Sources of elliptic flow fluctuations in transport model

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Outline

- **Motivation**
- **Results and discussions**

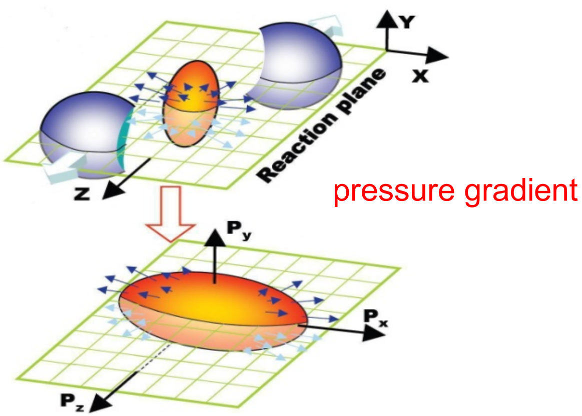
  1. η dependence of event-plane

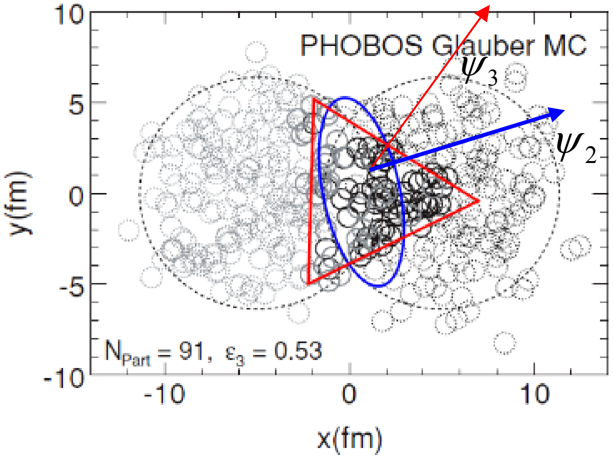
  2. sources of elliptic flow fluctuations

  K. Xiao, F. Liu, and F. Wang, PRC 87, 011901(R) (2013);
  K. Xiao, F. Liu, and F. Wang, arXiv:1307.6661v1

- **Summary and outlook**

Motivation





fluctuations → Triangularity ε_3 => Triangular flow v_3

Azimuthal distributions of final state particles:

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}(1 + 2v_1\cos(\phi-\psi_1) + \underbrace{2v_2\cos 2(\phi-\psi_2)}_{\text{elliptic flow}} + \underbrace{2v_3\cos 3(\phi-\psi_3)}_{\text{triangular flow}} + \ldots)$$

- Anisotropic flows are sensitive to the properties of QGP.
- Flow fluctuations are important to extract physics information.

How to measure anisotropic flows

Data: AMPT string melting at 200 GeV Au+Au

azimuthal anisotropy: $v_n = \langle \cos[n(\phi - \psi_n)] \rangle / \Re_n$

- configuration space: $\psi_{\mathrm{n}}^{conf.} = \dfrac{atan(\langle r^n \sin(\mathrm{n}\phi_{part})\rangle, \langle r^n \cos(\mathrm{n}\phi_{part})\rangle) + \pi}{n}$

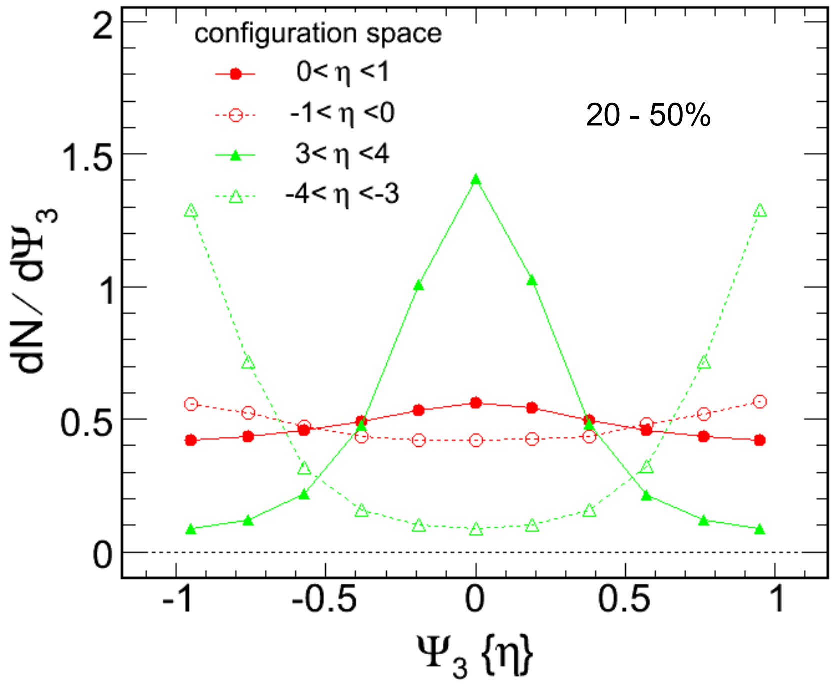
  (participant plane)

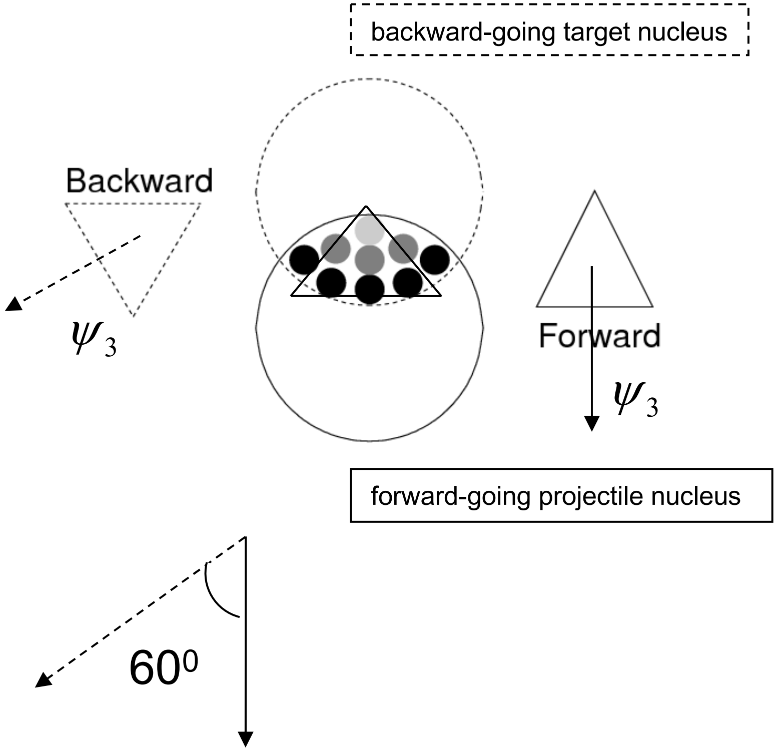
- momentum space: $\psi_{\mathrm{n}}^{mom.} = \dfrac{atan(\langle \sin(n\phi)\rangle, \langle \cos(n\phi)\rangle)}{n}$

- A η gap is often applied to reduce non-flow contributions.
- A assumption: same participant plane for all η regions.

We will test this assumption.

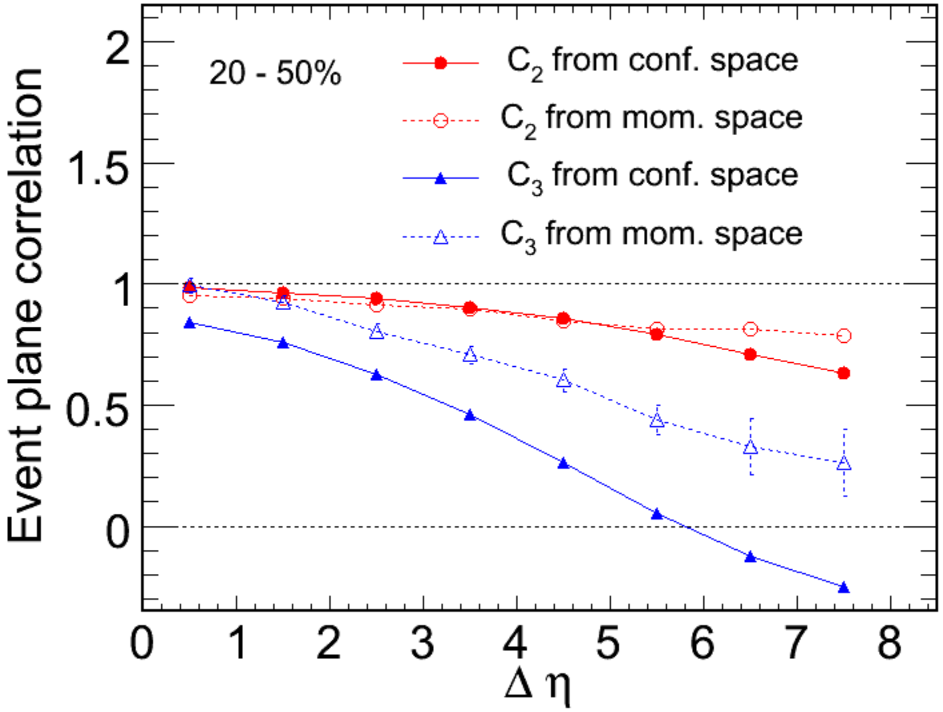
η dependence of event plane





- ψ_3 reconstructed at forward and backward rapidities are anticorrelated.
- This may root in the opposite orientation of the collision geometry triangularities.

