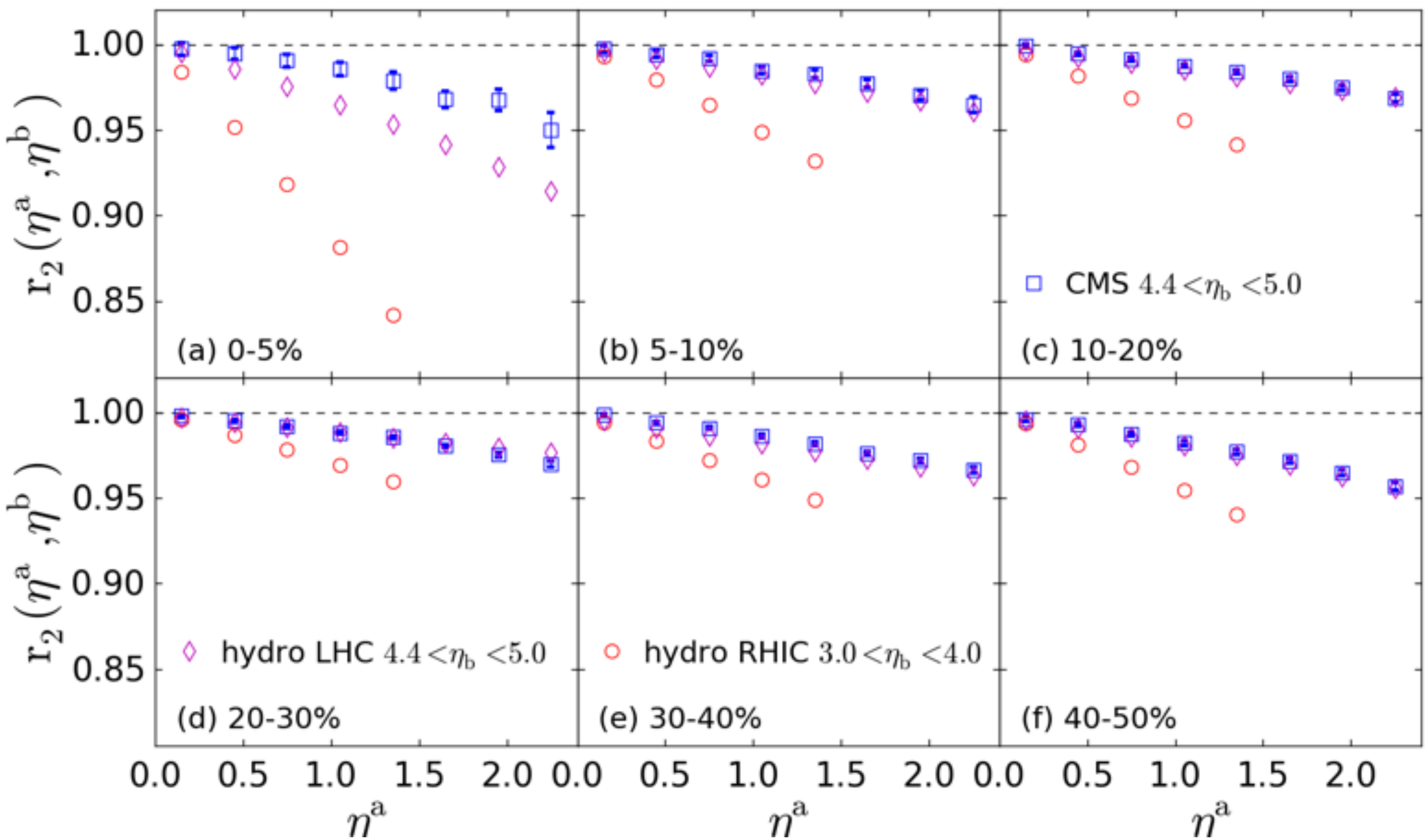
$$r_n(\Delta\eta = 2\eta^a) = \frac{< \mathbf{Q}_n(-\eta^a)\mathbf{Q}_n^*(\eta^b) >}{< \mathbf{Q}_n(\eta^a)\mathbf{Q}_n^*(\eta^b) >}$$





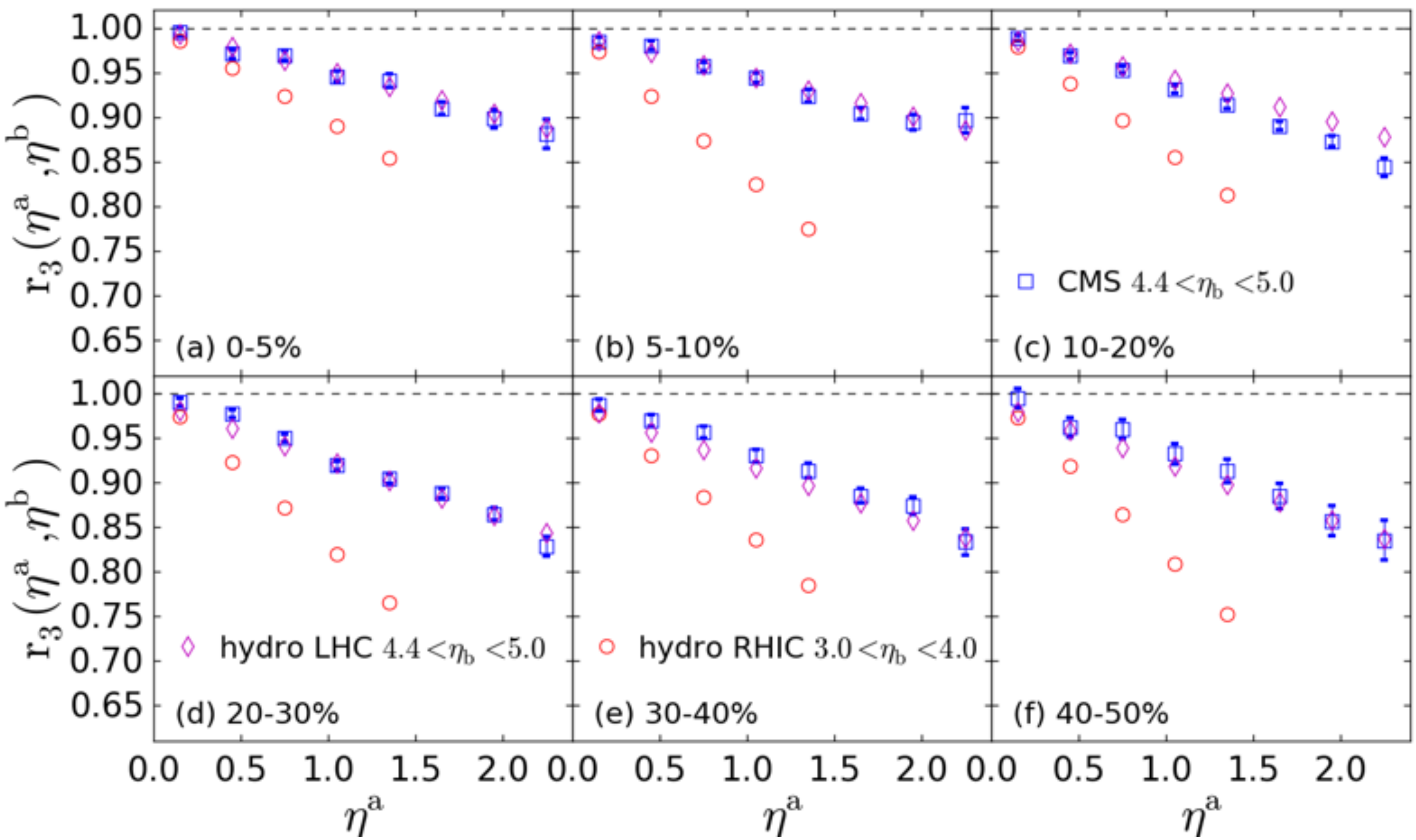
- The short range correlations (jet, resonance decay, Bose-Einstein correlation …) are removed if the rapidity gap between a and b is bigger than 2.

