Anisotropic flow at $\sqrt{s_{NN}}$ = 200 GeV in Au+Au collisions in AMPT model

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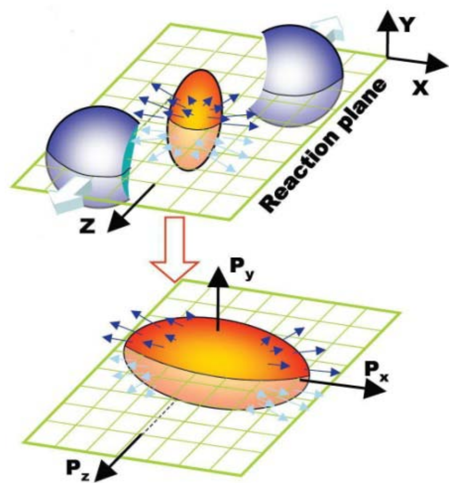
Outline

- Introduction
- Analysis methods
- Results and discussions
- Summary

Anisotropic Flow



Coordinate-Space Anisotropy

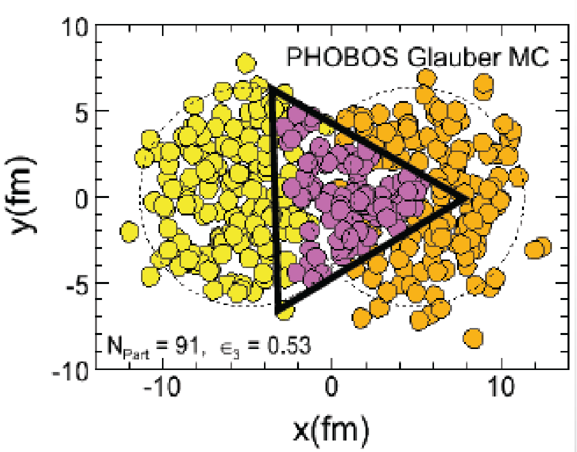
↓ pressure gradient

Momentum-Space Anisotropy

Azimuthal distributions of final state particles:

$$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}(1+2v_1\cos(\phi-\psi_R)+2v_2\cos 2(\phi-\psi_R)+2v_3\cos 3(\phi-\psi_R)+\ldots)$$

elliptic flow (v_2) **triangular flow** (v_3)



B. Alver et al. PRC 81, 054905 (2010)

✓**Triangular flow (v_3) provides a new handle on the initial collision geometry and collective expansion dynamics in heavy ion collisions.**

Analysis Methods

For n = 2 or 3 :

initial anisotropy:

$$\varepsilon_n = \frac{\sqrt{<r^2\cos(n\phi)>^2 + <r^2\sin(n\phi)>^2}}{<r^2>}$$

$$\varepsilon_n\{2\} = \sqrt{<\varepsilon_n^{\ 2}>}$$

$$\varepsilon_n\{4\} = (2<\varepsilon_n^{\ 2}>^2 - <\varepsilon_n^{\ 4}>)^{1/4}$$

initial state anisotropy in AMPT model

(r, ϕ): the polar coordinate position of each parton.

anisotropic flow:

Q-cumulants: $v_n\{2\}$ and $v_n\{4\}$

Event plane method:

$$v_n\{EP\} = \frac{<\cos[n(\varphi - \psi_n(p_t))]>}{\Re_n}$$

$$\psi_n(p_t) = \frac{1}{n}[\arctan\frac{<\sin n\varphi>}{<\cos n\varphi>}]$$

φ: the azimuthal angle of each particle in momentum space.