Event-plane decorrelation



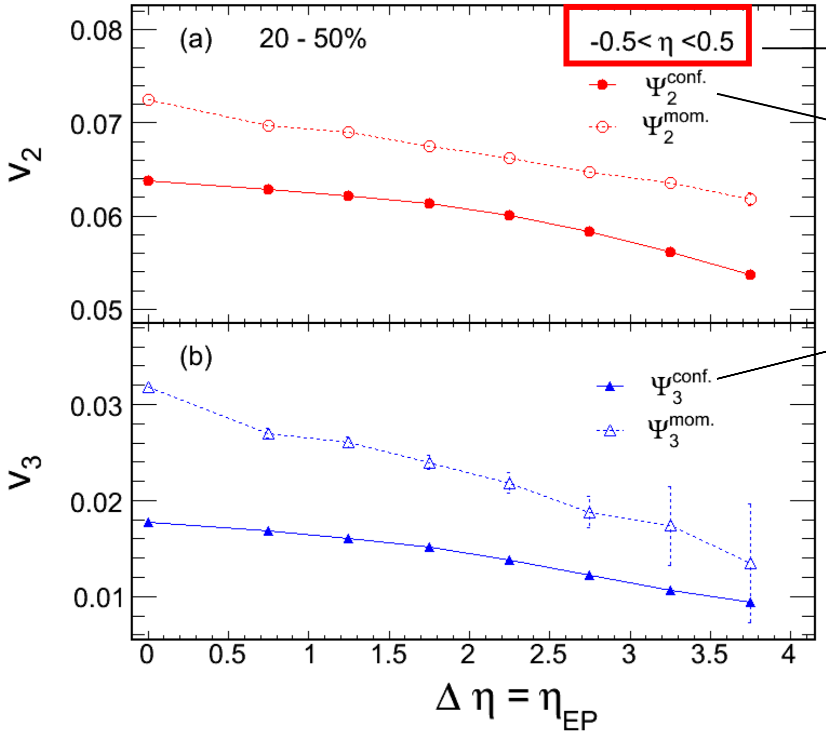
$$C_n = \frac{\langle \cos[n(\psi_n\{\eta\} - \psi_n\{-\eta\})] \rangle}{\Re_n\{\eta\}\Re_n\{-\eta\}}$$

η : 0~0.5, 0.5~1.0,....,3.5~4.0

$\Delta\eta = \eta - (-\eta)$

- ➢ The event planes at forward and backward η are indeed different.
- ➢ The event-plane decorrelation may call into question η gap designed to reduce non-flow.

Event-plane decorrelation effect



particle of interest

event-plane at different η regions:
$-0.5 < \eta_{EP} < 0.5$, $0.5 < \eta_{EP} < 1.0$ ... $3.5 < \eta_{EP} < 4.0$

- **The decrease of v_n with respect to:**

$\psi_n^{conf.}$: event-plane decorrelation effect.
$\psi_n^{mom.}$: reduced non-flow + event-plane decorrelation effect.

- **Difference between v_n with respect to $\psi_n^{conf.}$ and $\psi_n^{mom.}$:**

non-flow + difference between $\psi_n^{conf.}$ **and** $\psi_n^{mom.}$

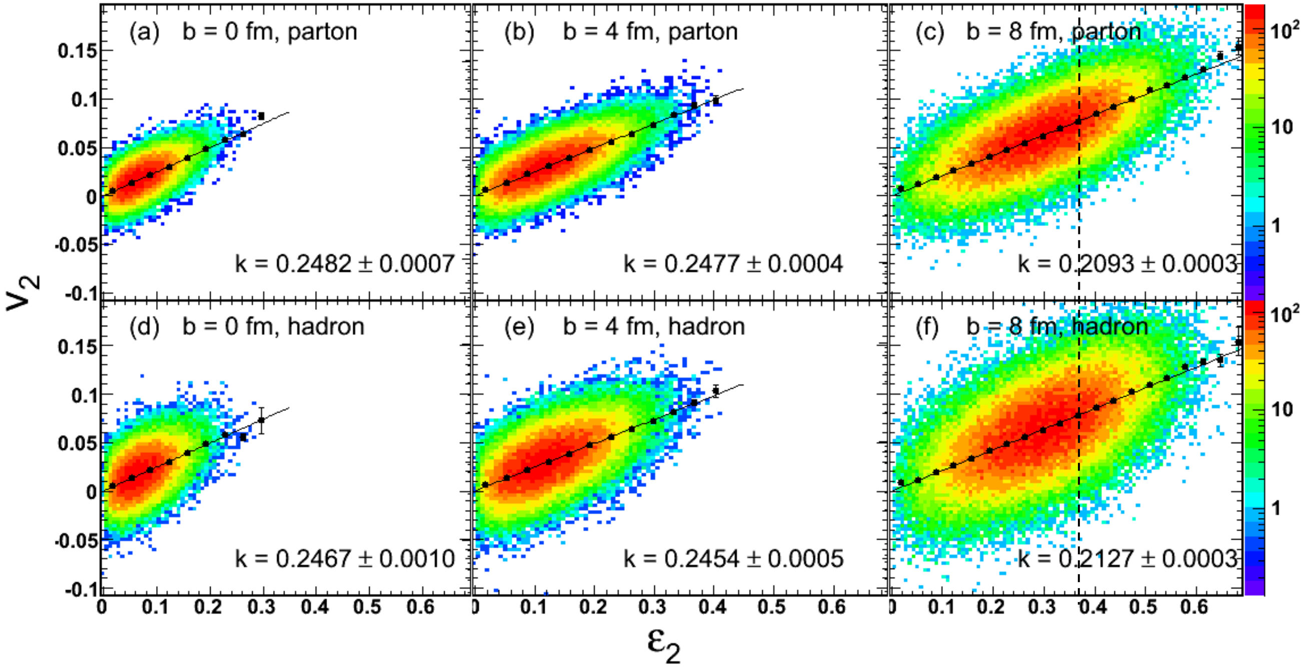
Event-by-event correlations

Elliptic flow fluctuations ⟵ Initial anisotropy (ε_2) fluctuations

B. Alver et al. (PHOBOS Collaboration), Phys. Rev. C 81, 034915 (2010); B. Alver et al. (PHOBOS Collaboration), Phys. Rev. Lett. 104, 142301 (2010).

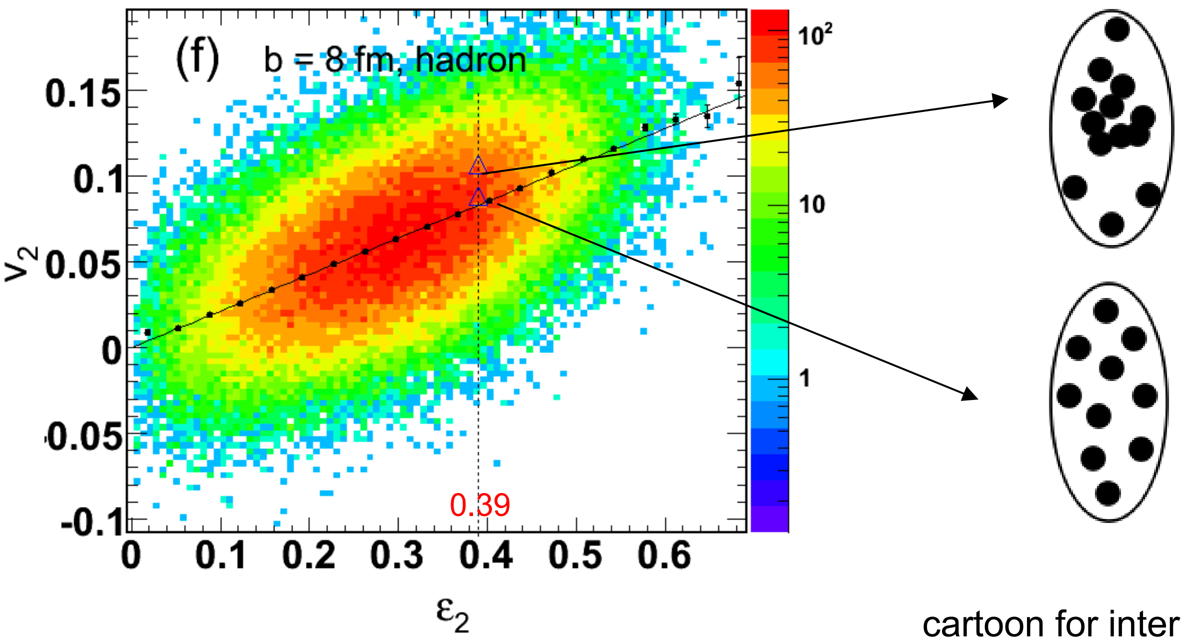
- $\Delta\eta = 0$
- ψ_2 constructed from configuration space

$$\varepsilon_2 = \frac{\sqrt{\langle r^2\cos(2\phi_{part})\rangle^2 + \langle r^2\sin(2\phi_{part})\rangle^2}}{\langle r^2\rangle}$$



- Average $<v_2>$ increases linearly with increasing ε_2.
- For a given ε_2, v_2 fluctuations are not solely due to ε_2 fluctuations.

