Decorrelation of anisotropic flows along longitudinal direction

LongGang Pang from FIAS,
with Hannah Petersen, XinNian Wang, GuangYou Qin and Victor Roy

July 16, 2015

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

HELMHOLTZ ASSOCIATION

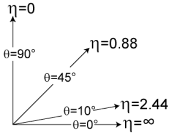
HIC for FAIR Helmholtz International Center

Outline

Definition of longitudinal fluctuations

Longitudinal

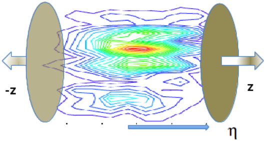
- Spatial rapidity $\eta_s = \frac{1}{2}\ln\frac{t+z}{t-z}$ at initial state
- Pseudo rapidity $\eta = \frac{1}{2}\ln\frac{E+Pz}{E-Pz}$ at final state.



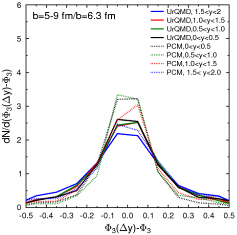
Longitudinal fluctuations

- Energy density(fluid velocity) fluctuations along η_s
- Multiplicity (flow anisotropy + event plane) fluctuations along η

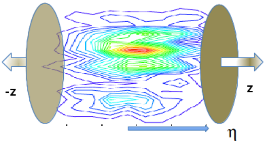
Historical study of longitudinal fluctuations



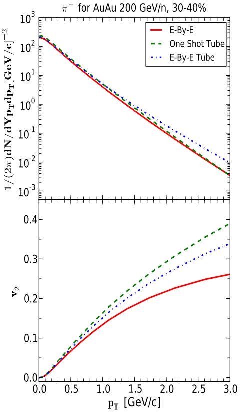
Petersen, Hannah et al.
PRC84 (2011) 054908



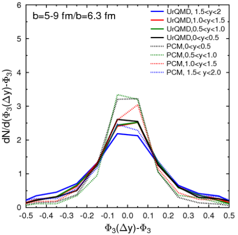
Historical study of longitudinal fluctuations



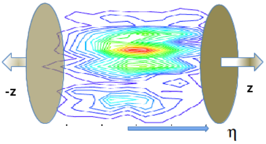
LongGang, Pang et al.
PRC86 (2012) 024911



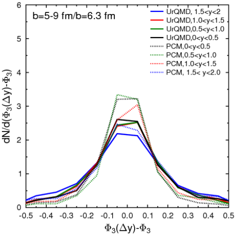
Petersen, Hannah et al.
PRC84 (2011) 054908



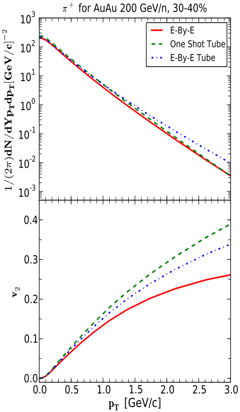
Historical study of longitudinal fluctuations



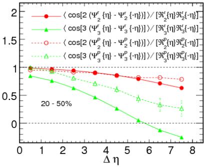
Petersen, Hannah et al. PRC84 (2011) 054908

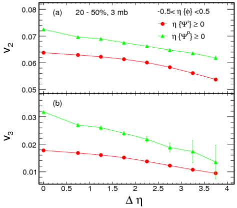


LongGang, Pang et al. PRC86 (2012) 024911



Xiao, Kai et al. PRC87 (2013) 1, 011901



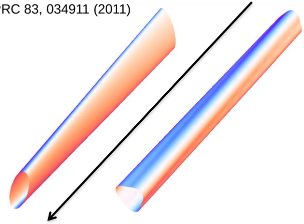


Twist as one kind of longitudinal fluctuations

Twist of Event planes

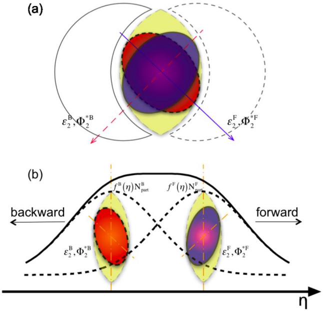
Hydrodynamics , torqued fireball

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



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

Transport



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

Decorrelations with big $\Delta\eta$ gap

Bozek Piotr's method

$$\cos(k\Delta_{FB})2 = \frac{< \exp\left(ik(\phi_F - \phi_B)\right) >}{\sqrt{< \exp\left(ik(\phi_{F1} - \phi_{F2})\right) >< \exp\left(ik(\phi_{B1} - \phi_{B2})\right) >}} \quad (1)$$

Kai Xiao's method

$$r_n(\Delta\eta = 2\eta_a) =< \cos\left(\Psi_n(-\eta_a) - \Psi_n(\eta_a)\right) > /(R_n(\eta_a)R_n(-\eta_a)) \quad (2)$$

- R_n is the resolution factor to remove the effect of finite multiplicity.