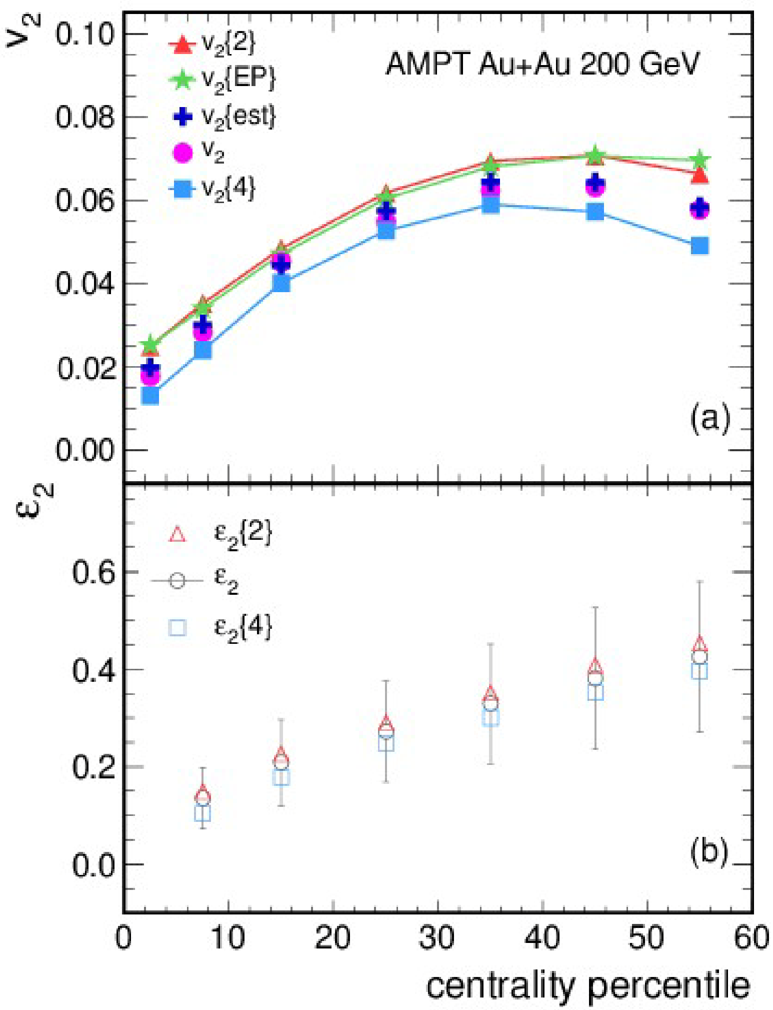
Participant plane flow:

$$v_n = <\cos[n(\varphi - \psi_n(r))]) >$$

$$\psi_n(r) = \frac{1}{n}[\arctan\frac{<r^2\sin(n\phi)>}{<r^2\cos(n\phi)>}]$$

(r, ϕ): the polar coordinate position of each parton.

Integrated Flow (v_2)



S.Voloshin et al. PLB 659,537 (2008)

Gaussian fluctuation, for: $\sigma_{v_2} \ll v_2$

$$v_2\{2\}^2 = v_2{}^2 + \sigma_{v_2}{}^2 + \delta$$

$$v_2\{4\}^2 = v_2{}^2 - \sigma_{v_2}{}^2$$

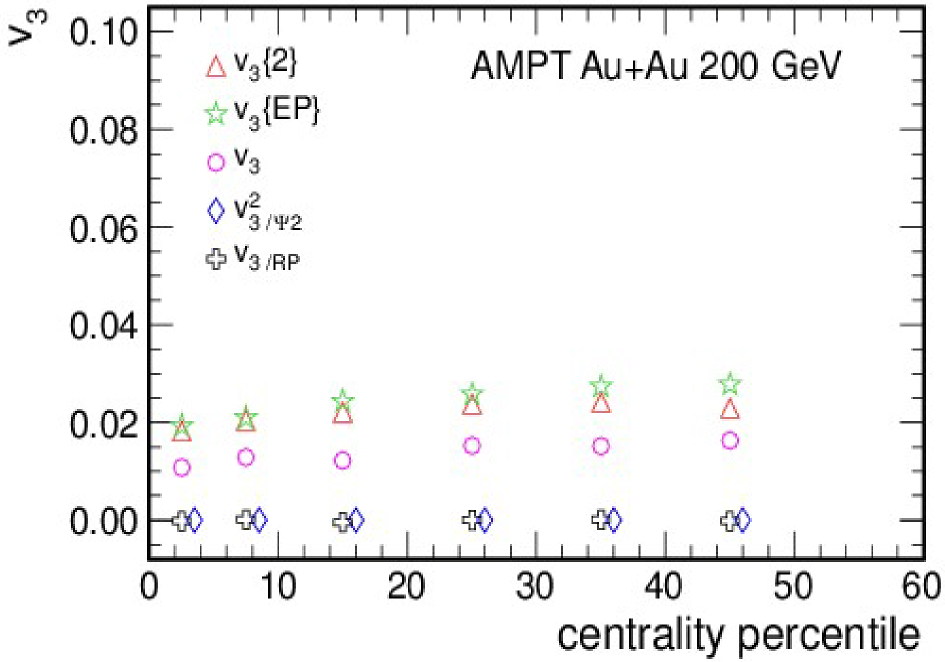
δ corrected → $v_2\{est\} = \sqrt{(v_2\{2\}^2 + v_2\{4\}^2)/2}$

✓It implies that we can use $v_2\{2\}$ (non-flow corrected) and $v_2\{4\}$ to estimate the participant plane v_2 in experiments.