Configuration fluctuation effect



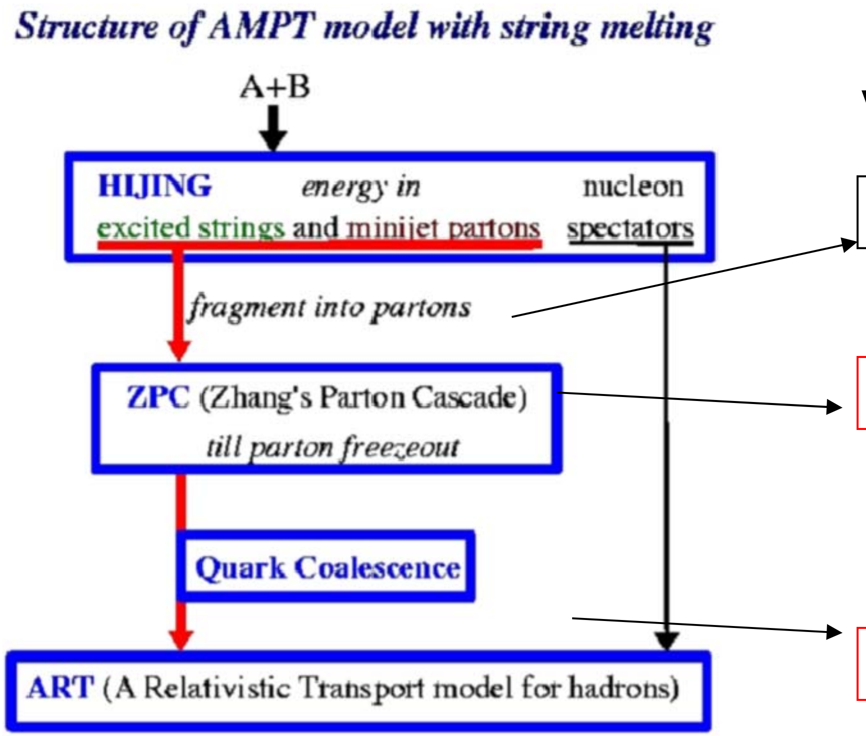
cartoon for interacting participants

two different sets of events

$$\boxed{\varepsilon_2\{\text{set1}\} = \varepsilon_2\{\text{set2}\} = 0.39}$$

- There are differences between the average $\langle v_2 \rangle$.
- v_2 fluctuations are not only due to statistical fluctuations ($\sigma_{v_2}\{sta\}$). Configuration fluctuations are important.

Other fluctuation sources



v_2 fluctuations may be caused by:

initial configuration fluctuations ($\sigma_{v_2}\{cfg\}$)

parton interactions ($\sigma_{v_2}\{par\}$)

hadronization and hadronic scatterings ($\sigma_{v_2}\{had\}$)

v_2 fluctuations vs. ε_2

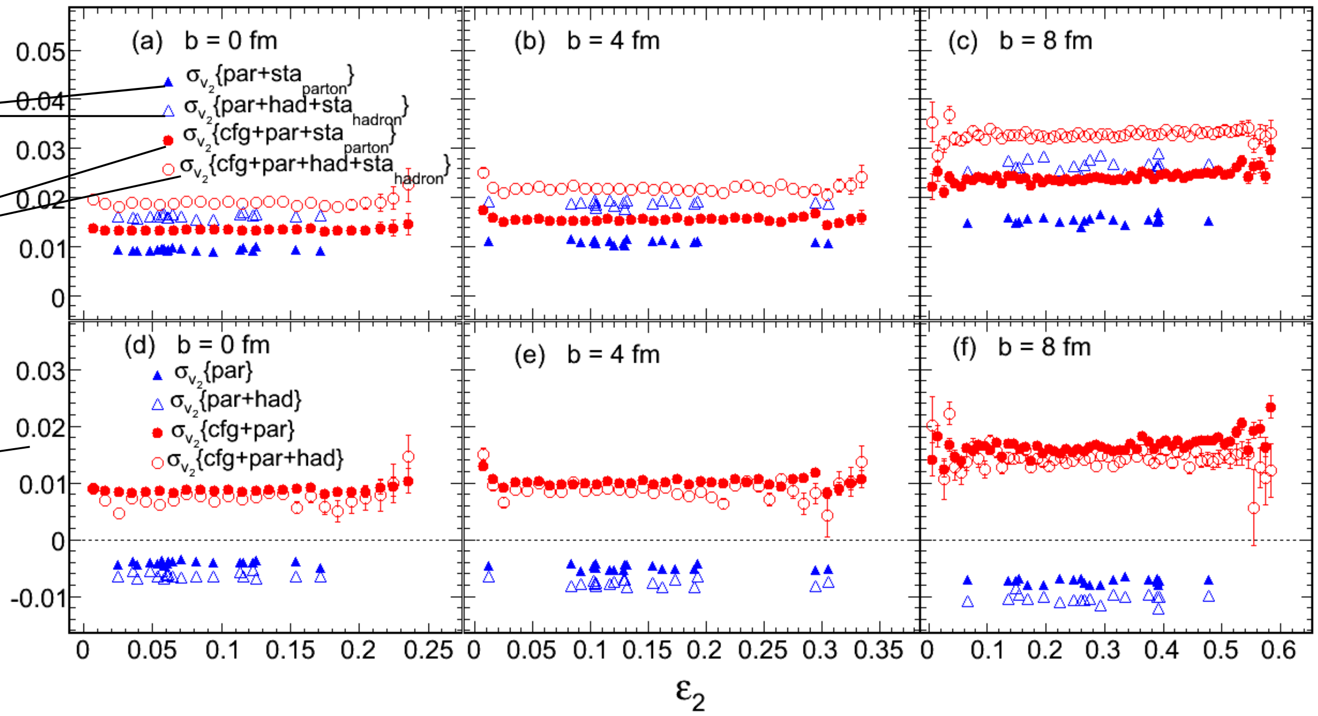
$$\sigma_{v_2} = \sqrt{\langle v_2^2 \rangle - \langle v_2 \rangle^2}$$

identical configuration

default settings

statistical fluc. subtracted

$$\sigma_{v_2}\{sta\} = \sqrt{(1-2\langle v_2 \rangle^2)/2N}$$



dynamical fluctuations:

$$W_{dyn}\{par\} = \sigma^2_{v_2}\{par+sta\} - \sigma^2_{v_2}\{sta\} < 0$$

$$W_{dyn}\{par+had\} = \sigma^2_{v_2}\{par+had+sta\} - \sigma^2_{v_2}\{sta\} < 0$$

$$\sigma_{v_2}\{par\} = -\sqrt{-W_{dyn}\{par\}}$$

$$\sigma_{v_2}\{par+had\} = -\sqrt{-W_{dyn}\{par+had\}}$$

- ➢ v_2 fluctuations are approximately independent of ε_2 at a fixed impact parameter.
- ➢ v_2 fluctuations depend on impact parameter.

Induced v_2 fluctuations

Assumption: $\sigma_{v_2}^2\{a+b\}=\sigma_{v_2}^2\{a\}+\sigma_{v_2}^2\{b\}$

1. default settings with identical ε_2:

$$\sigma_{v_2}^2\{cfg+par+had\}=\sigma_{v_2}^2\{cfg\}+\sigma_{v_2}^2\{par\}+\sigma_{v_2}^2\{had\}$$