Our method based on Qn vector (LongGang, Pang et.al PRC91 (2015)4, 044904)

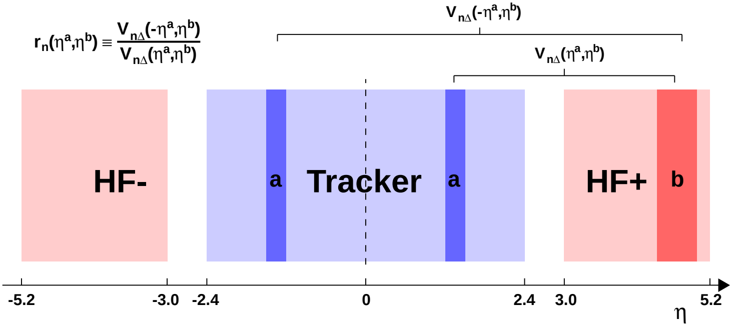
$$\mathbf{Q}_n = \frac{1}{N}\sum_{j=1}^{N} \exp(in\phi_j) = V_n \exp\left(in\Psi_n\right) \quad (3)$$

where $\phi_j = \arctan(p_y/p_x)$.

$$r_n(\Delta\eta = 2\eta_a) = \frac{< \mathbf{Q}_n(\eta_a)\mathbf{Q}_n^*(-\eta_a) >}{\sqrt{< \mathbf{Q}_n^2(\eta_a) >< \mathbf{Q}_n^2(-\eta_a) >}} \quad (4)$$

- This method captures both anisotropic fluctuations and event plane angle fluctuations.

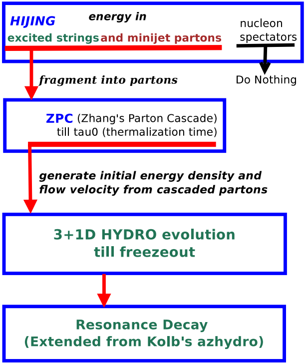
CMS methods (Wei, Li et. al arXiv:1503.01692)



$$r_n(\Delta\eta) = \frac{< \mathbf{Q}_n(-\eta_a)\mathbf{Q}_n^*(\eta_b) >}{< \mathbf{Q}_n(\eta_a)\mathbf{Q}_n^*(\eta_b) >} \quad (5)$$

- If η_b is far away from η_a, no short range correlation.

Model: Hydro with AMPT(A Multiple-Phase Transportation) initial condition

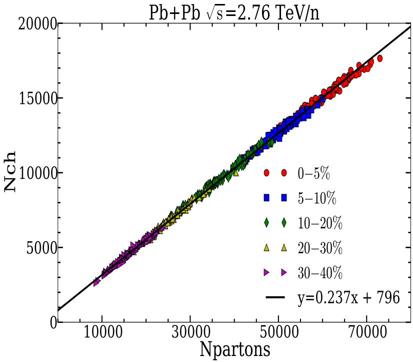


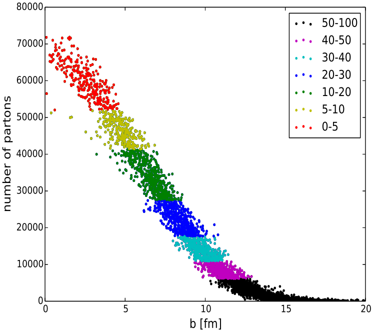
- Number of strings = Number of participants (Lund string model)
- Number of mini-jets per binary collision = Poisson distribution with mean given by mini-jet cross section (depends on PDF with shadowing, Pythia).
- Number of participants and binary collisions from MC Glauber model

3+1D hydrodynamic model

- Effects of initial flow velocity fluctuation in event-by-event (3+1)D hydrodynamics. PRC86 (2012) 024911
- Analytical and numerical Gubser solutions of the second-order hydrodynamics (PRD91 (2015)7, 074027