✓$v_2\{2\}$ corrected for non-flow effects is almost consistent with $v_2\{EP\}$. (Large η gap was used for $v_2\{EP\}$.)

✓The efficiency of initial eccentricity transferring into the elliptic flow may be lower in the more peripheral collisions.
(The error bar of ε_2 shows its fluctuations.)

Integrated Flow (v_3)



large η gap ($|\Delta\eta|>1$) used for $v_3\{EP\}$.

non-flow subtracted for $v_3\{2\}$.

✓v_3 measurements show weaker centrality dependence which is qualitatively consistent with the hydrodynamic calculations. B. Alver et al. PRC 82, 034913 (2010)

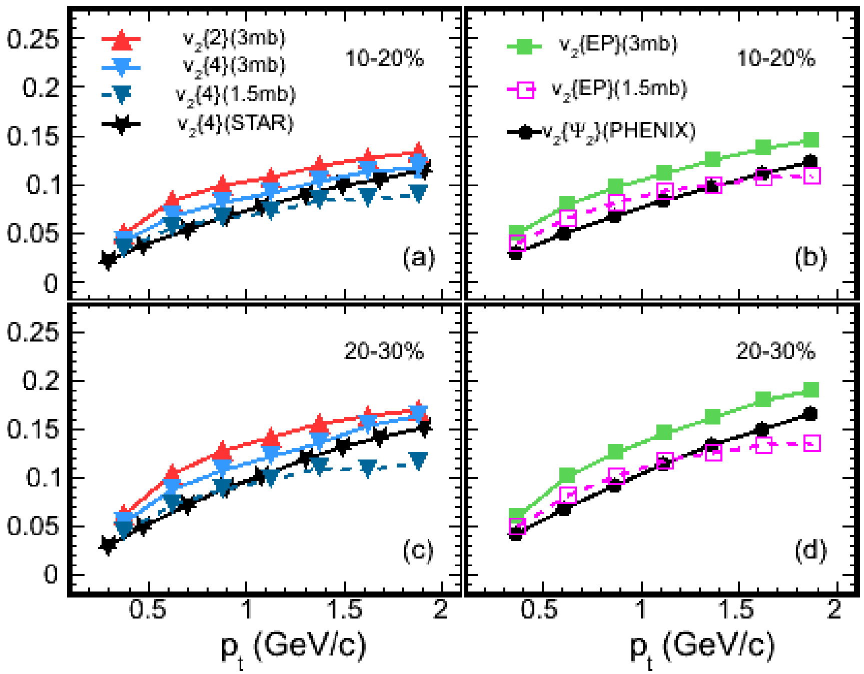
✓Large η gap may not remove non-flow contributions entirely for $v_3\{EP\}$.

✓Neither Ψ_{RP} nor Ψ_2 contribute to the v_3 measurement which is consistent with the experimental results. K. Aamodt et al. PRL 107, 032301 (2011)

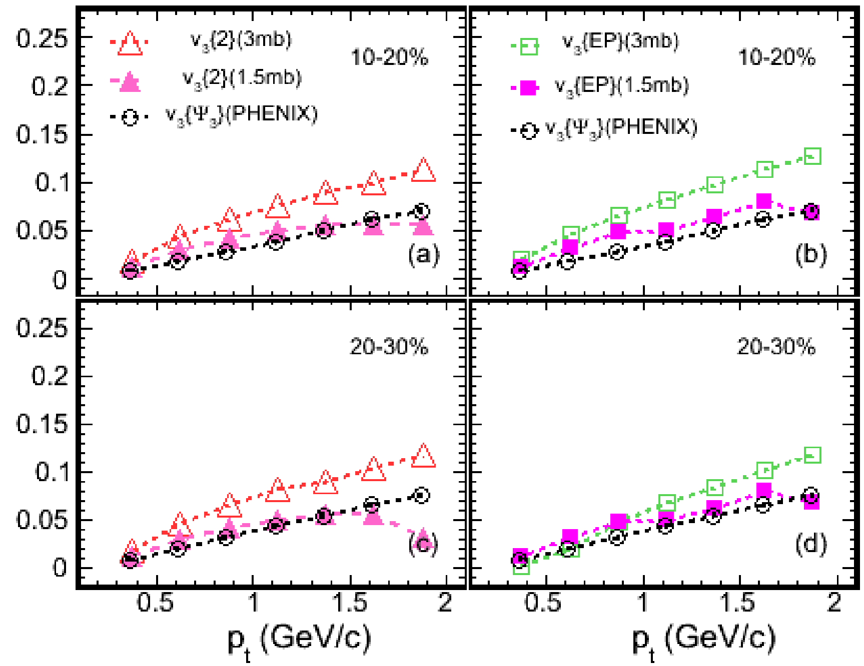
Differential Flow (v_2,v_3)