……

2. identical configuration:

$$\sigma_{v_2}^2\{par+had\}=\sigma_{v_2}^2\{par\}+\sigma_{v_2}^2\{had\}$$

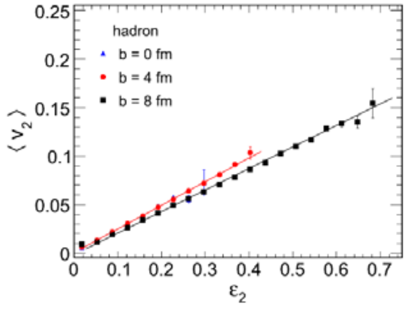
……

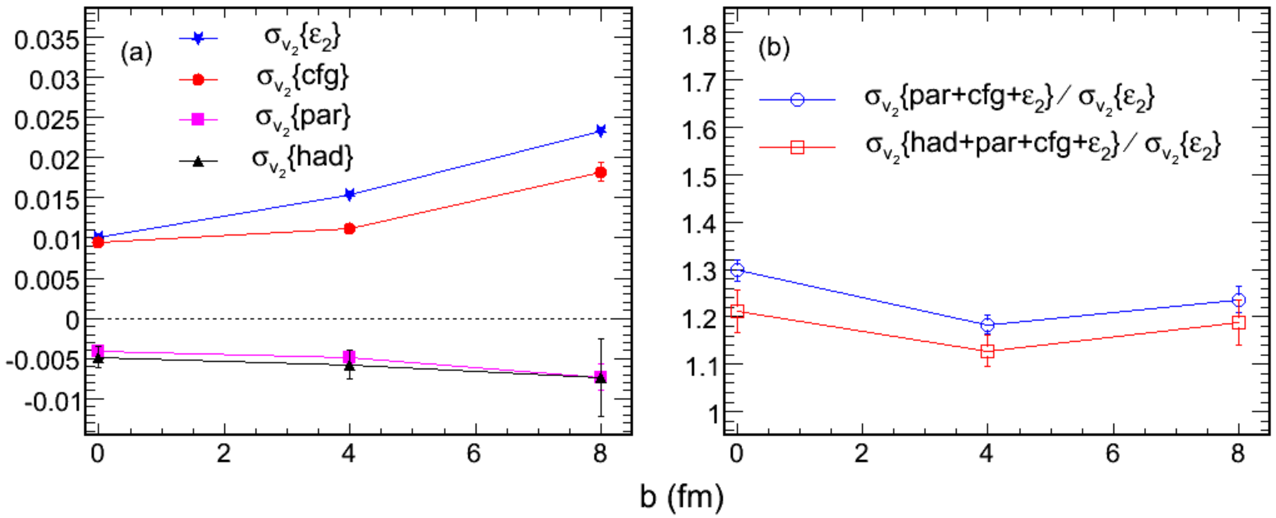
components of v_2 fluctuations: $\sigma_{v_2}\{cfg\}$, $\sigma_{v_2}\{par\}$, $\sigma_{v_2}\{had\}$

Sources of v_2 fluctuations

$\sigma_{v_2}\{\varepsilon_2\} = k \times \sigma_{\varepsilon_2}$

k: linear fit to data



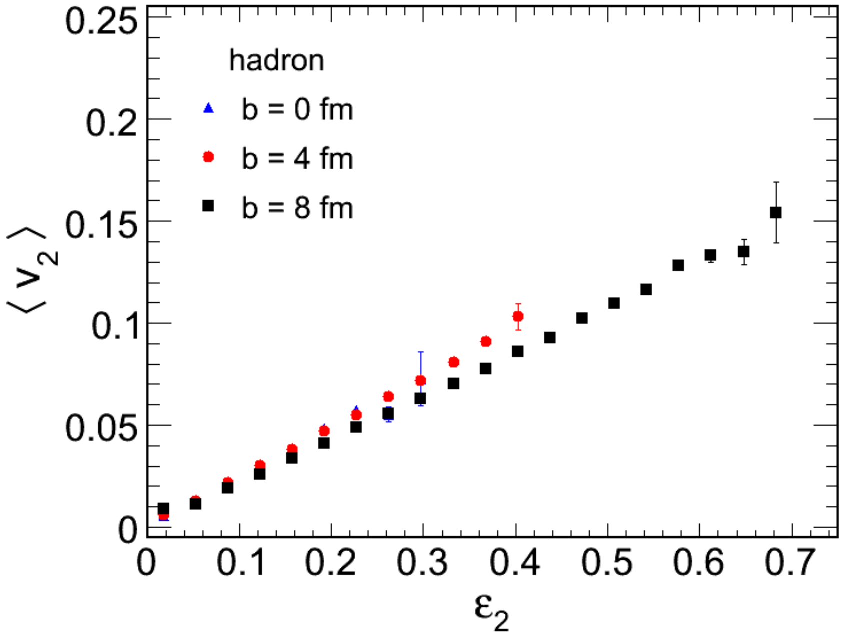


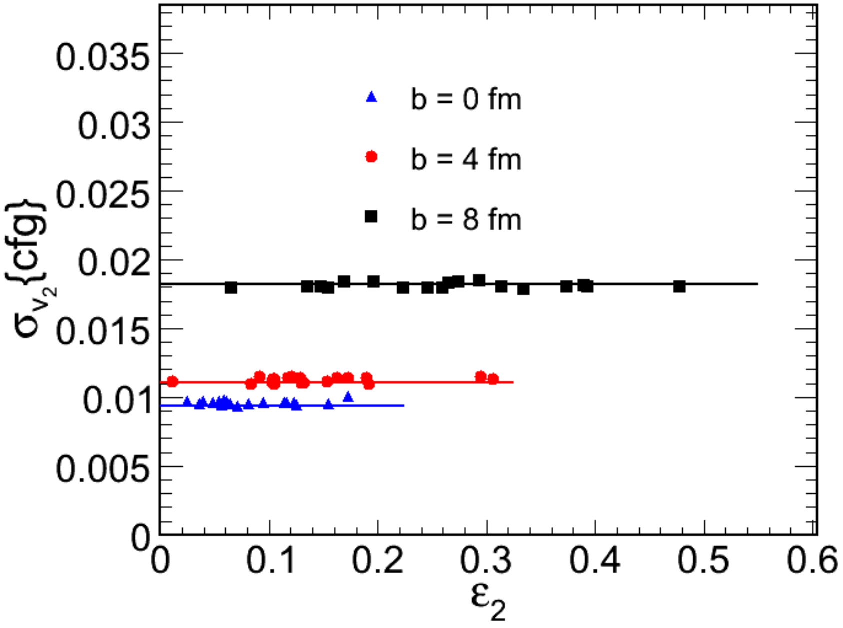
- $\sigma_{v_2}\{cfg\}$ and $\sigma_{v_2}\{\varepsilon_2\}$ increase with increasing impact parameter. Configuration fluctuations are as important as ε_2 fluctuations.
- $\sigma_{v_2}\{par\}$ and $\sigma_{v_2}\{had\}$ are both negative.
- Total v_2 fluctuations are larger than $\sigma_{v_2}\{\varepsilon_2\}$ by 20%.

Hydrodynamic fluctuations affect the elliptic flow besides initial state fluctuations.

St. Mrowczynski et al. Acta Phys. Polon. B34, 4241 (2003) ; J. I. Kapusta,et al. Phys. Rev. C 85, 054906 (2012).

Impact parameter and ε_2 dependence





- Average $<v_2>$ depends on ε_2, but is insensitive to impact parameter.
- $\sigma_{v_2}\{cfg\}$ depends on impact parameter, but is insensitive to ε_2.

Summary and outlook

- **Event-plane decorrelates over Δη.**
- **Event-plane decorrelation may call into question η gap method.**
- **Several other sources of dynamical fluctuations are studied.**
  (configuration fluctuations, parton interactions, hadronization + hadronic scatterings)

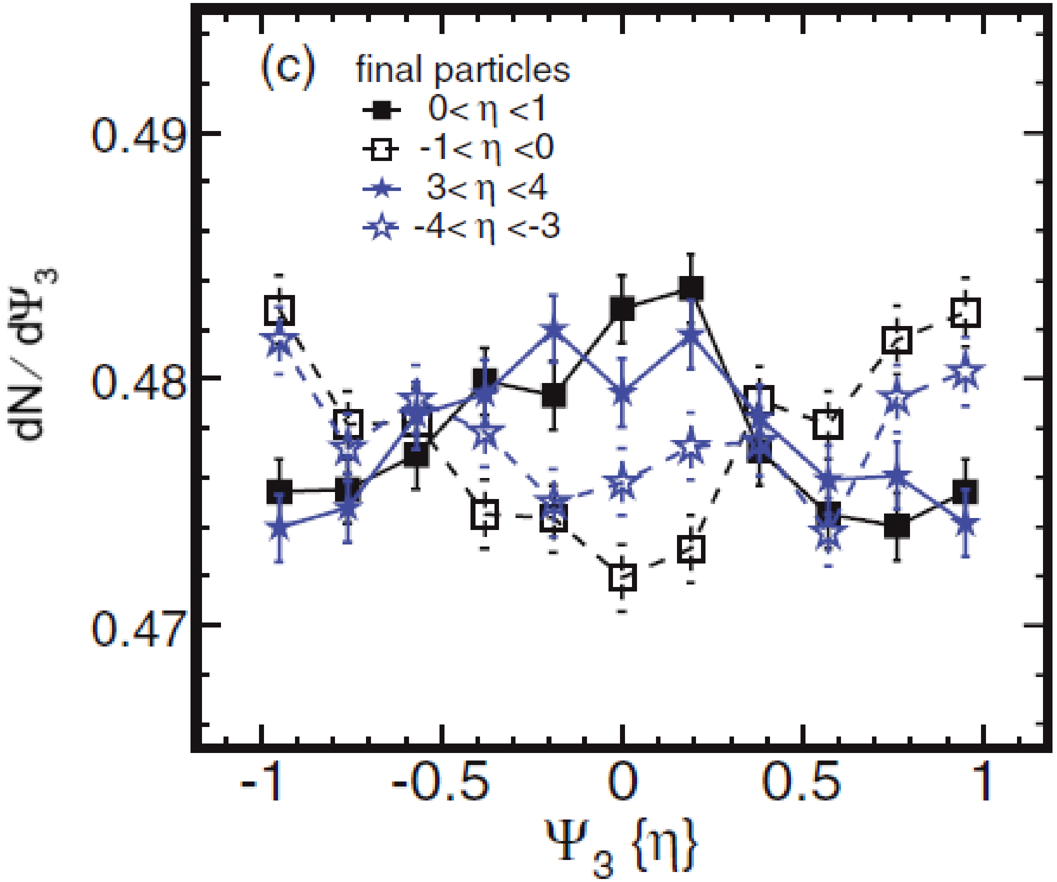
1. Configuration fluctuations are as important as ε_2 fluctuations.
2. Total v_2 fluctuations are larger than those due to ε_2 fluctuations by 20%.
3. Configutation fluctuations may affect the conclusions from models in comparison to data.