Compare with CMS, predictions for RHIC



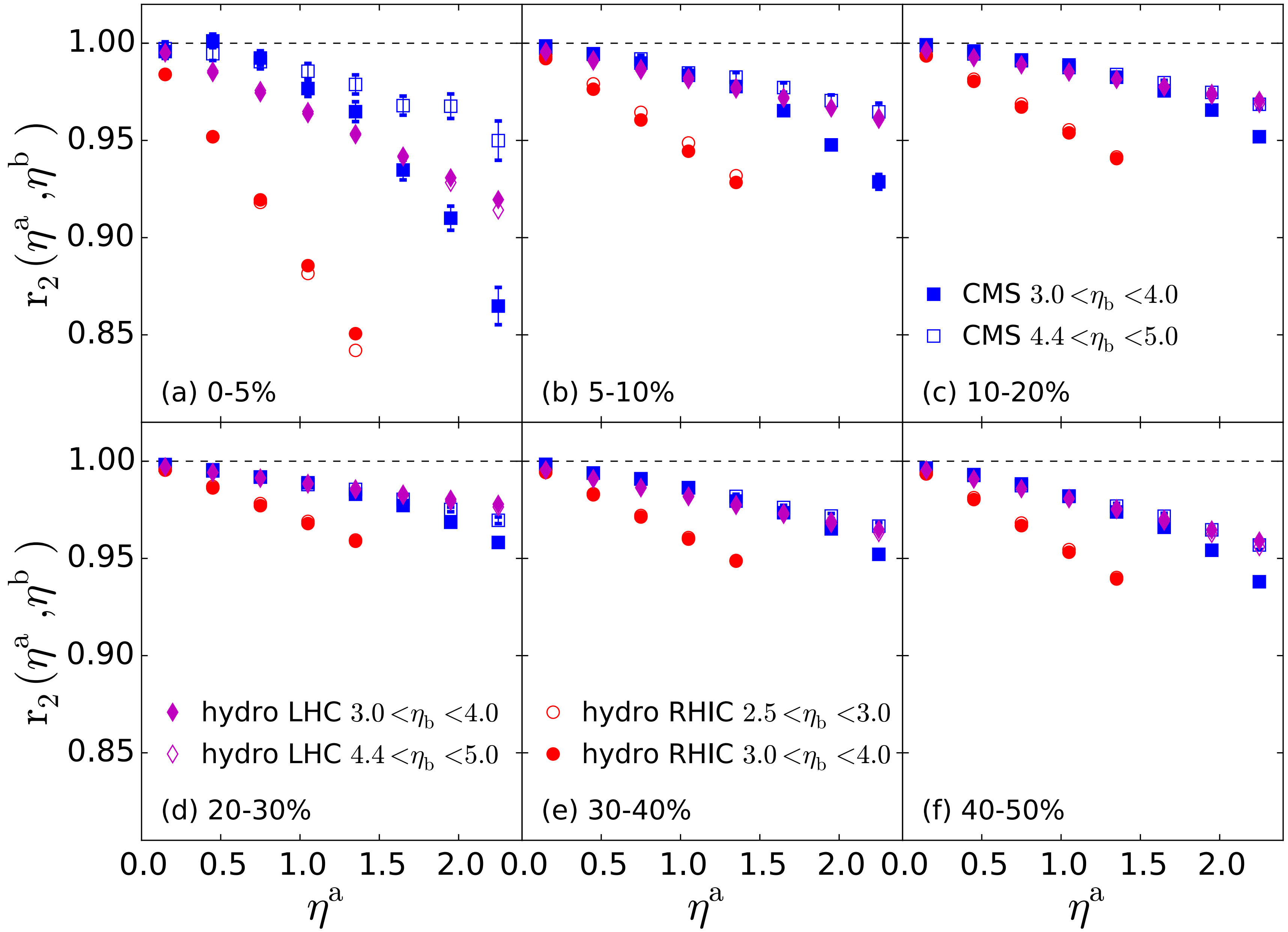
- De-correlation r_2 agrees with CMS perfectly except 0-5% centrality.
- Centrality dependence comes from both FB asymmetry and string length fluctuations.
- RHIC shows much stronger de-correlation which indicates stronger fluctuations at lower collision energies

Compare with CMS, predictions for RHIC



- r_3 has weak centrality dependence
- Strings from dual parton model or saturation model may increase r_2 in most central collisions, however, it is still unclear how to keep all other centrality unchanged. (future work)

