Longitudinal Fluctuation And Di-hadron Correlation In Event-by-event 3+1D Hydrodynamics

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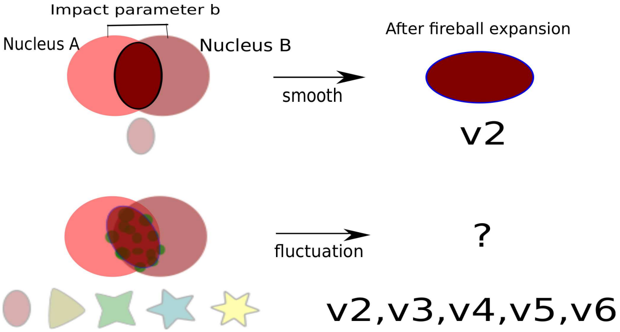
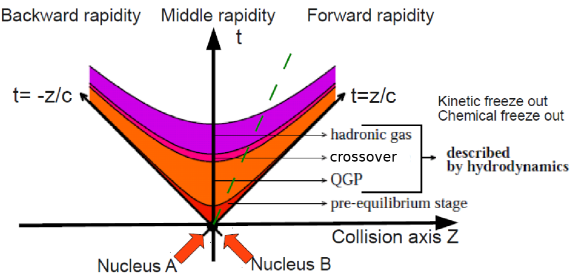
Nov. 22nd, 2013 @ YITP

Outline for section 1



$$\frac{dN}{dY p_T dp_T d\phi} = N_0(1 + 2\sum_{i=1}^{\infty} v_n \cos(n(\phi - \Psi_n))) \tag{1}$$

E-by-E hydro with fluc. initial conditions tells us more!



Milne coordinate

- Proper time: $\tau = \sqrt{t^2 - z^2}$
- Spatial rapidity: $\eta_s = \frac{1}{2} \ln \frac{t+z}{t-z}$
- The metric: $g^{\mu\nu} = diag(1, -1, -1, -\tau^2)$
- Momentum rapidity: $Y = \frac{1}{2} \ln \frac{E+Pz}{E-Pz}$,
- Pseudo-rapidity: $\eta = \frac{1}{2} \ln \frac{P+Pz}{P-Pz}$.

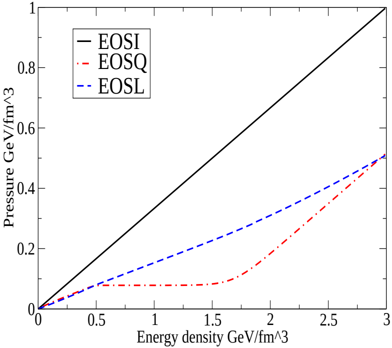
Hydrodynamic Equations

$$\nabla_\mu T^{\mu\nu} = 0 \tag{2}$$
$$\nabla_\mu J^{\mu} = 0 \tag{3}$$

- Energy momentum tensor: $T^{\mu\nu} = (\varepsilon + P)u^\mu u^\nu - Pg^{\mu\nu} + X^{\mu\nu}$
- Net baryon current: $J^\mu = nu^\mu$
- u^μ: four velocity which obeys $u_\mu u^\mu = 1$.

For ideal hydro

- $X^{\mu\nu} = 0$
- 6 variables: ε, P, n, v_x, v_y, v_η; 5 equations
- Equation of state (EOS) $P = P(\varepsilon, n)$ is needed.



- EOSI: Massless ideal partons gas $p = e/3$.
- EOSQ: First order phase transition between QGP and HRG
- EOSL: Smoothed crossover between lattice QCD Eos and HRG
- EOSL parameterized in Nucl.Phys. A837 (2010) 26-53 is used in this talk.

s95p-v1 By Pasi Huovinen and Peter Petreczky

QCD in hydrodynamic simulations

EOS

$$P = \frac{\partial(T \ln Z)}{\partial V} \tag{4}$$

$$\ln Z^{QCD} = \ln \int dU d\Psi d\bar{\Psi} e^{-S_E(U,\Psi,\bar{\Psi})} \tag{5}$$

$$\ln Z^{RHG} = \sum_{i \in Mesons} \ln Z^M_{mi}(T, V, \mu) \tag{6}$$

$$+ \sum_{i \in Baryons} \ln Z^B_{mi}(T, V, \mu) \tag{7}$$

- where U is gauge filed, Ψ and $\bar{\Psi}$ are fermionic field. $S_E = S_g + S_f$.
- and $\ln Z^{M/B}_{mi} = \mp \frac{V g_i}{2\pi^2} \int_0^\infty dk k^2 \ln(1 \mp z_i e^{-\varepsilon_i/T})$.