We will further study the sources of v_3 fluctuaions.

Thanks!

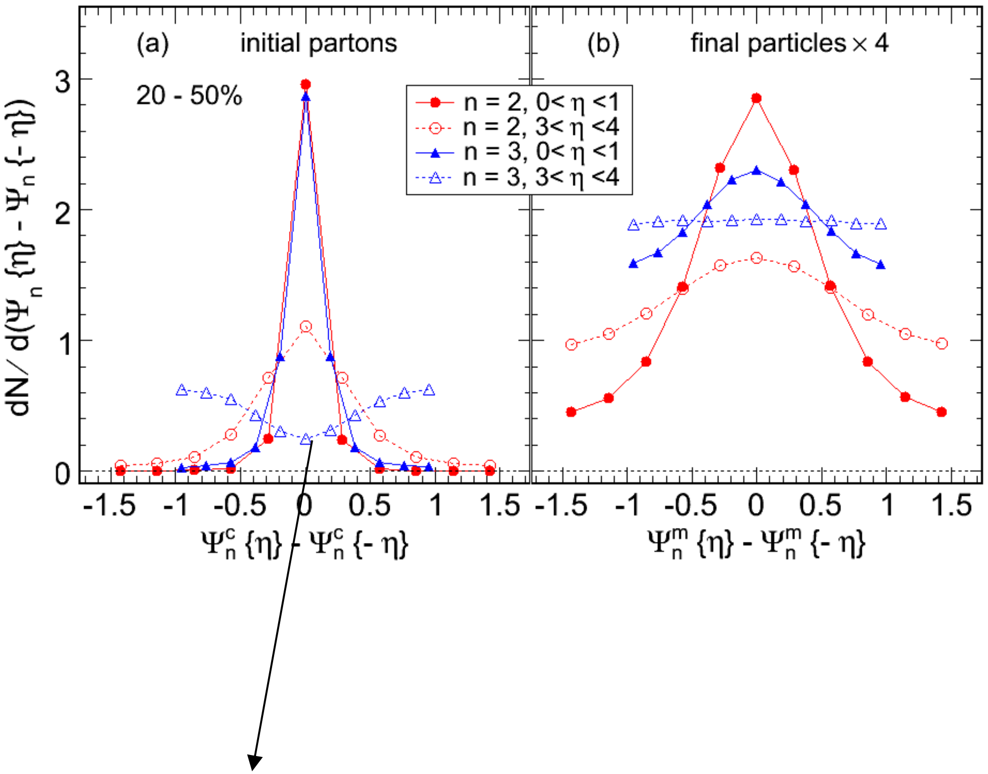
backup

Ψ_3 from momentum space



Anticorrelation is observed from momentum space.

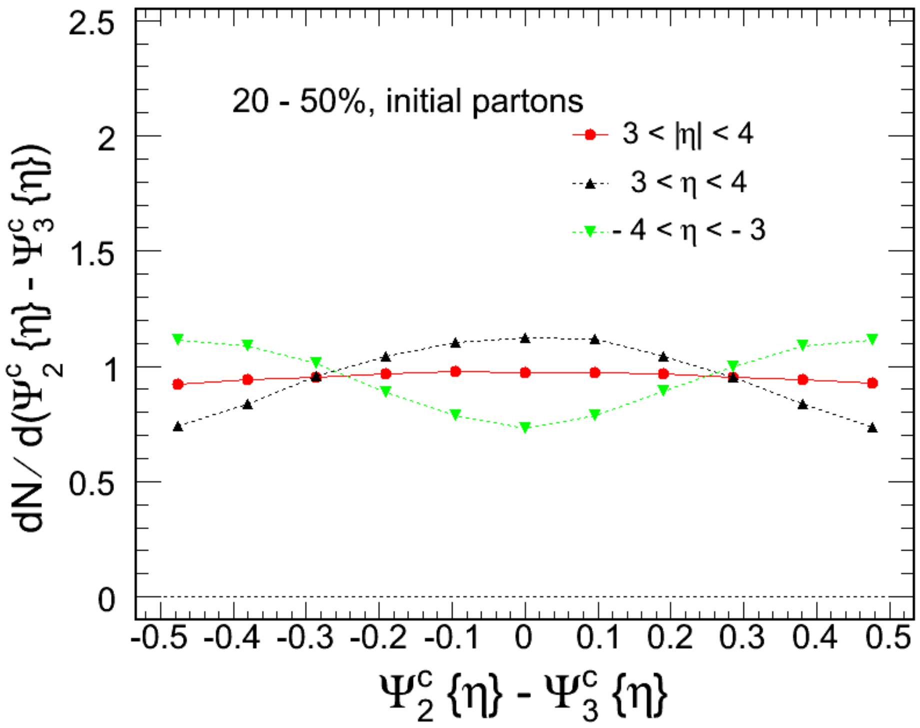
Difference of event planes



Distribution of event-by-event difference between forward and backward Ψ3

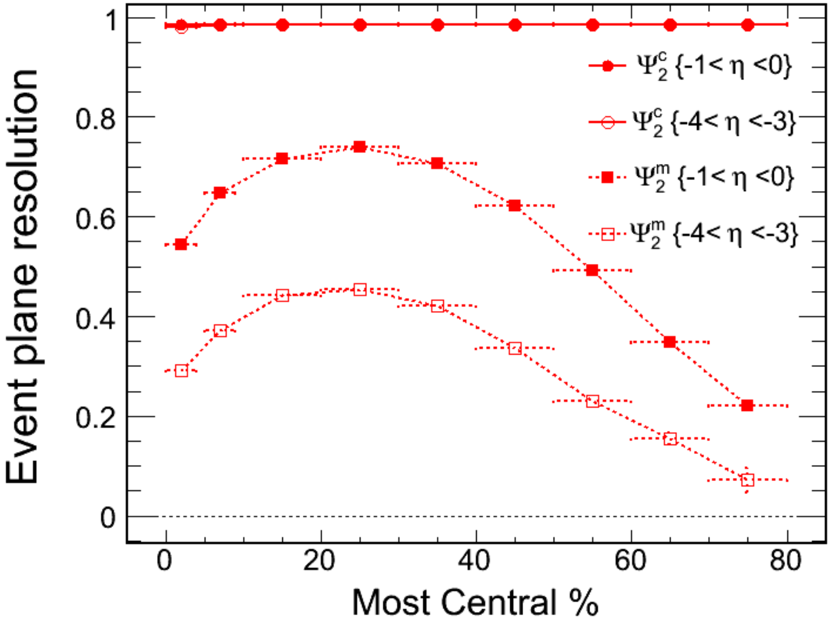
Forward and backward Ψ3 are anticorrelated with large Δη.

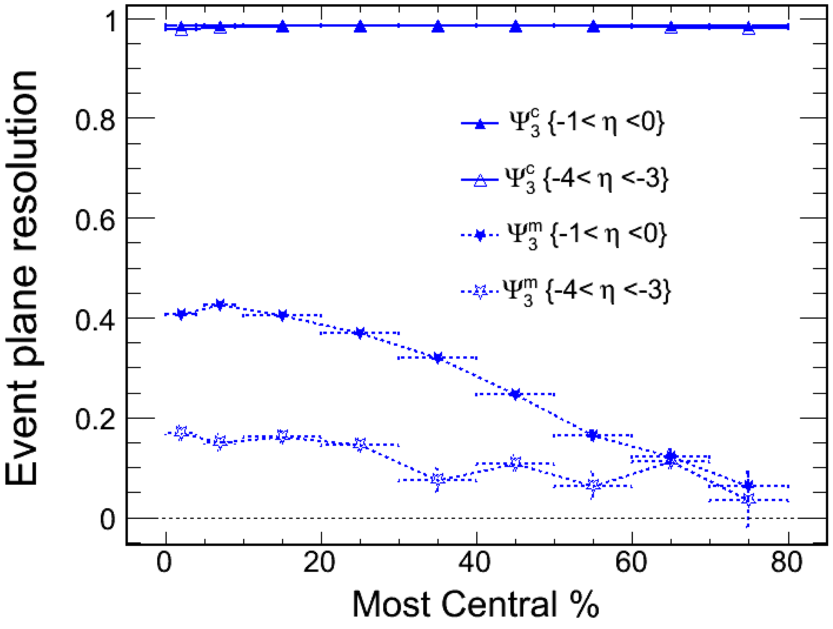
Correlations between Ψ_2 and Ψ_3



Only after averaging forward and backward η, do the two planes Ψ_2 and Ψ_3 appear uncorrelated.