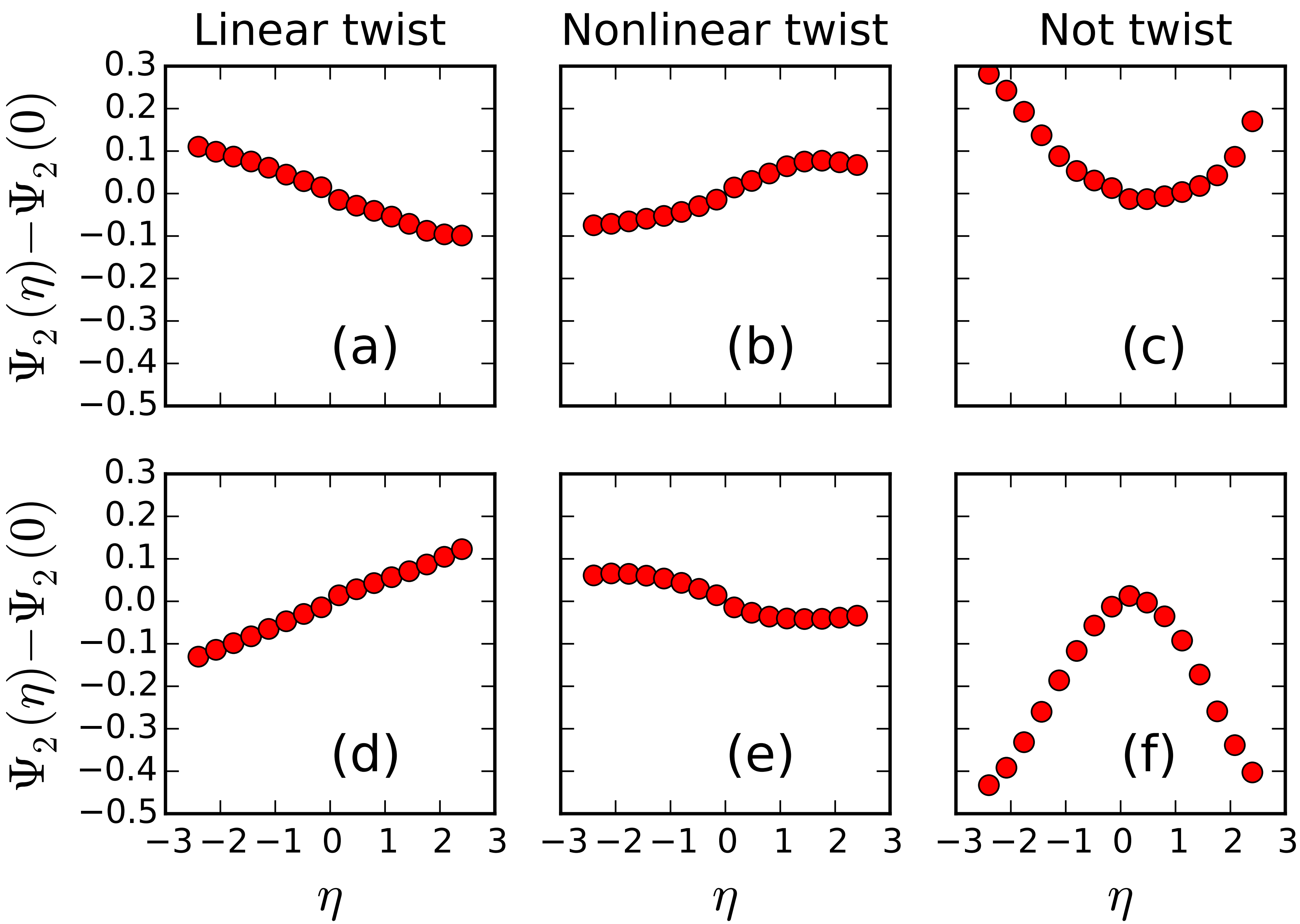
Compare with CMS, Predictions for RHIC



- Results are not sensitive to short range correlation in hydro

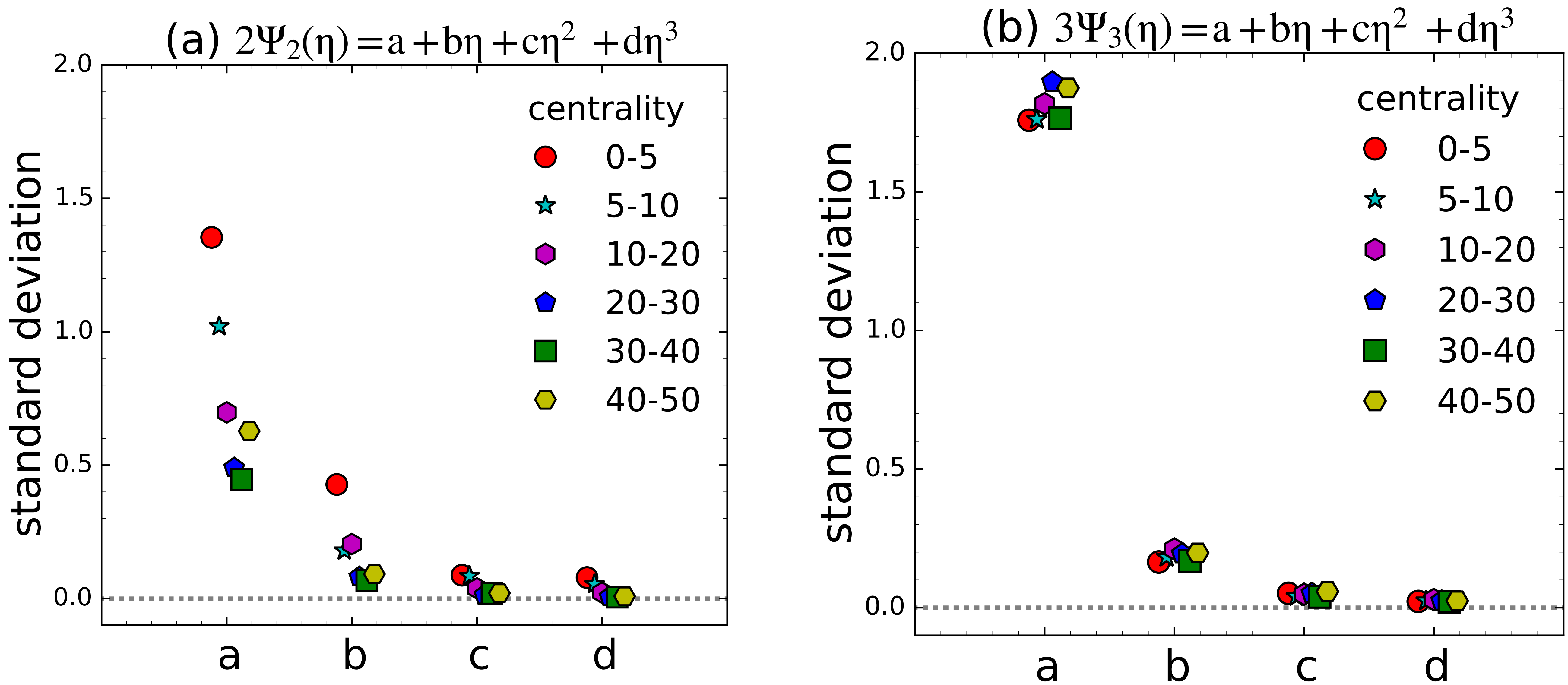
- Big rapidity gap (Forward rapidity detector) is required in experiment to remove the short range correlation.

Twist or random fluctuations (6 typical events)



- η dependent event planes from AMPT+Hydro

Biggest contribution from linear twist



- Bigger linear and non-linear twist for 2nd order in 0-5% central collisions than semi-central collisions

- The linear twist of Ψ_2 is larger than Ψ_3 in most central collisions

Summary

- Event-by-event hydro with AMPT initial conditions describe CMS data pretty well with asymmetric distribution of forward and backward going participants + random lengths of the strings + string position fluctuations.

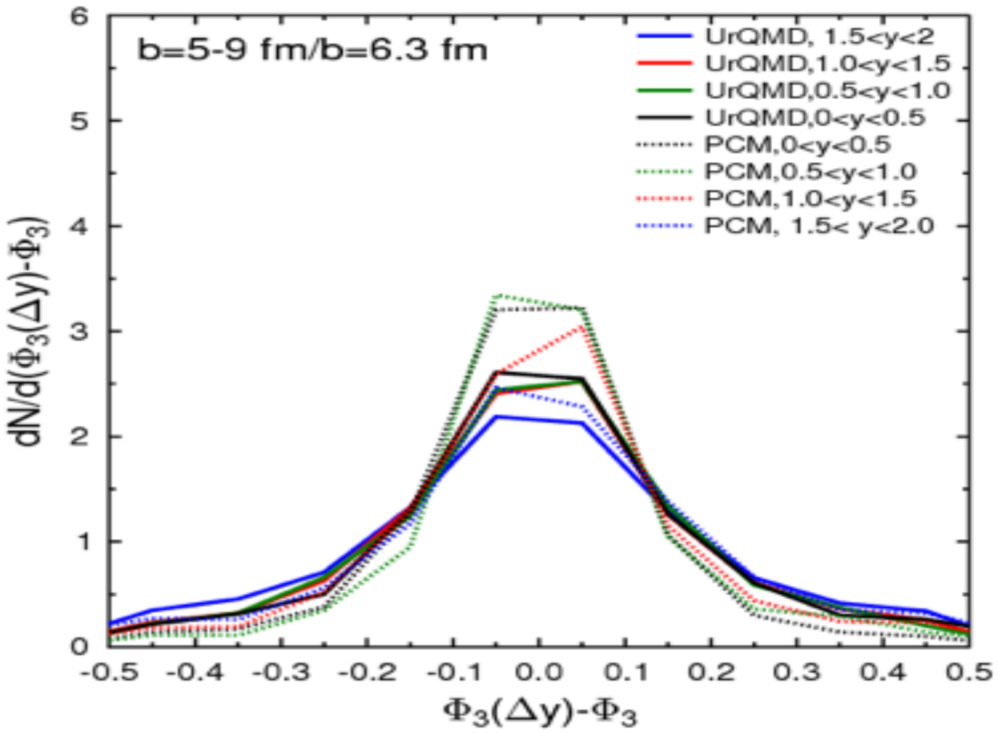
- The fluid expansion transfers the initial state fluctuation to de-correlation of anisotropic flow in the final state.