QCD in hydrodynamic simulations

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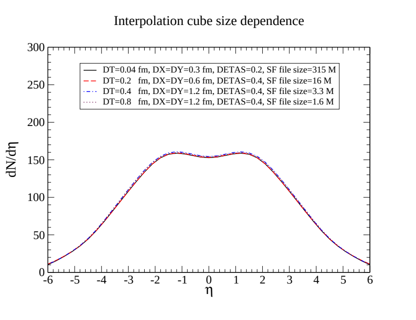
Others

- Ini: CGC, IP-Glasma, EPOS, HIJING+ZPC

Speed up spectra calc.

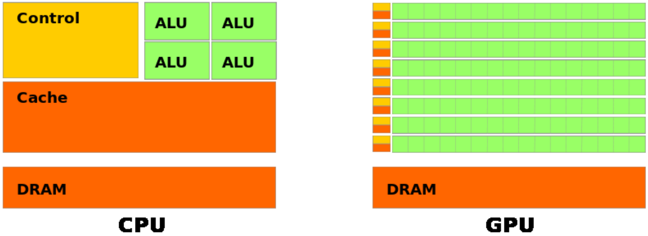
$$\frac{dN}{dY p_T dp_T d\phi} = \frac{g_s}{(2\pi)^3} \int_\Sigma p^\mu d\Sigma_\mu \frac{1}{\exp((p \cdot u - \mu)/T_{FO}) \pm 1} \tag{8}$$

Reduce the filesize of freeze out hyper surface



Spectra calc. and resonance decay take 2-3 times longer than hydro evolution even with smaller SF data file.

Further speed up by GPU parallel computing (developing)



Perfect job for GPU

- Up to 200, 000 small pieces of freeze out hyper surface.
- More than 100 resonance particles.
- At least 100 events for fluctuating initial conditions.

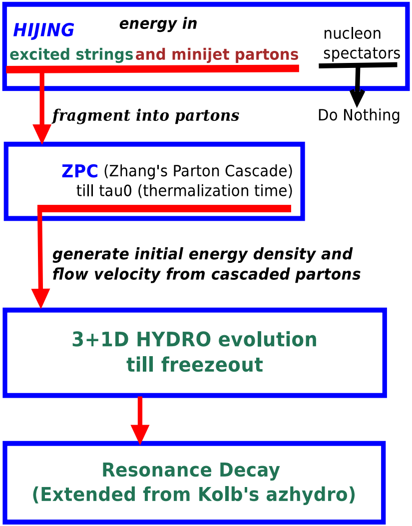
Simple test on my own laptop:
π^+ spectra for Pb+Pb 2.76TeV/n, 20-25%

CPU—i5-430M: 7 minutes .VS. GPU—GT-240M: 30 seconds

10 times faster on my laptop with 48 cuda cores!

Recent NVIDIA K20 GPU has 2496 Cuda Cores.

Fluctuating initial conditions by AMPT



Comparing to usual MC Glauber

HIJING + ZPC

Glauber Geometry + PYTHIA for PP + Shadowing + Parton cascade

Comparison

	MC Glauber	HIJING+ZPC
Glauber Geometry	yes	yes
Transverse Fluc	yes	yes
Longitudinal Fluc	no	yes
Ini flow velocity	no	yes
Sub-nucleon, QCD	no	yes
Intrinsic corr.	no	yes

The initial condition from cascaded partons

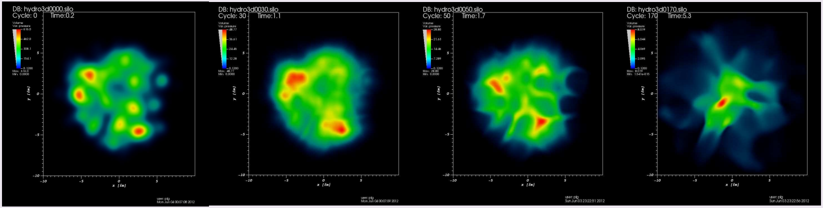
$$T_0^{\mu\nu} = K \sum_i \frac{p_i^\mu p_i^\nu}{p_i^\tau} f \quad (9)$$

$$f = \frac{1}{\tau_0 \sqrt{2\pi\sigma_{\eta_s}^2} 2\pi\sigma_r^2} \exp(-\frac{(x-x_i)^2 + (y-y_i)^2}{2\sigma_r^2} - \frac{(\eta_s - \eta_{si})^2}{2\sigma_{\eta_s}^2}) \quad (10)$$