Event plane resolutions





We calculate the resolution factor by the subevent method.

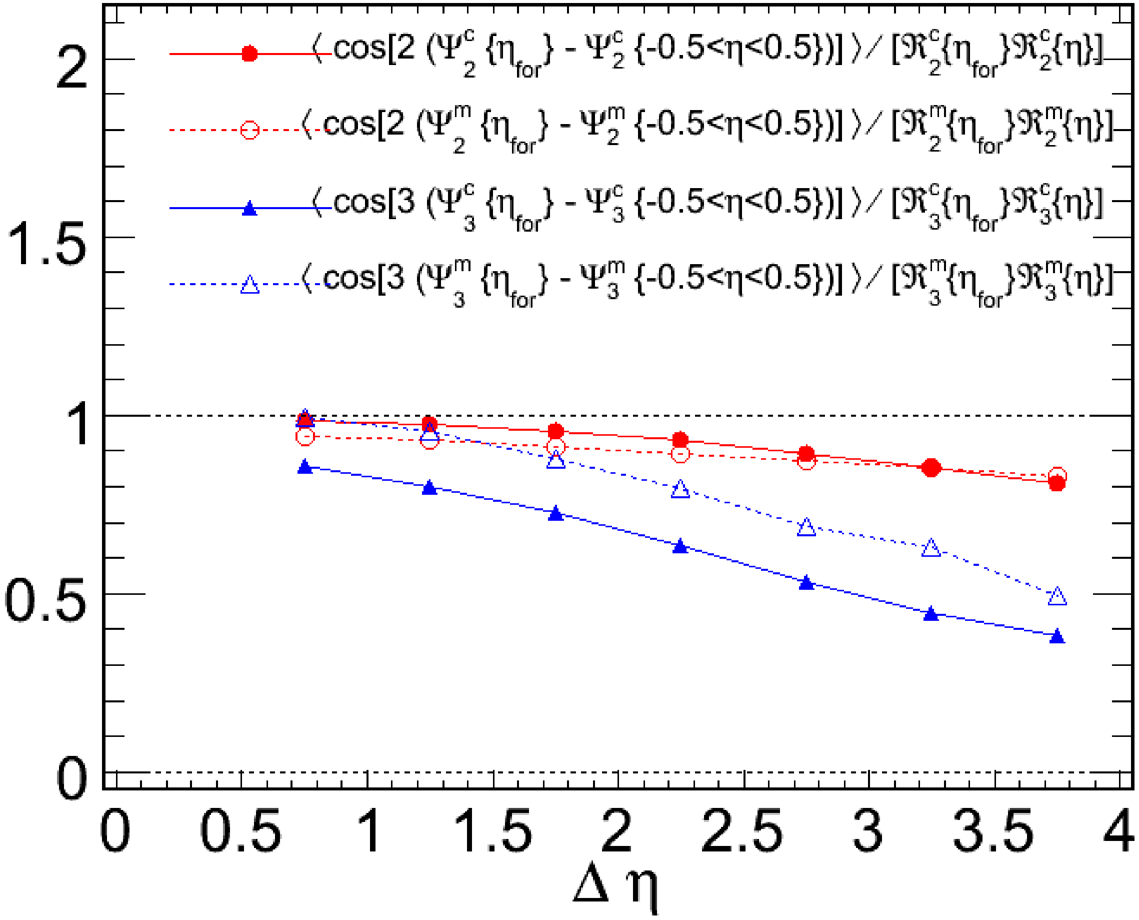
The resolutions of configuration space event plane are nearly unity.

2-particle cumulant

1. Cumulant method is also affected by event-plane decorrelation.
2. $\Phi_1 - \Phi_2 = (\Phi_1 - \Psi\{\eta_1\}) - (\Phi_2 - \Psi\{\eta_2\})$

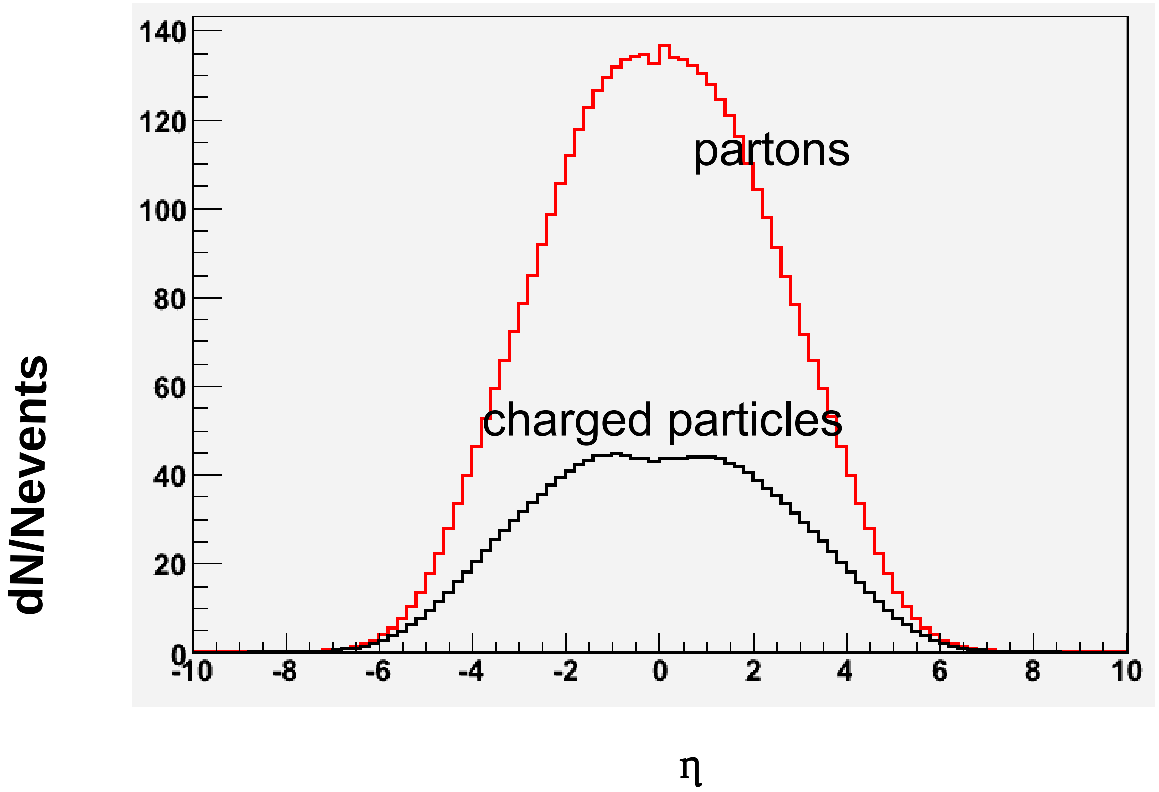
If Ψ is different between two η regions, the measurement would be $v_2\{\eta_1\} * v_2\{\eta_2\} * \langle\cos(\Psi\{\eta_1\} - \Psi\{\eta_2\})\rangle$

Correlation between forward and mid rapidity



Event plane decorrelates over $\Delta\eta$

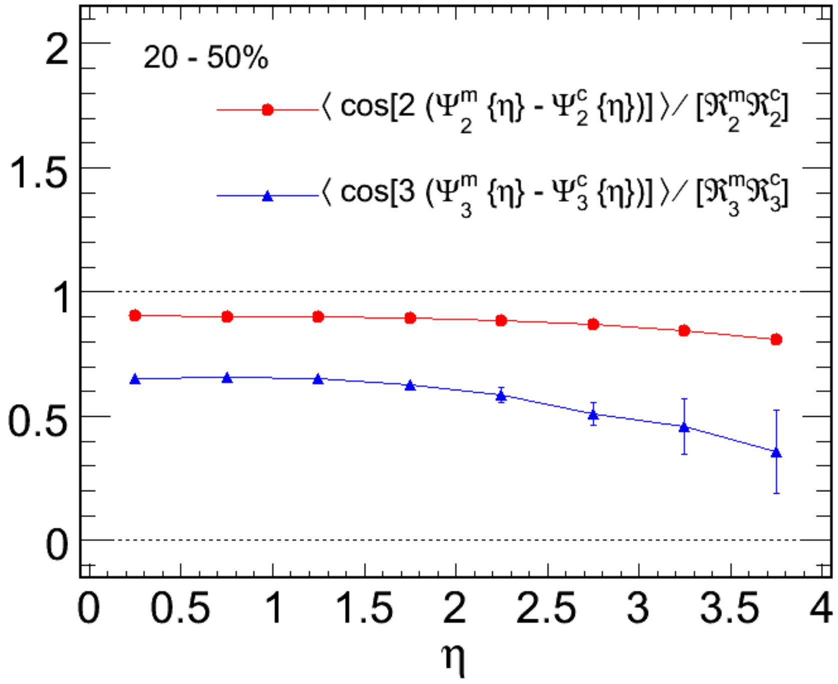
η distributions



longitudinal expansion of the system

more charged particles than partons at midrapidity, 3 times.