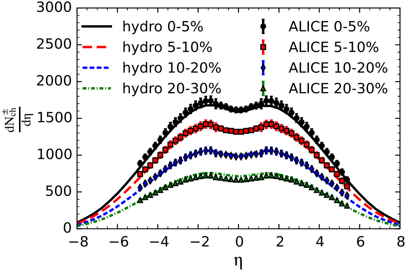
Centrality classes

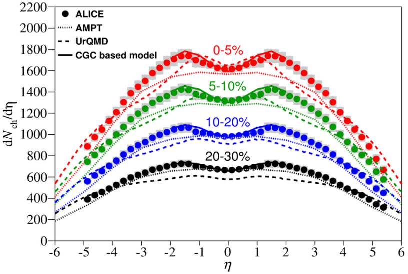




- $N_{charge} \propto N_{partons}$.
- Use number of initial partons to determine the centrality classes in Pb+Pb collisions.

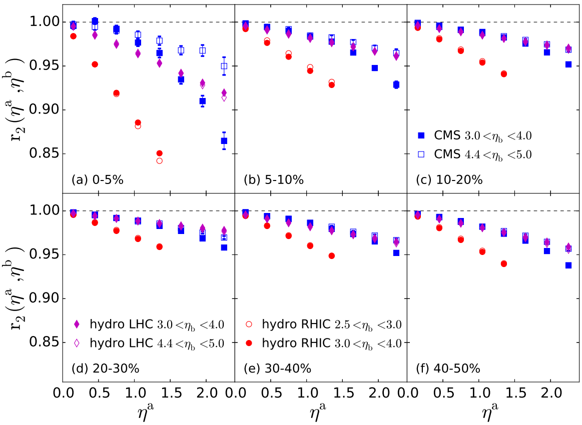
Multiplicity distribution along η





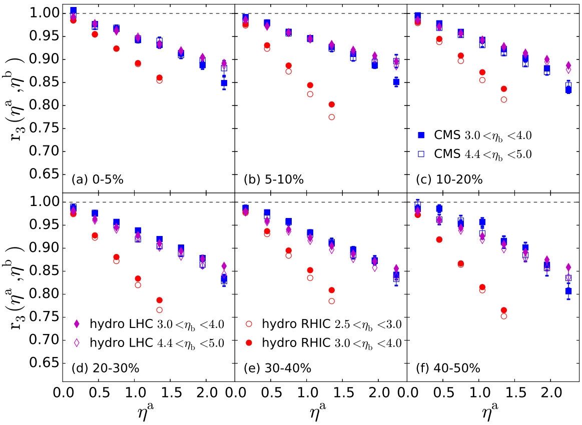
- Event-by-event hydro with AMPT initial condition can describe Multiplicity distribution along η.

Results (n=2), 200 events for each centrality



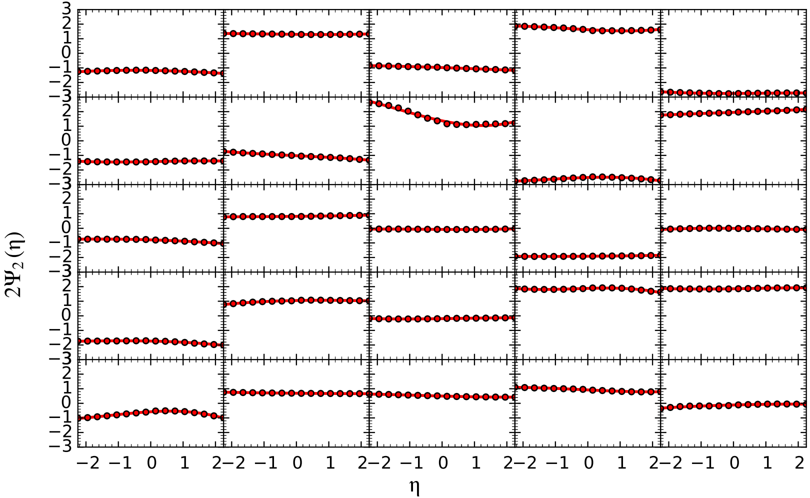
- No splitting in event-by-event hydro
- Non-linear shape for $0 - 5\%$.