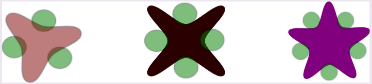
- We assumed local thermalization and solve e and u^μ from $T^{\mu\nu}$.
- K and τ_0 are got from fitting the multiplicity of charged hadrons for central collisions.
- $K = 1.45$ and $\tau_0 = 0.4$ fm for $\sqrt{s} = 200$ GeV/n Au+Au collisions.
- $K = 1.6$ and $\tau_0 = 0.2$ fm for $\sqrt{s} = 2.76$ TeV/n Pb+Pb collisions.
- $\sigma_r = 0.6$ fm, $\sigma_{\eta_s} = 0.6$.
- Longitudinal fluctuation and initial flow velocity are introduced from cascaded partons.

Hydrodynamic evolution for AMPT initial condition

Transverse plane

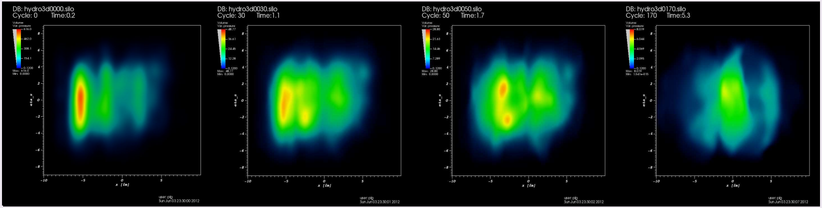


The hot spikes squeezed out by hot spots may play an import role in understanding v_n.

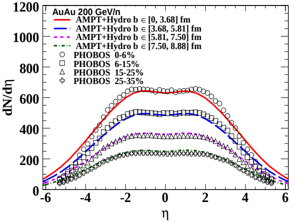


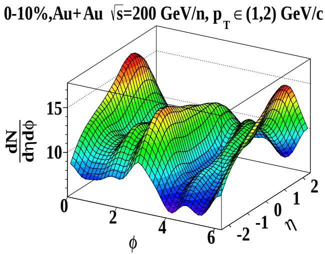
Hydrodynamic evolution for AMPT initial condition

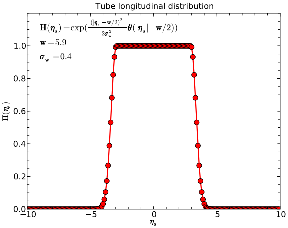
Reaction plane

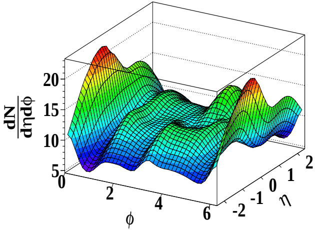


Outline for section 2





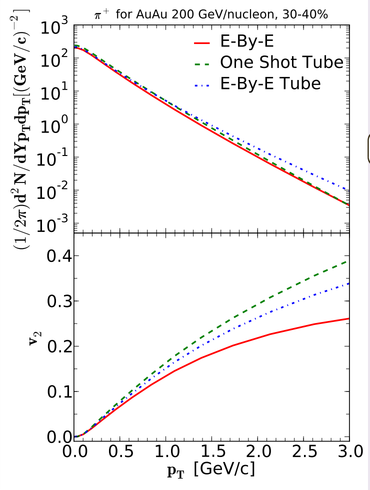


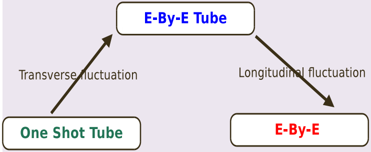


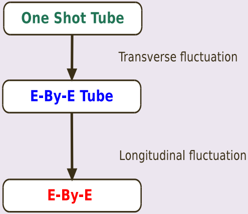
- Usually a tube-like dist. in initial condition is used to get Bjorken scaling.