- After hydrodynamic evolution, $\Psi_n(\eta)$ is dominated by linear twist along the rapidity direction.

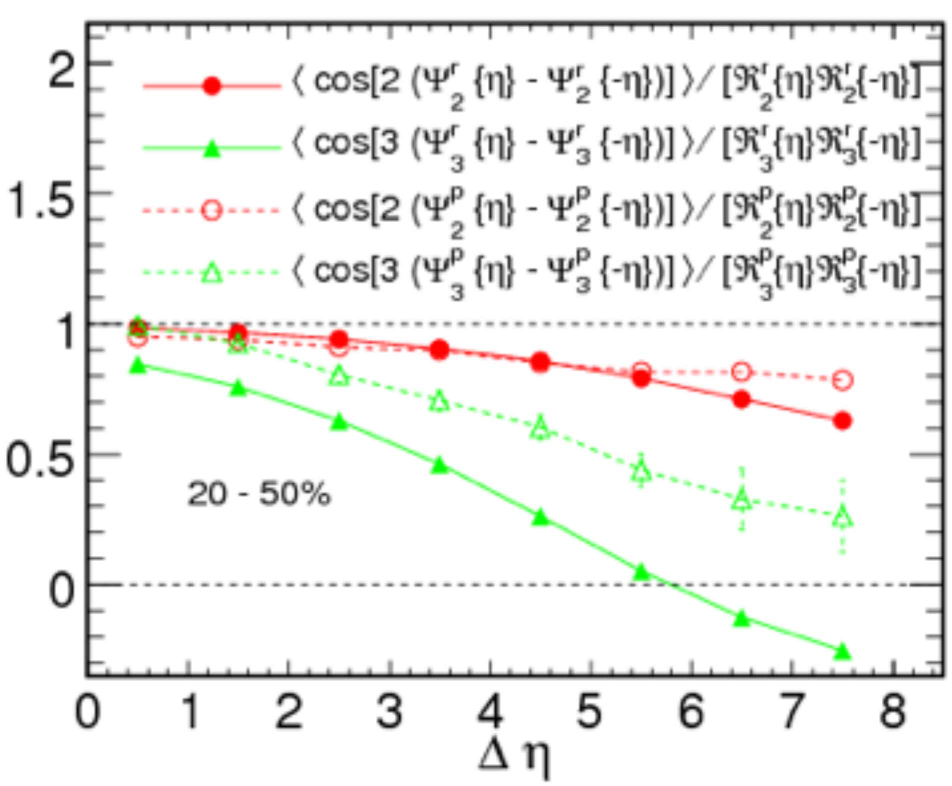
- More rapidity dependent observables at RHIC and LHC are needed to study the initial entropy production along longitudinal direction (like the 2 particle pseudo rapidity correlation ATLAS-CONF-2015-020).

Ways to measure

H.Petersen et al.

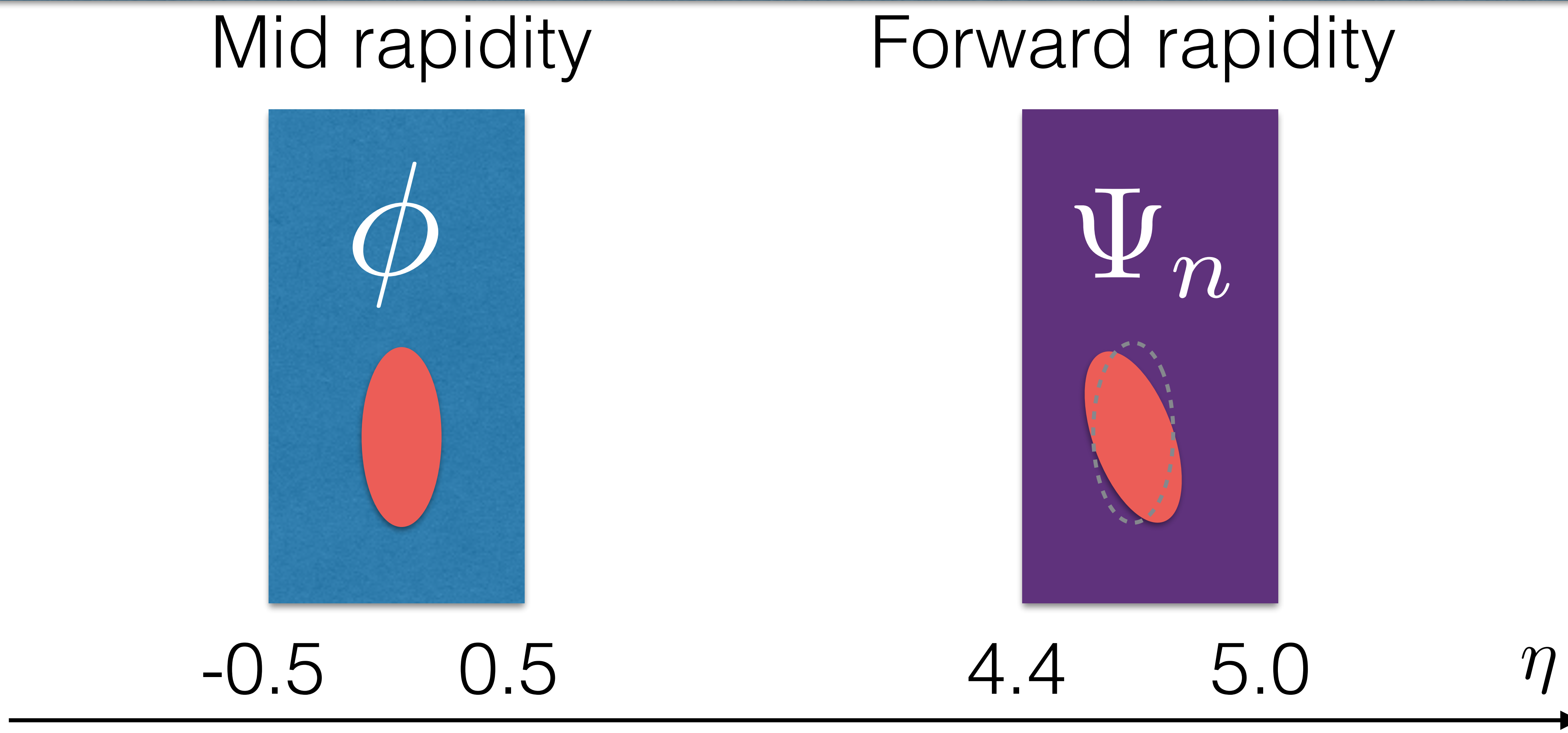


K.Xiao et al.