Results (n=3), 200 events for each centrality



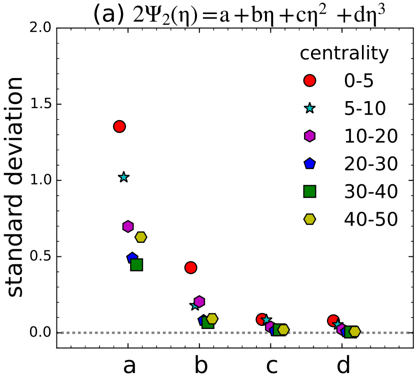
- Very weak centrality dependence (non trivial).

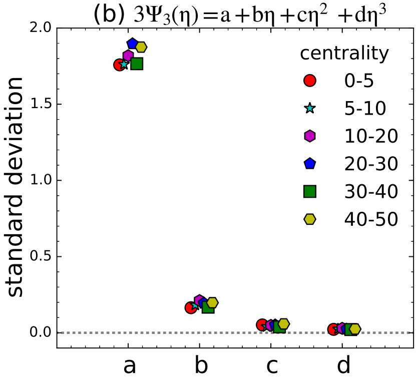
Twist or pure fluctuations



- twist of event plane angles means: monotonic behavior of $\Psi_n(\eta)$
- $\Psi_n(\eta)$ can be: linear twist, non-linear twist, pure fluctuations

Twist or pure fluctuations of event plane angles





- Standard deviation for non-linear coefficients is small for $\Psi_3(\eta)$.
- Standard deviation for non-linear coefficients is big for $\Psi_2(\eta)$ in most central collisions.

Definition of longitudinal decorrelation in initial conditions

Eccentricity in coordinate space

$$\epsilon_n(\eta_s) = \epsilon_n \exp(i\Psi_n) = \frac{\int_0^{r_{max}}\int_0^{2\pi} r^n \varepsilon(r,\phi,\eta_s) e^{in\phi} r dr d\phi}{\int_0^{r_{max}}\int_0^{2\pi} r^n \varepsilon(r,\phi,\eta_s) r dr d\phi}$$

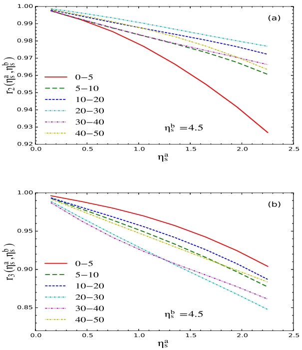
where r is the transverse distance from the mass center.

Decorrelation along η_s

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

Decorrelation at initial state

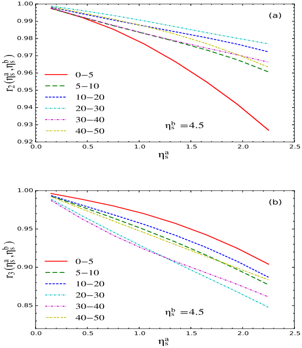
Initial state decorrelation



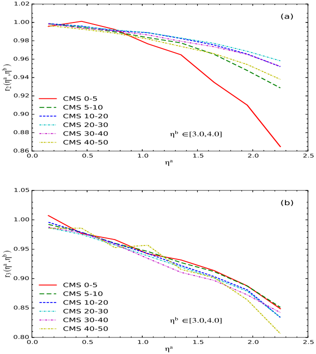
- Good centrality dependence for r_2 from initial state decorrelation.
- Hydro evolution is important for (3rd order).
- Not apple to apple comparison.

Decorrelation at initial state

Initial state decorrelation

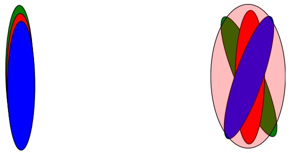


Final state decorrelation(CMS)



- Good centrality dependence for r_2 from initial state decorrelation.
- Hydro evolution is important for (3rd order).
- Not apple to apple comparison.