Effects of Longitudinal fluctuations on p_T spectra and v_2

Phys.Rev. C86 (2012) 024911 by LongGang Pang, Qun Wang and XinNian Wang

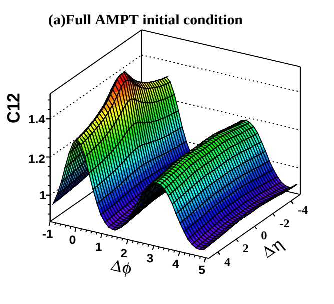


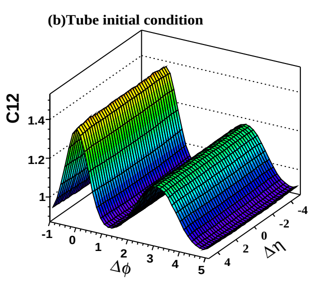




Longitudinal fluctuations on di-hadron correlation

AuAu 200 GeV/n Centrality $30-40\%$, $2\ \mathrm{GeV/c} \le p_t^{trig}, p_t^{assoc} \le 3\ \mathrm{GeV/c}$.

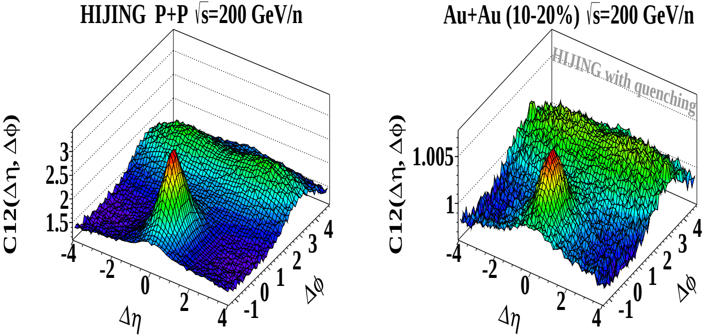




- Without longitudinal fluctuation, di-hadron correlation is constant along rapidity direction
- We want to study the di-hadron correlation more quantitively.

Outline for section 3

Two dimensional dihadron correlation from HIJING



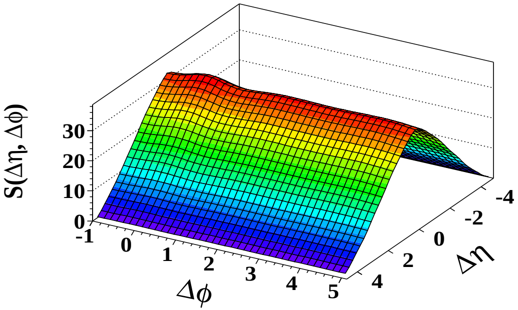
- Intrinsic correlation in P+P: near side peak + away side ridge.
- A+A is a superposition of P+P due to absent of final state interaction in HIJING.
- No near side ridge in P+P and A+A in HIJING.

Di-hadron correlation and per-trigger particle yield in hydro

Formula

$$C12(\Delta\eta, \Delta\phi) = S(\Delta\eta, \Delta\phi)/B(\Delta\eta, \Delta\phi) \quad (11)$$

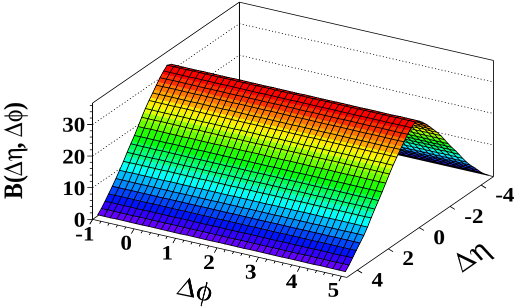
$$S(\Delta\eta, \Delta\phi) = \frac{1}{N_{trig}} \frac{d^2 N^{same}}{d\Delta\eta d\Delta\phi} \quad (12)$$



Formula

$$C12(\Delta\eta, \Delta\phi) = S(\Delta\eta, \Delta\phi)/B(\Delta\eta, \Delta\phi) \quad (11)$$

$$B(\Delta\eta, \Delta\phi) = \frac{1}{N_{trig}} \frac{d^2 N^{mixd}}{d\Delta\eta d\Delta\phi} \quad (12)$$