- Correlation of 3rd order event planes along rapidity (H. Petersen 2011 PRC)
- Forward-backward event plane correlation (P. Bozek)
- Event plane de-correlation with varying rapidity gap (K.Xiao, FQ. Wang, F. Liu PRC 2013)
- De-correlation of Qn vector with varying rapidity gap(LG. Pang, GY. Qin, V. Roy, XN.Wang, GL. Ma 2015 PRC)

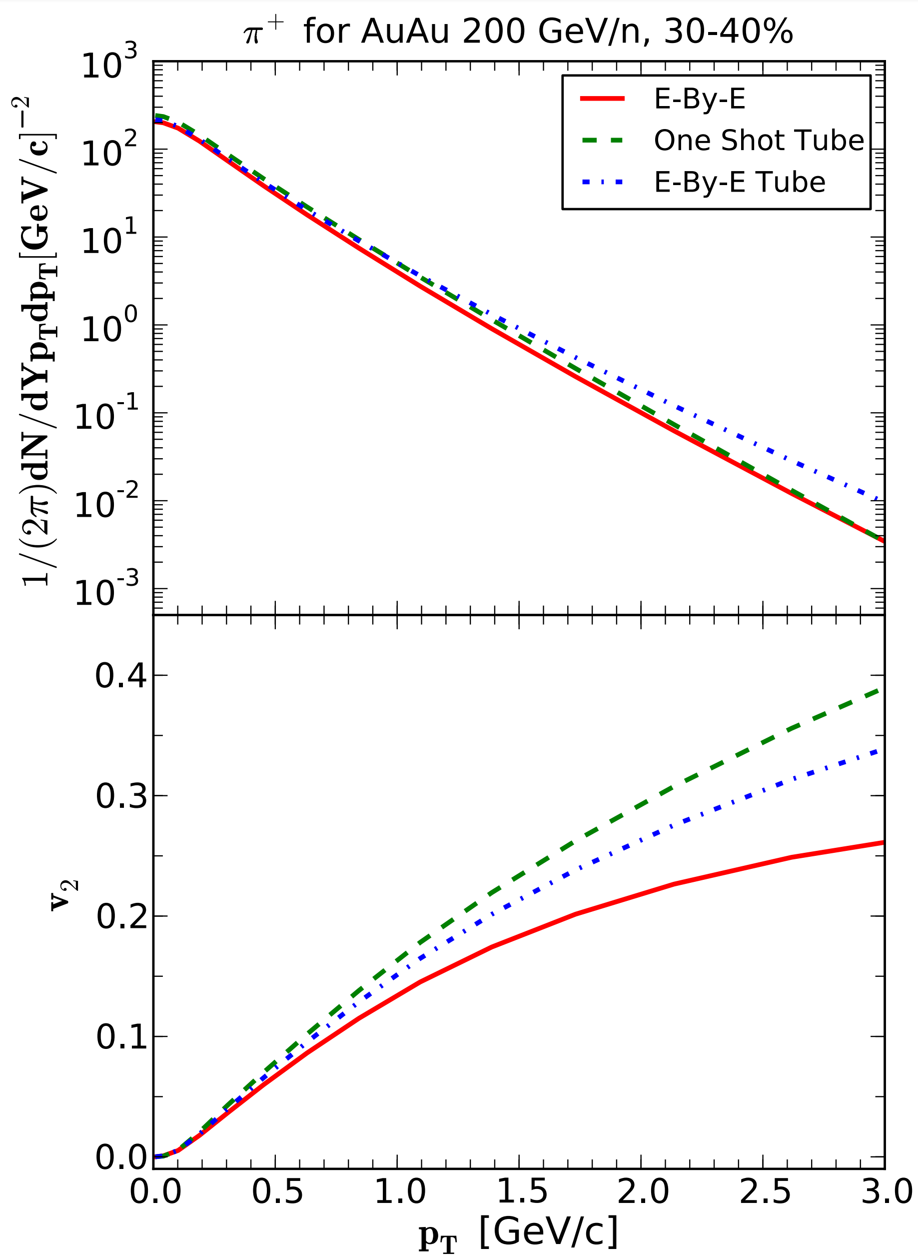
Effect of longitudinal fluctuations on anisotropic flow



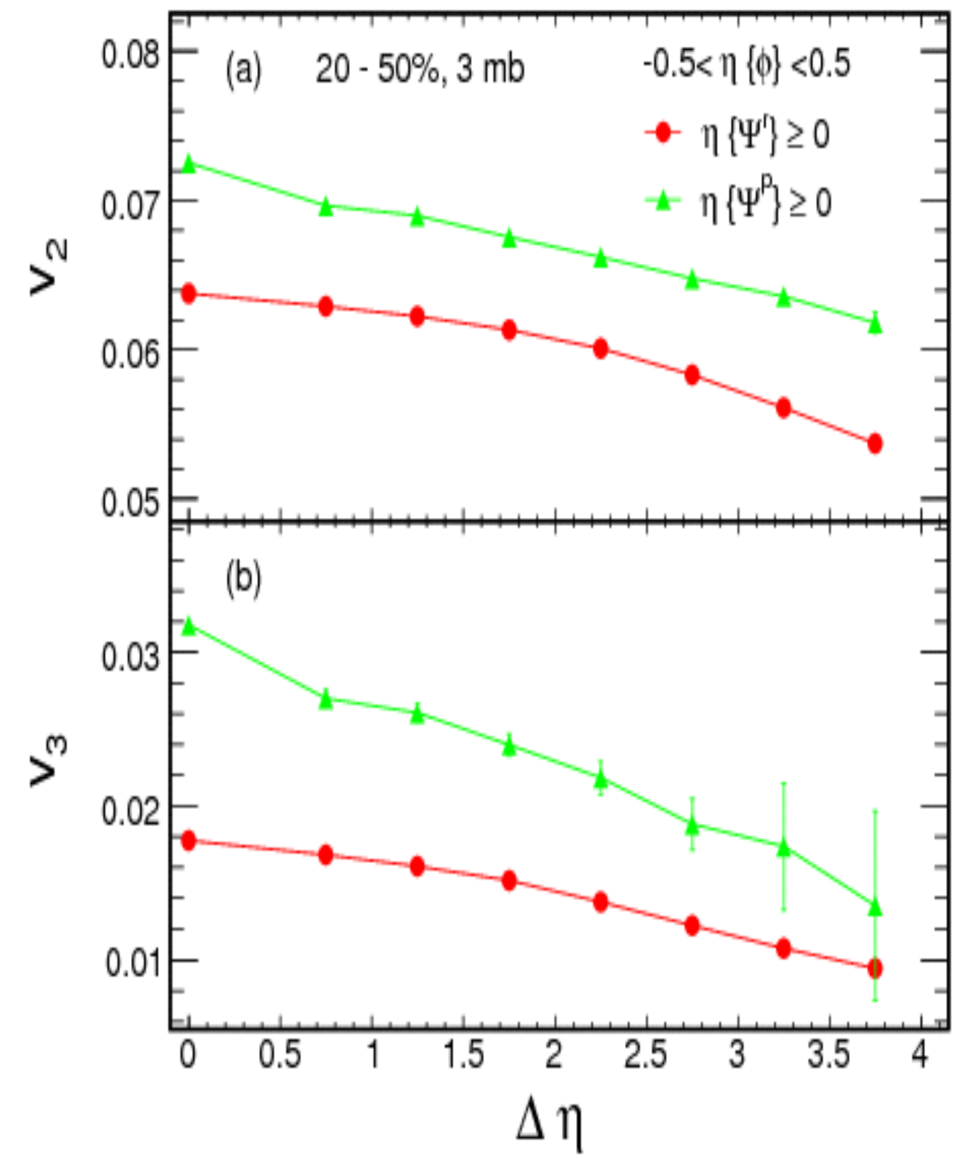
$$v_n = \frac{< \cos(n(\phi - \Psi_n)) >}{R}$$