AMPT, Au+Au 200GeV

elliptic flow



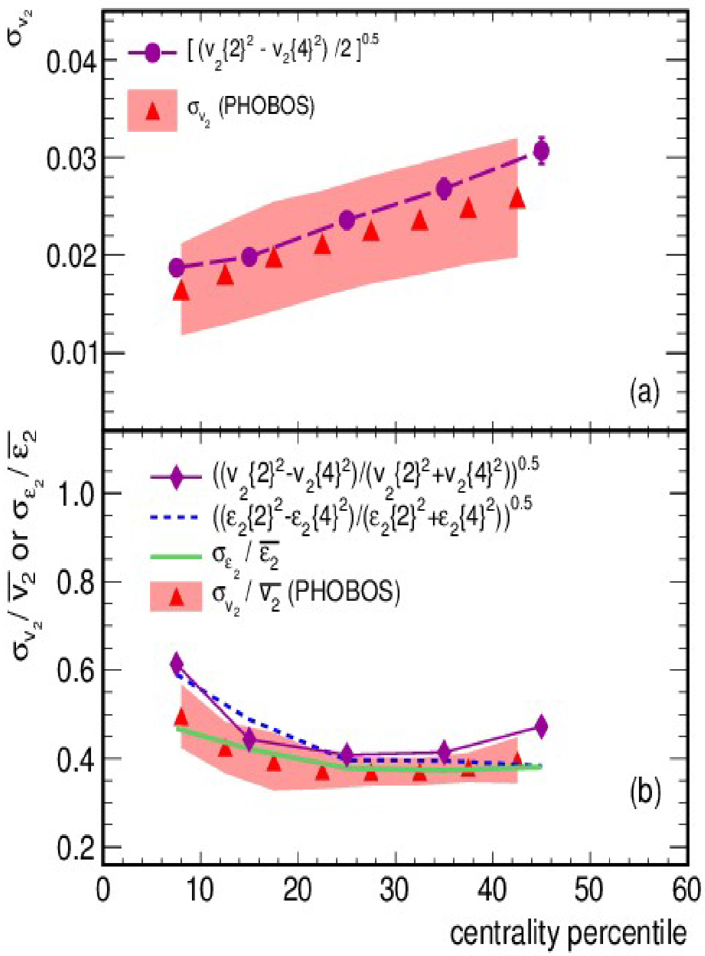
triangular flow



- ✓ Both v_2 and v_3 with 3mb overestimate the measurements in experiments.
- ✓ New set of parameters(1.5mb) can describe the experimental measurements better. It suggests that η/s equals to 0.38. J. Xu and C. M. Ko PRC 84, 014903 (2011)