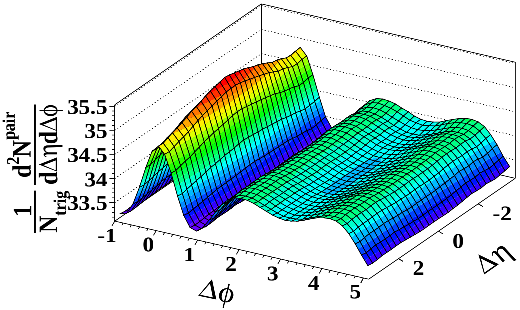


Di-hadron correlation and per-trigger particle yield in hydro

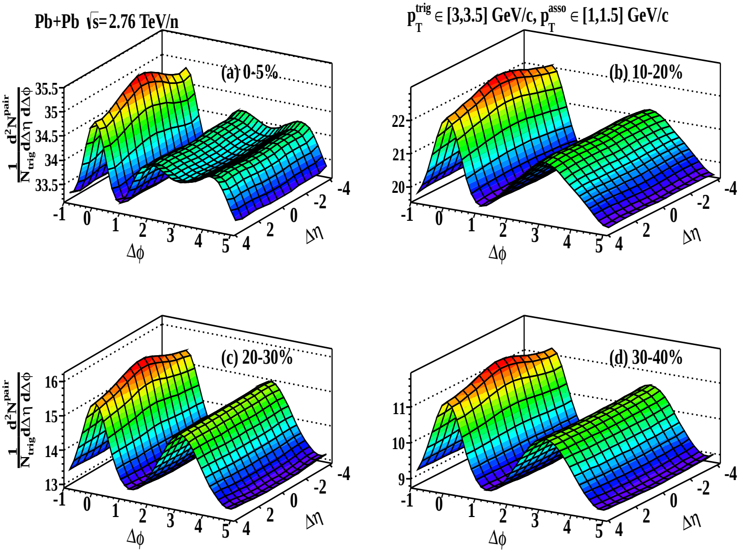
Formula

$$C12(\Delta\eta, \Delta\phi) = S(\Delta\eta, \Delta\phi)/B(\Delta\eta, \Delta\phi) \quad (11)$$

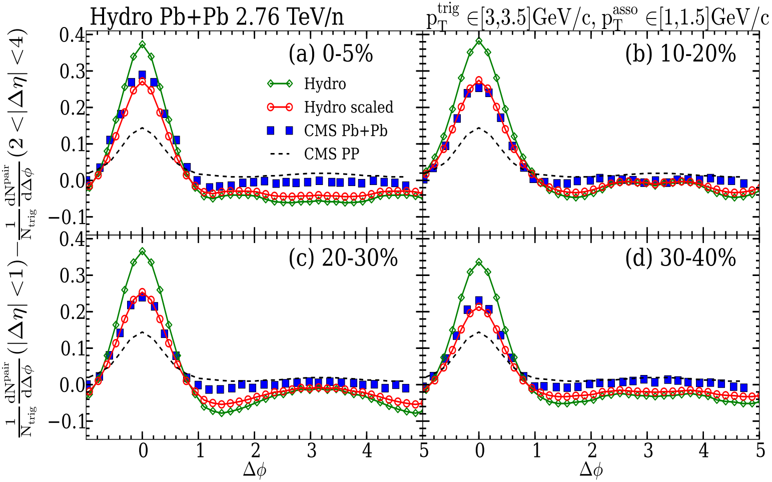
$$\frac{1}{N_{trig}} \frac{d^2 N^{pair}}{d\Delta\eta d\Delta\phi} = \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)} \times B(0,0) \quad (12)$$



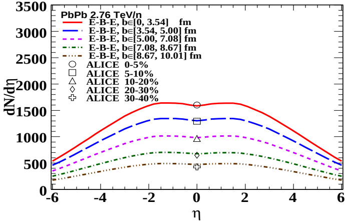
Two dimensional per-trigger particle yield from hydro

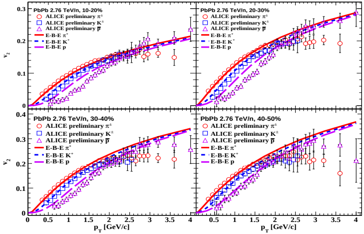


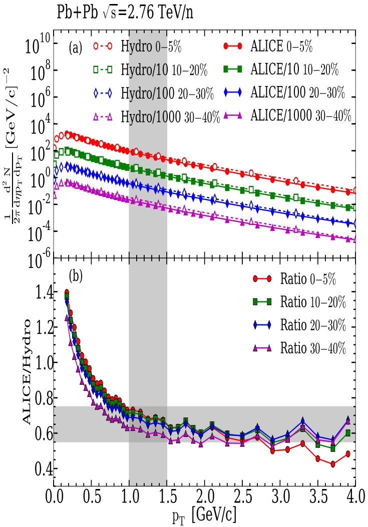
Per-trigger particle yield (subtract long range contribution)



- Flow at near side, flow and back-to-back jet at away side are subtracted.
- The scale factor is defined as $N_{ALICE}^{asso}/N_{Hydro}^{asso}$ for each centrality.
- Collectivity makes Per-trigger particle yield bigger for central collisions.