- Big rapidity gap are used to reduce non-flow (short range correlations)
- The event plane resolution is not only from finite number of particles, but also from de-correlation of event planes.
- Event plane method corrected the de-correlation for those linear twist events. (See LiWei's talk)

Effect of longitudinal fluctuation: reduce anisotropic flow



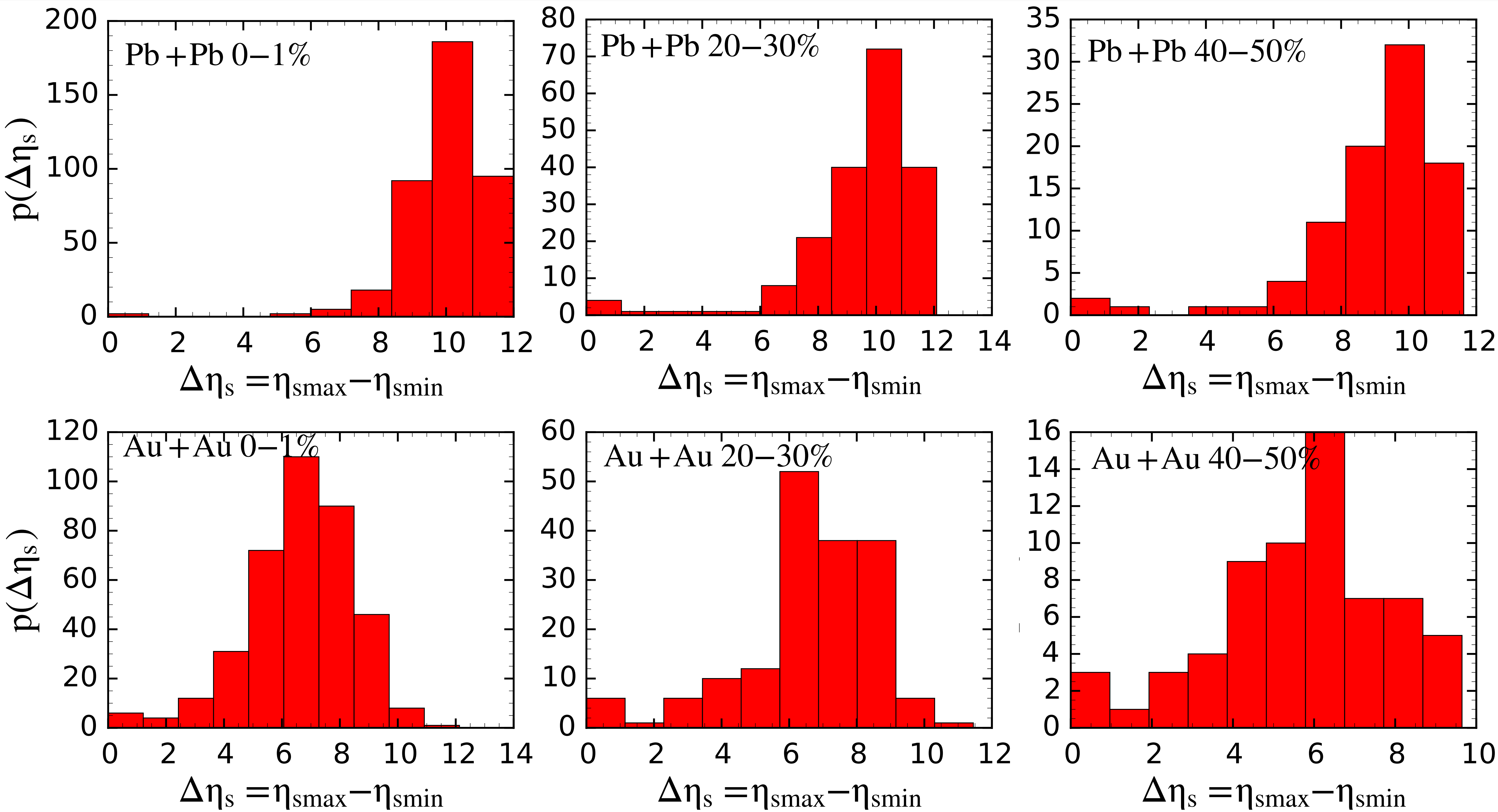
LG Pang, Q Wang, XN Wang 2012 PRC



- K.Xiao, FQ. Wang, F. Liu 2013 PRC

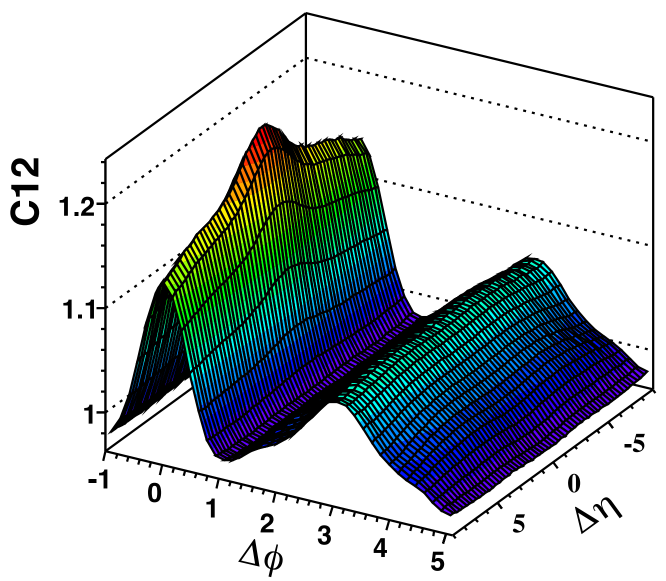
- The anisotropic flow is reduced not only because of decoration of event planes, but also because longitudinal expansion reduces eccentricity of QGP at neighboring slices.