Flow Fluctuations

AMPT, Au+Au 200GeV



initial eccentricity fluctuations ➡ elliptic flow fluctuations

B. Alver et al. PRC 81,034915(2010)   B. Alver et al. PRL 104,142301(2010)

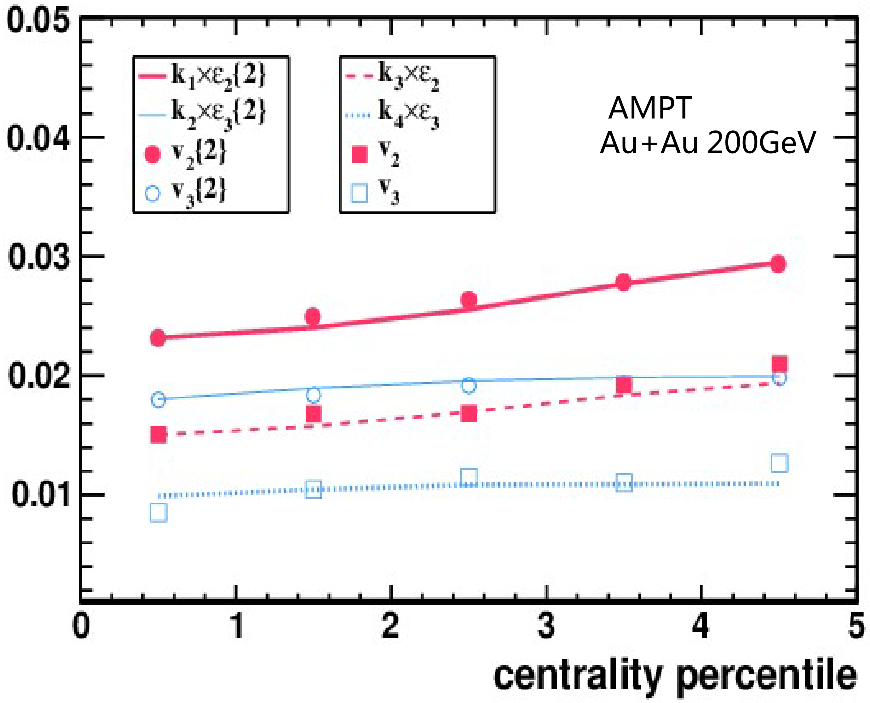
✓The estimated flow fluctuations (σ_{v_2}) follow the measurements in PHOBOS.

✓The relative flow fluctuations are consistent with the relative eccentricity fluctuations except for the peripheral collisions.
It provides a basis for the initial fluctuation measurements in experiments.

✓There are deviations between the estimated and real eccentricity fluctuations in the more central collisions.
(The condition $(\sigma_{v_2} \ll v_2)$ may be not valid in this region.)

Anisotropy and Anisotropic Flow

In a small centrality range (0-5%), viscous effects don't change too much.
Anisotropic flow might be directly sensitive to the change in the initial spatial geometry.
K. Aamodt et al. PRL 107, 032301 (2011)



$$v_2\{2\} = k_1 \times \varepsilon_2\{2\}, v_2 = k_3 \times \varepsilon_2$$
$$v_3\{2\} = k_2 \times \varepsilon_3\{2\}, v_3 = k_4 \times \varepsilon_3$$

✓Anisotropic flow can be described in terms of the initial eccentricity and triangularity as well as their fluctuations.

$$k_1 \neq k_3, k_2 \neq k_4$$ Why?

v_n/ε_n

The efficiency of the initial anisotropy transferring into the anisotropic flow:

R. S. Bhalerao et al. PLB 627, 49 (2005)

$$k = \frac{v_n}{\varepsilon_n} = [\frac{v_n}{\varepsilon_n}]_{hydro} \frac{1}{1+K/K_0},$$

K_0 : a constant (0.7)

$K = (\sigma c_s \frac{1}{S}\frac{dN}{dy})^{-1}$ (Knudsen number)

K (related to S and dN/dy) → dN/dy (fluctuates event-by-event) → v_n/ε_n (event-by-event fluctuations)

AMPT calculation

The observed v_n/ε_n fluctuates instead of a constant value.

→

$k_1 =< k'^2 >^{1/2}$, but $k_3 =< k' >$

$k_2 =< k''^2 >^{1/2}$, but $k_4 =< k'' >$

→

$k_1 \neq k_3$

$k_2 \neq k_4$

✓The efficiency of the initial anisotropy transferring into the anisotropic flow fluctuates event-by-event.

Summary

- ✓ $v_2\{2\}$ and $v_2\{4\}$ can not only constrain but also estimate the participant plane flow.
- ✓ v3 measurements show weaker centrality dependence which is qualitatively consistent with the hydrodynamic calculations.
- ✓ Neither Ψ_{RP} nor Ψ_2 contribute to the v_3 measurements.
- ✓ The estimated relative flow fluctuations are almost in an agreement with relative eccentricity fluctuations.
- ✓ v_2 and v_3 measurements can be described in terms of the initial eccentricity and triangularity as well as their fluctuations in the most centrality collisions.

Thanks!