Correlations between Ψ^{m} and Ψ^{c}

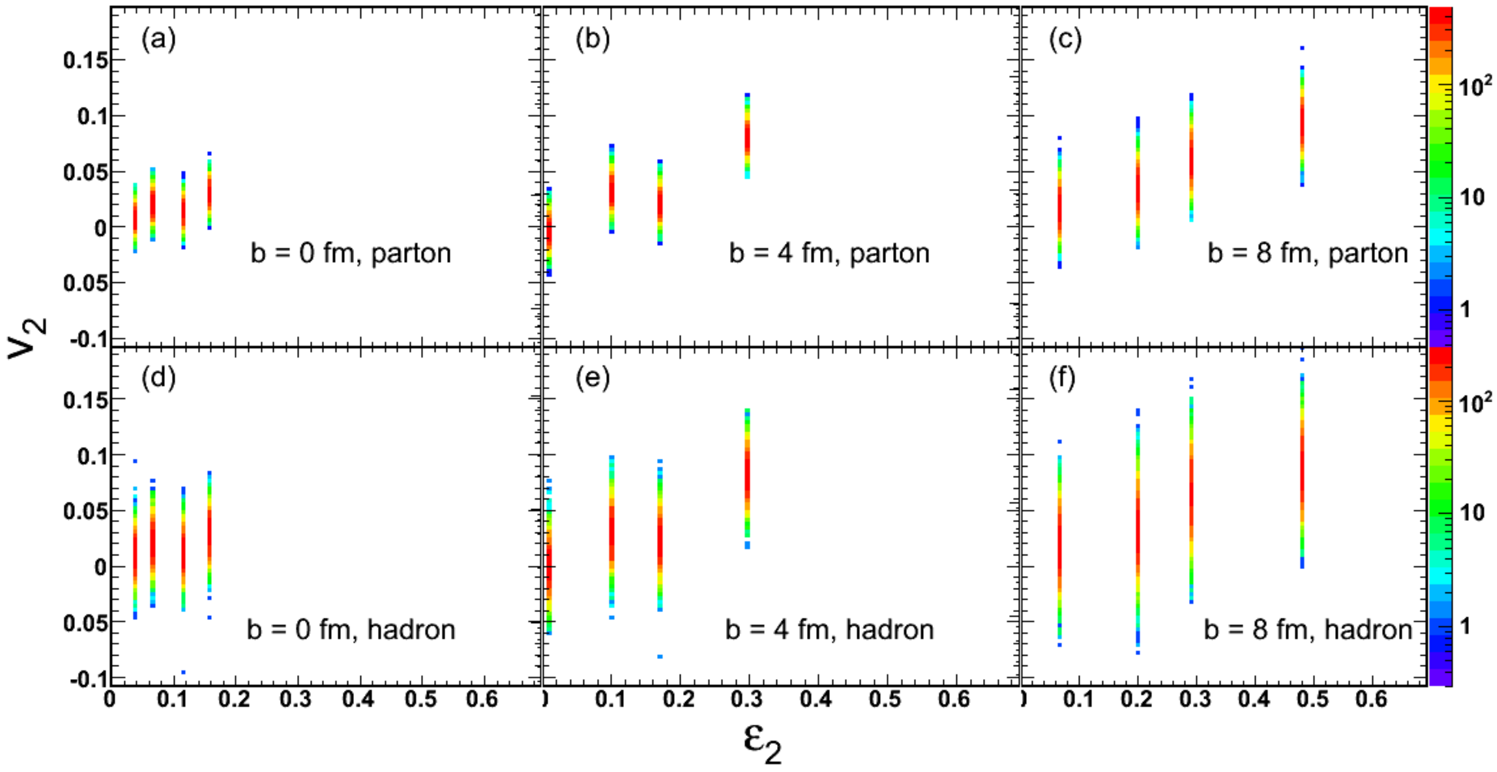


ψ_n^m and ψ_n^c , after resolution corrections , are not the same.

This is expected but the discussions of its physics is beyond our study.

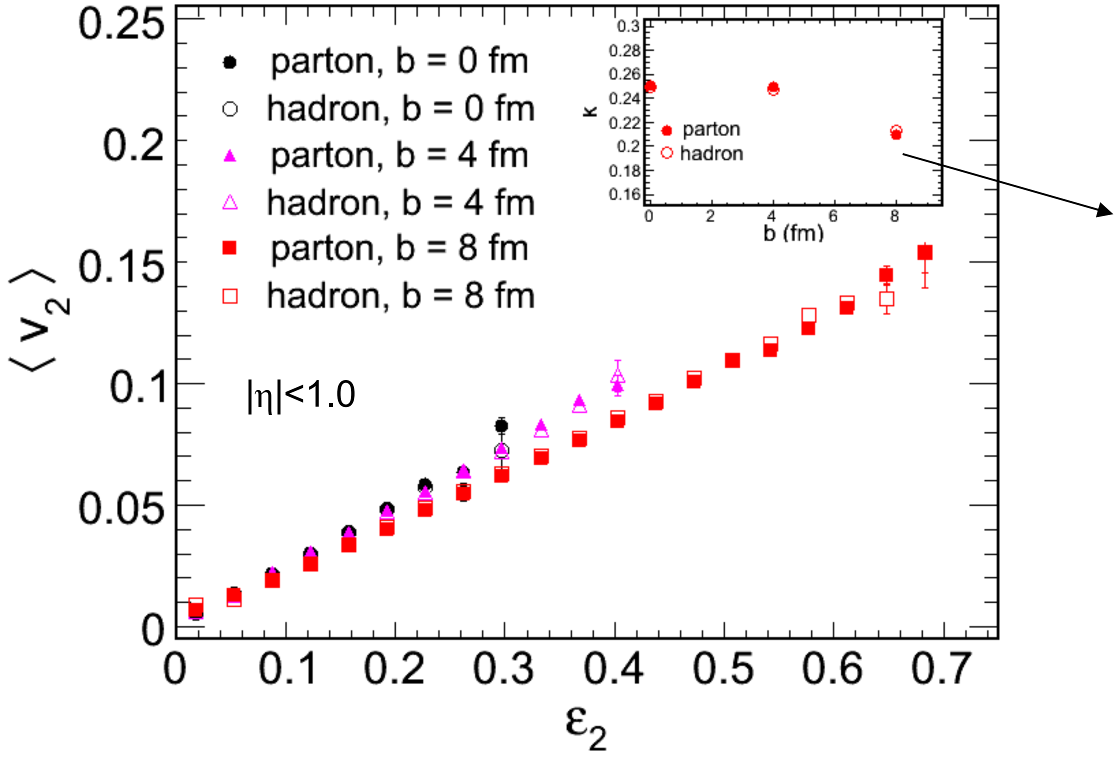
Event-by-event correlation (2)

Data with identical initial condition



Even with identical initializations, large fluctuations are observed in v_2.