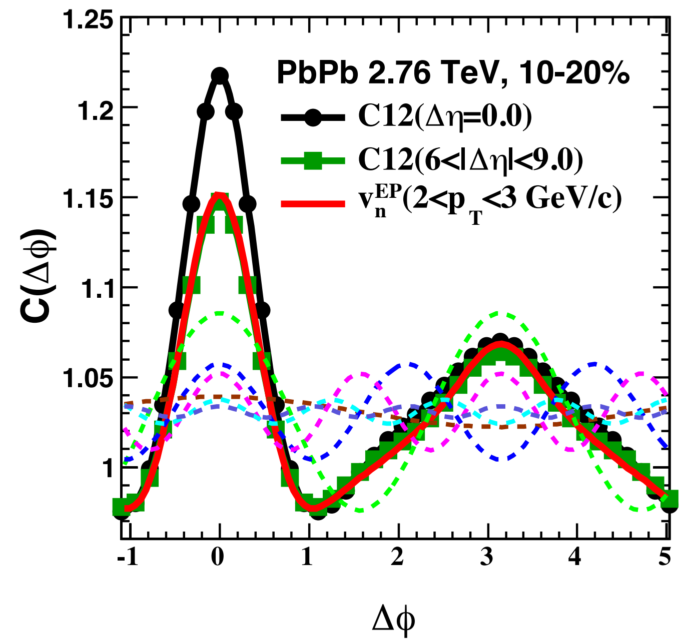
String length distribution

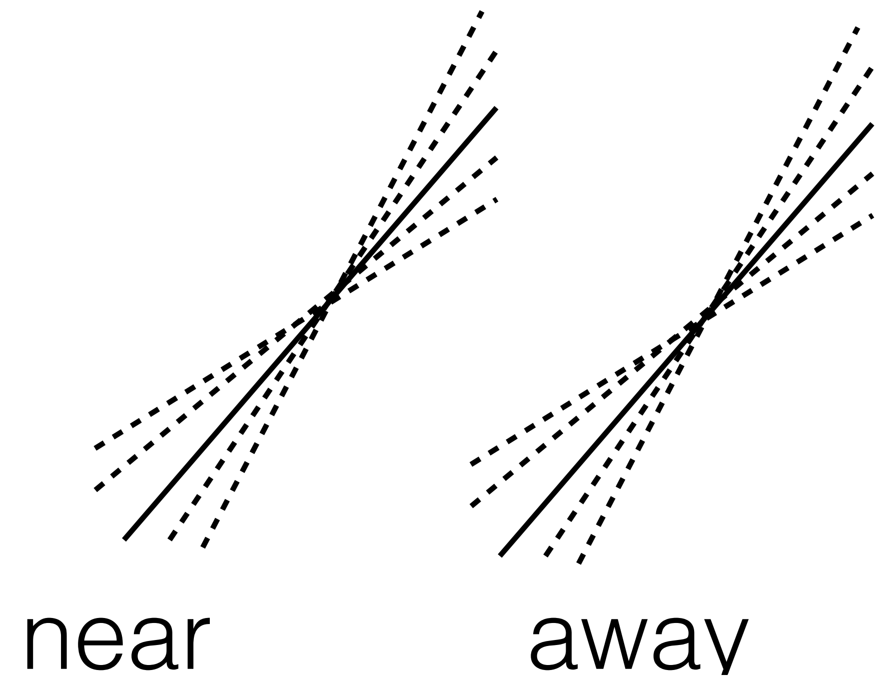


- Larger fluctuations at RHIC are intrinsic to study the longitudinal distribution of QGP,
- Provide stronger constraint to initial models, string distributions and entropy production mechanisms.

The effect of twist on di-hadron correlation

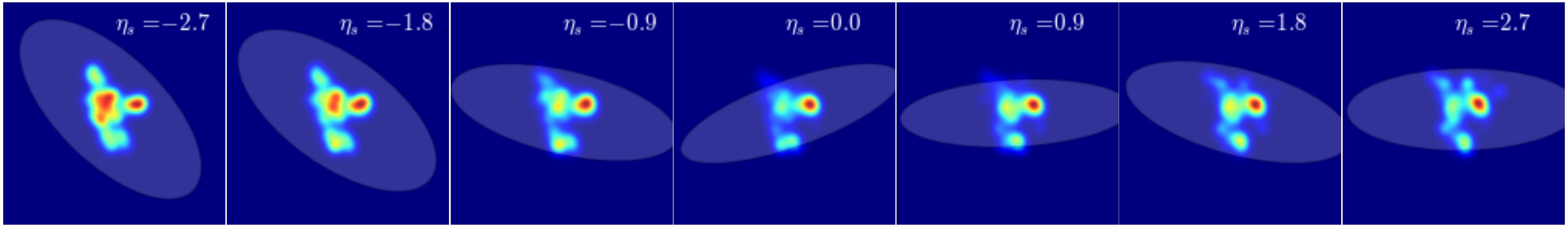






- The long range di-hadron correlation will be broadened, according to the slope of the linear twist.
- Then there will be a peak at $(\Delta\eta, \Delta\phi) = (0, \pi)$, however, what we found in AMPT and hydro is a dip instead of peak.
- The broadening increases measured v3.
- See also PRC.90.034915 by J.Jia and P.Huo

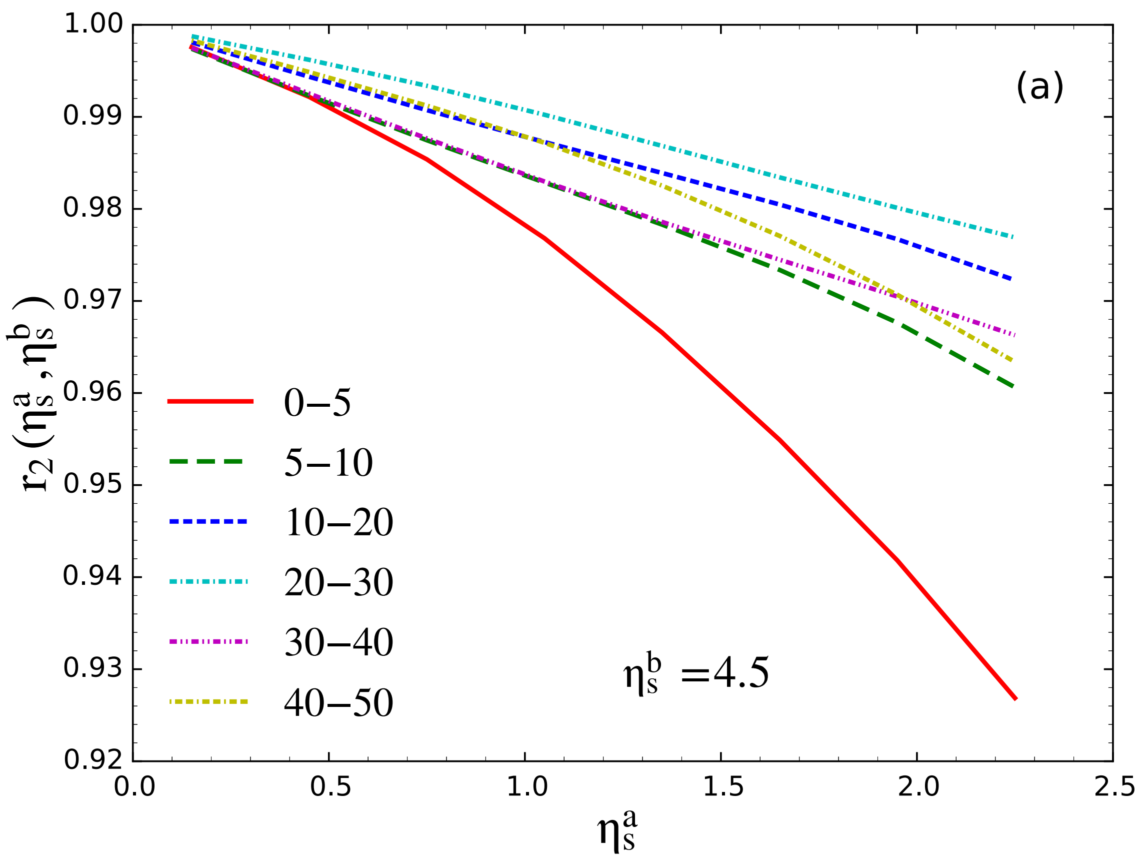
Longitudinal fluctuations in the initial state