Use twist as an example



v_n is suppressed in present of longitudinal fluctuations or twist

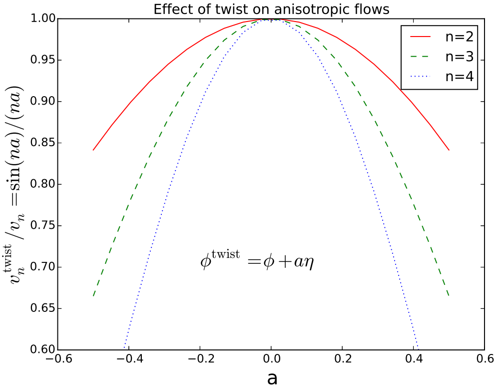
$$E\frac{d^3N}{d\vec{p}^3} = \frac{1}{2\pi}\frac{d^2N}{dY p_T dp_T d\phi}\left(1+2\sum_1^\infty v_n\cos(n\phi(Y))\right) \tag{6}$$

$$v_n^{\mathrm{twist}} = \frac{1}{2}\frac{\int_{-1}^{1}dY\int_{-\pi}^{\pi}d\phi\cos(n\phi)E\frac{d^3N}{d\vec{p}^3}}{\int_{-1}^{1}dY\int_{-\pi}^{\pi}d\phi E\frac{d^3N}{d\vec{p}^3}} \tag{7}$$

$$= v_n\frac{\sin(na)}{na} \tag{8}$$

where linear twist of event plane angles $\phi(Y)=\phi+aY$ is assumed, and Ψ_{RP} is set to 0 for simplicity.

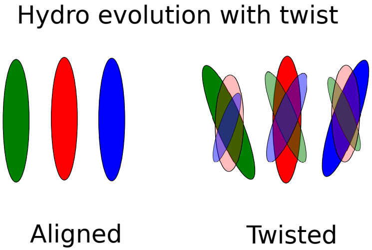
The suppression of anisotropic flows from twist



- Bigger a for $\Psi_2(\eta)$ than $\Psi_3(\eta)$ may explain why $v_3 > v_2$ in most central collisions.
- From page 14, $a \approx 0.22$ for 2nd order and $a \approx 0.07$ for 3rd order.
- $v_2^{twist}/v_2 \approx 0.968$ and $v_3^{twist}/v_3 \approx 0.99$.

Effect of longitudinal fluctuations and decorrelations

Effect of hydrodynamic expansion



- No fluctuation: the eccentricity at each slice is not affected by hydro expansion.
- With longitudinal fluctuation: the eccentricity at each rapidity slice is reduced by hydro expansion along longitudinal direction.

Conclusion

- Very good agreement between event-by-event hydro and CMS measurements
- The decorrelation in momentum space comes from fluctuations in coordinate space.
- Hydro evolution is important to transfer initial state decorrelations to final state.
- The suppression of anistropic flows from twist equals to $\sin(na)/(na)$.
- Bigger v_3 than v_2 in most central collisions may come from longitudinal fluctuations or (twist).

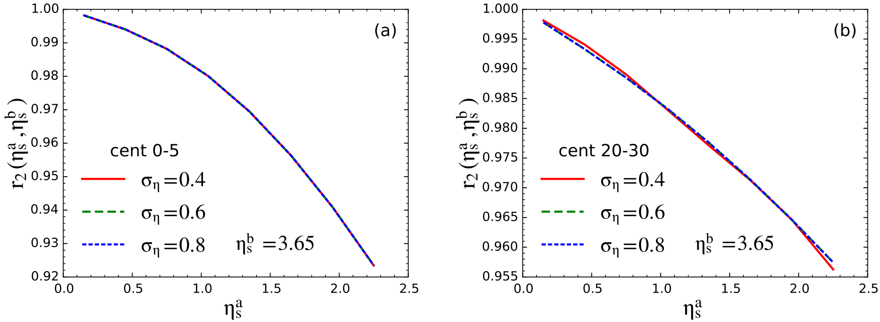
Conclusion

- Very good agreement between event-by-event hydro and CMS measurements
- The decorrelation in momentum space comes from fluctuations in coordinate space.
- Hydro evolution is important to transfer initial state decorrelations to final state.
- The suppression of anistropic flows from twist equals to $\sin(na)/(na)$.
- Bigger v_3 than v_2 in most central collisions may come from longitudinal fluctuations or (twist).

Outlook

- Hydro evolution increases long range correlation.
- The sensitivity of r_2 and r_3 to different strings

Effect of Gaussian smearing



Model: 3+1D hydrodynamics on GPU

- Smearing on GPU to get initial conditions 10s vs 2-3 minutes
- Hydro evolution on GPU to get bulk information 50s vs 1 hour
- Freeze out hyper-surface finding on CPU 1s
- Smooth spectral calculations on GPU 2.5m on K20 vs 6-8 hours
- Resonance decay on GPU 2m on K20 vs 30-40 miniutes