Average behavior

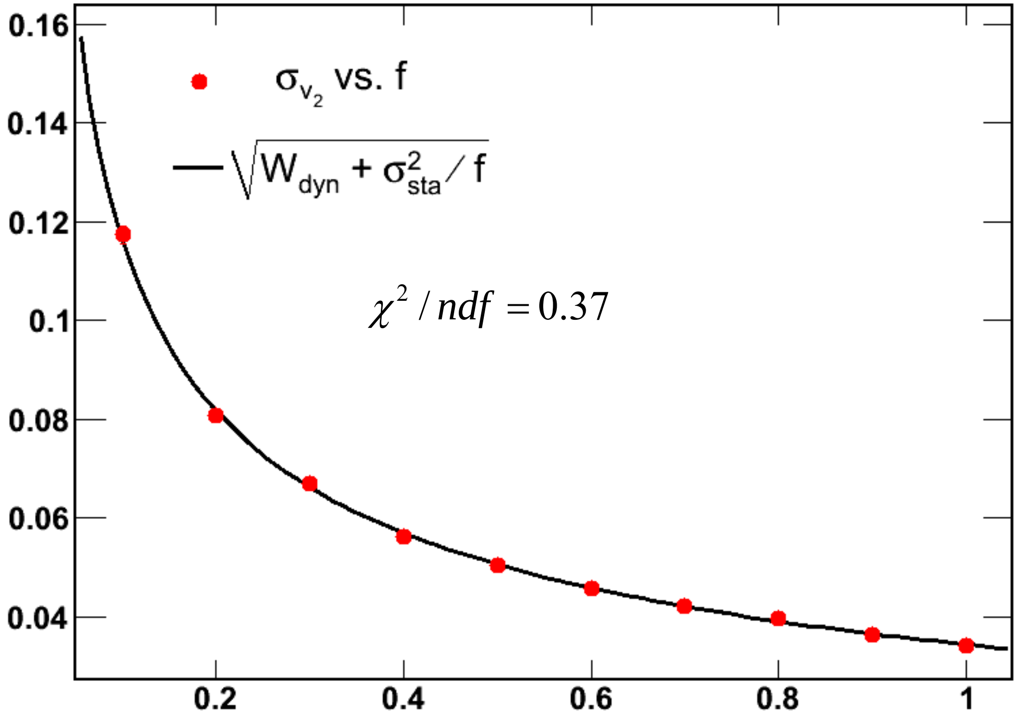


conversion power

1. The final-stage hadronic scatterings in AMPT does not generate significant additional $<v_2>$.

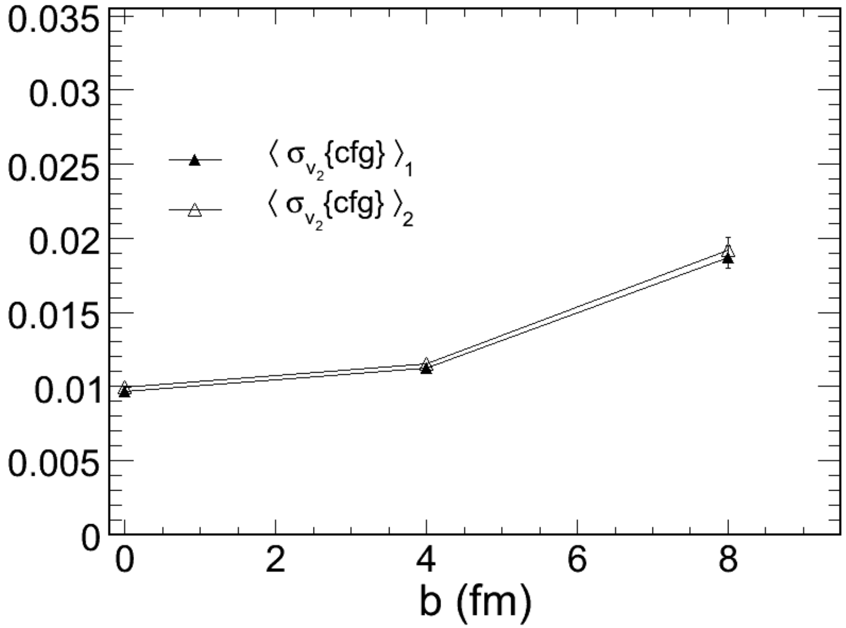
2. A relatively larger converting power from ε_2 to v2 is shown for more central collisions.

Fitting



σ_{v_2} vs. f
$\sqrt{W_{dyn} + \sigma_{sta}^2 / f}$
$\chi^2 / ndf = 0.37$
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.2
0.4
0.6
0.8
1

Redundancy

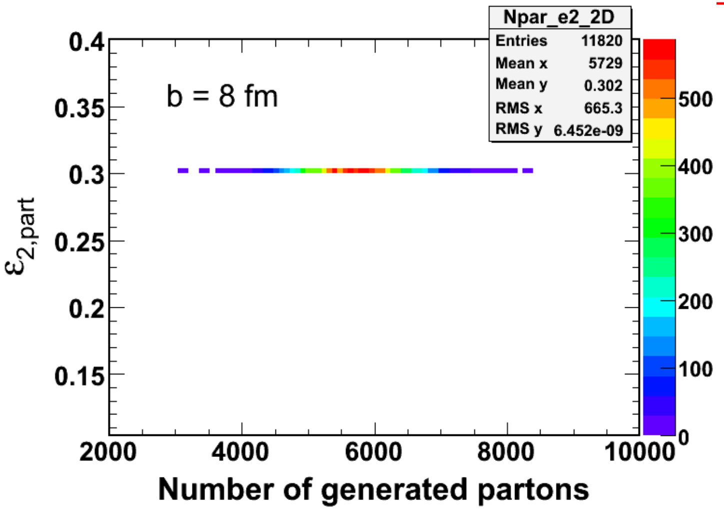


$\sigma_{v_2}\{\mathrm{cfg}\}$ by taking difference between:

1. $\sigma_{v_2}\{par\}$ and $\sigma_{v_2}\{par+cfg\}$
2. $\sigma_{v_2}\{\mathrm{had}+par\}$ and $\sigma_{v_2}\{\mathrm{had}+par+cfg\}$

The redundancy gives consistent results.

One possibility



We generate events:

1. default settings with identical ε_2

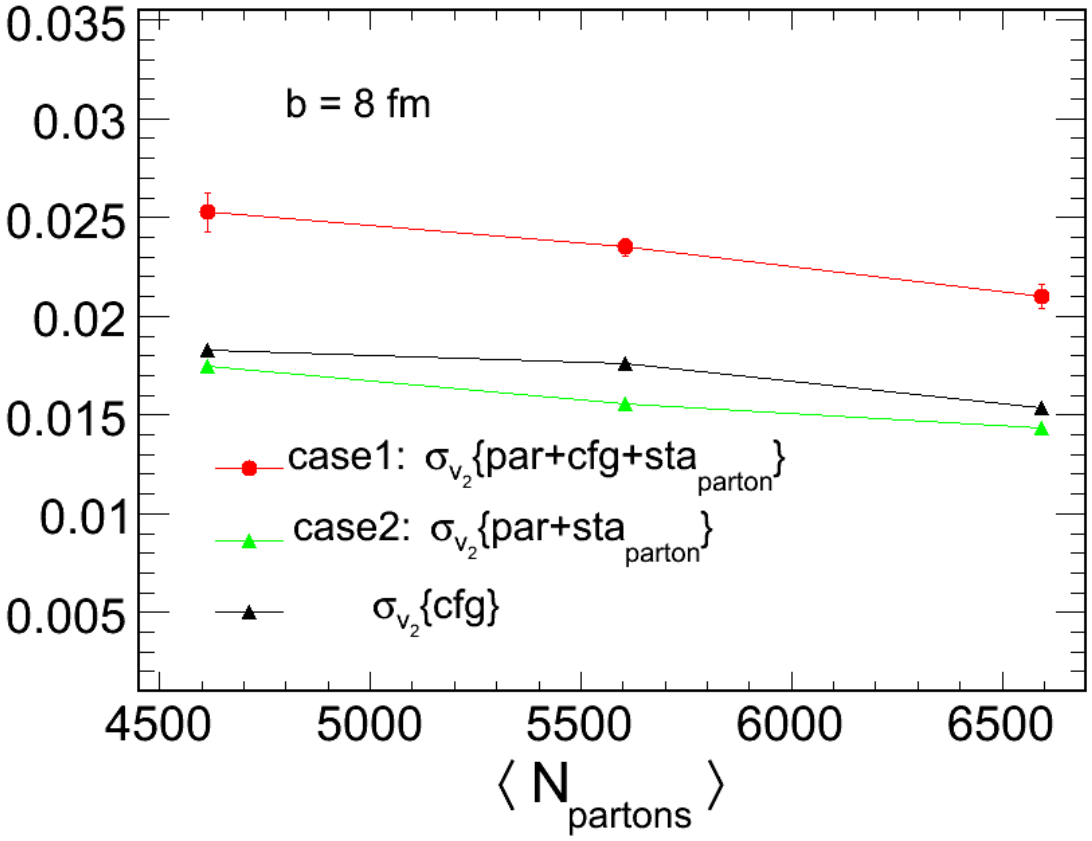
ε_2	0.3015		
Numbef of partons per event	**4500~4700**	**5500~5700**	**6500~6700**
Number of events	**349**	**1341**	**566**

2. with identical parton configuration && same values of ε_2 as default settings && number of partons (mean values of default settings)

ε_2	0.3015		
Numbef of partons per event	**4615**	**5604**	**6593**
Number of events	**2000**	**2000**	**2000**

The difference of v_2 fluctuations betwen case1 and case2: $\sigma_{v_2}\{cfg\}$

Comparisons



1. Initial parton configuration fluctuations play a role in v_2 fluctuations.
2. As the number of partons increase, this effect seems weaker.

Statistical fluctuations

Two ways:

(1). ϕ between 0 and 2 π according to a v_2 modulation ($1+2v_2*\cos(2\phi)$).

$$\sigma_{v_2}\{sta\} = \sqrt{(\langle\cos(2\phi)^2\rangle - \langle\cos(2\phi)\rangle^2)/N} \approx \sqrt{(1-2\langle v_2\rangle^2)/2N}$$

(2). AMPT data themselves && randomly discarding various fractions of particles.

$$\sqrt{W_{dyn} + \sigma_{v_2}^2\{sta\}/f}$$

f : remaining fraction of particles

W_{dyn} and $\sigma_{v_2}\{sta\}$: two free parameters

$\sigma_{v_2}\{sta\}$ from these two ways are consistent.

$W_{dyn}\{par\} < 0$ and $W_{dyn}\{had+par\} < 0$ (dynamical fluctuations from identical configuration)

We define:

$$\sigma_{v_2}\{par\} = -\sqrt{-W_{dyn}\{par\}}$$

$$\sigma_{v_2}\{had+par\} = -\sqrt{-W_{dyn}\{had+par\}}$$