- Phys.Rev. C86 (2012) 024911 by LongGang Pang, Qun Wang and XinNian Wang
- arXiv:1309.6735 by LongGang Pang, Qun Wang and XinNian Wang

Long range correlation and v_n in AMPT+3DHydro model

For Di-hadron correlation from AMPT+3DHydro

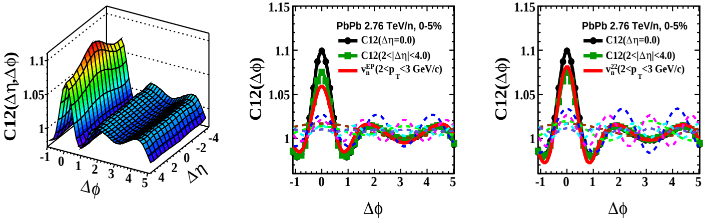
$$C12(\Delta\phi) = \frac{1}{\Delta\eta_{max} - \Delta\eta_{min}} \int_{\Delta\eta_{min}}^{\Delta\eta_{max}} C12(\Delta\eta, \Delta\phi) d\Delta\eta \qquad (13)$$

For vn-decomposition from AMPT+3DHydro

$$C12^{EP}(\Delta\phi) = b_1 \cos(\Delta\phi) + b_2(1.0 + v_{n,t}^{EP} v_{n,a}^{EP} \cos(n\Delta\phi)) \qquad (14)$$

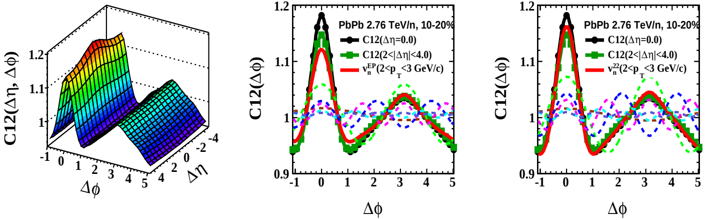
$$C12^{22}(\Delta\phi) = b_1 \cos(\Delta\phi) + b_2(1.0 + v_{n,t}^{22} v_{n,a}^{22} \cos(n\Delta\phi)) \qquad (15)$$

where $v_n^{22} = \sqrt{< v_n^{EP} * v_n^{EP} >}$.

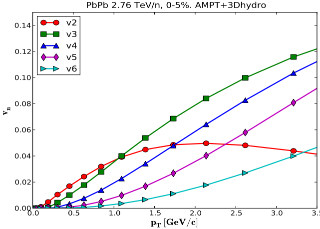


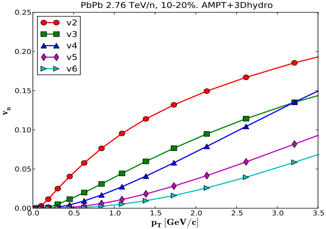
- Di-hadron correlation at large $\Delta\eta$ can be decomposed in v_n^{22}.
- Since initial flow and LF is introduced in AMPT initial condition, short range correlation can't be decomposed in v_n.

C12 for $Pb+Pb\sqrt{s}=2.76TeV/n$, (10-20%), $p_T^{trig}, p_T^{asso} \in [2,3]GeV/c$



- For different centralities, the weight of harmonic flow at a special p_T range will be different, so as the away side dihadron correlation structure.





- For $0-5\%$, v_3 and v_4 are larger than v_2 at $[2,3]$ GeV/c in our model, which caused the two bumps at away side correlation.
- For $10-20\%$, v_2 is larger, the away side structure has a strong centrality and p_T cut dependence.

- Hijing and ZPC describes the pre-equilibrium dynamics
  - Longitudinal fluctuation, Initial flow, Intrinsic correlation
- Longitudinal fluctuation suppress elliptic flow.
- Longitudinal fluctuation + intrinsic correlation describes di-hadron correlation.
- Long range correlation can be decomposited by v_n^{22}.

Thanks!