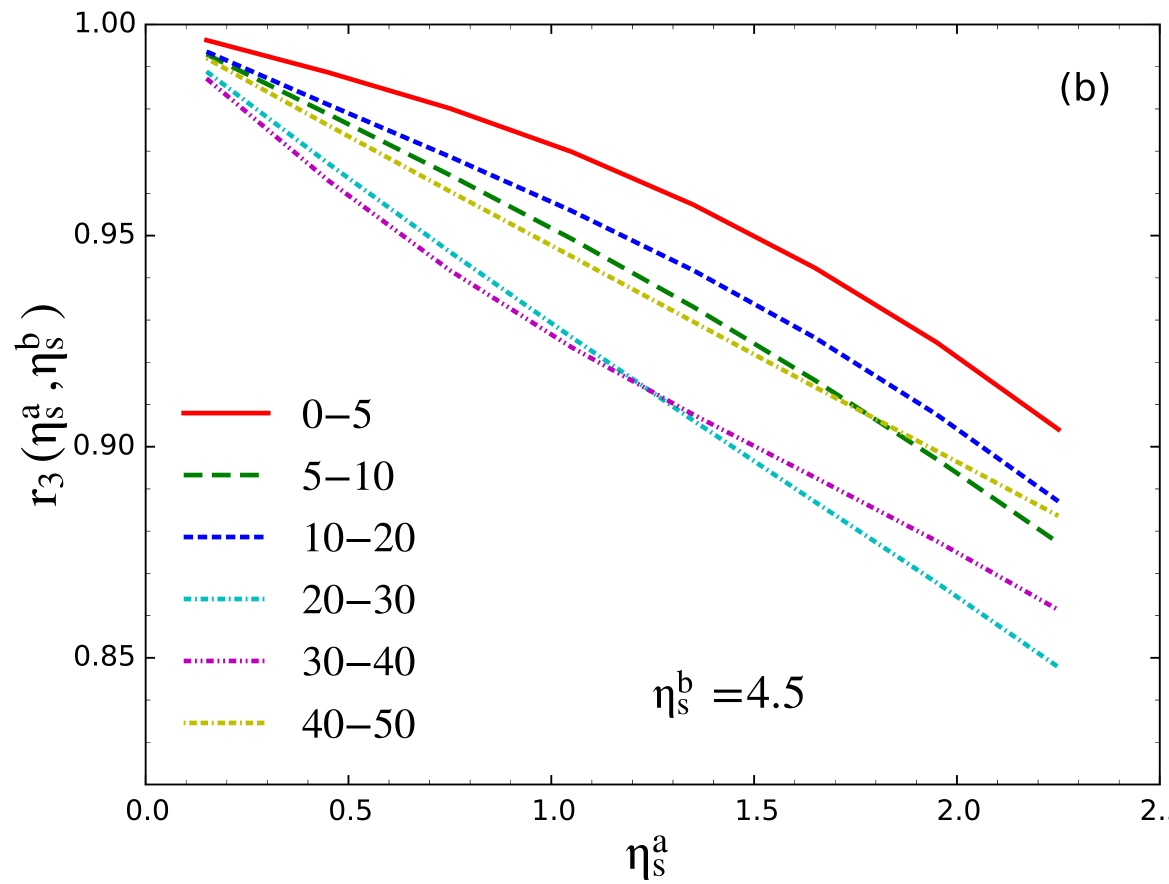


- The participant plane and spatial eccentricity fluctuates along longitudinal direction
- Long string + Short string + mini-jets
- Spatial rapidity $\eta_s = \frac{1}{2} \ln \frac{t+z}{t-z}$
- η_s dependent eccentricity vectors

$$\epsilon_n(\eta_s) = \epsilon_n \exp(i\Psi_n) = \frac{\int d\mathbf{r}_\perp{}^2 \varepsilon(r, \phi, \eta_s) e^{in\phi} r^n}{\int d\mathbf{r}_\perp{}^2 \varepsilon(r, \phi, \eta_s) r^n}$$

De-correlation of eccentricity in the initial state

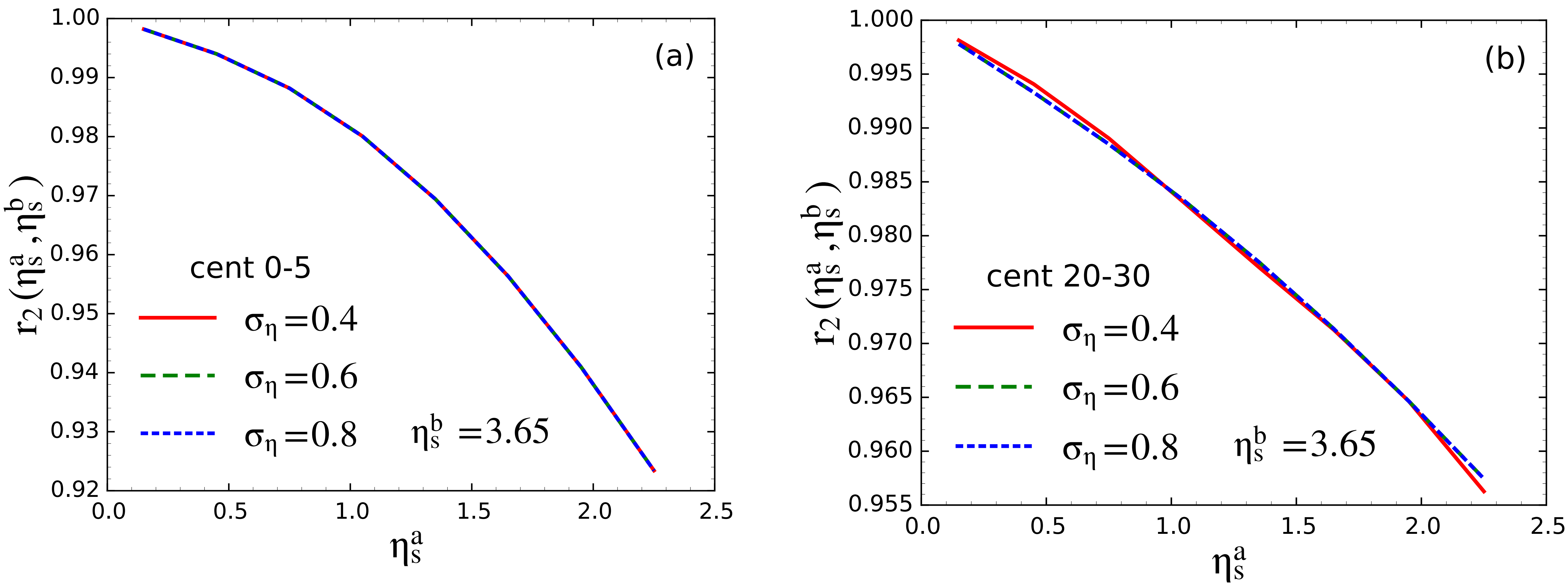




$$r_n(\eta_s^a, \eta_s^b) = \frac{\left\langle \epsilon_n(-\eta_s^a)\epsilon_n^*(\eta_s^b) \right\rangle}{\langle \epsilon_n(\eta_s^a)\epsilon_n^*(\eta_s^b) \rangle}$$

- Fluctuations in coordinate space generates de-correlation of eccentricity at initial state
- Fluid expansion converts it to de-correlation of anisotropic flow in momentum space

Not Sensitive to Gaussian smearing parameter



- Not sensitive to Gaussian smearing along longitudinal direction

- Reason: (1) partons are dense along eta, (2) short range correlation is removed by definition.