Investigation of the linear and mode-coupled flow harmonics in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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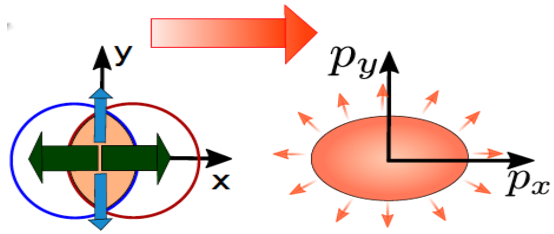
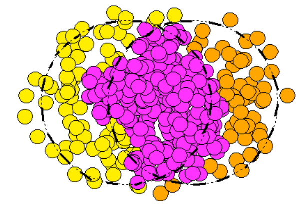
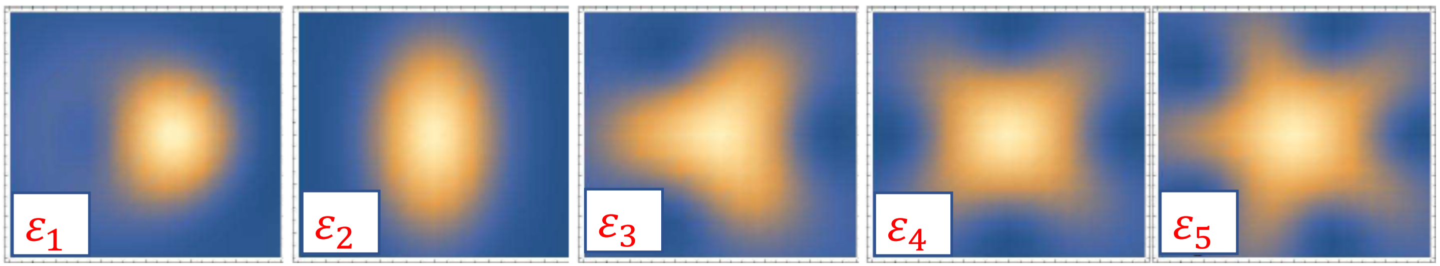
Introduction

Anisotropic flow

Asymmetry in initial geometry → Final-state momentum anisotropy







What are the respective roles of ε_n and its fluctuations, flow correlations and $\eta/\mathrm{s}(T)$ on the v_n ?

Higher-order flow harmonics ($v_{\mathrm{n}>3}$) have multiple contributions:

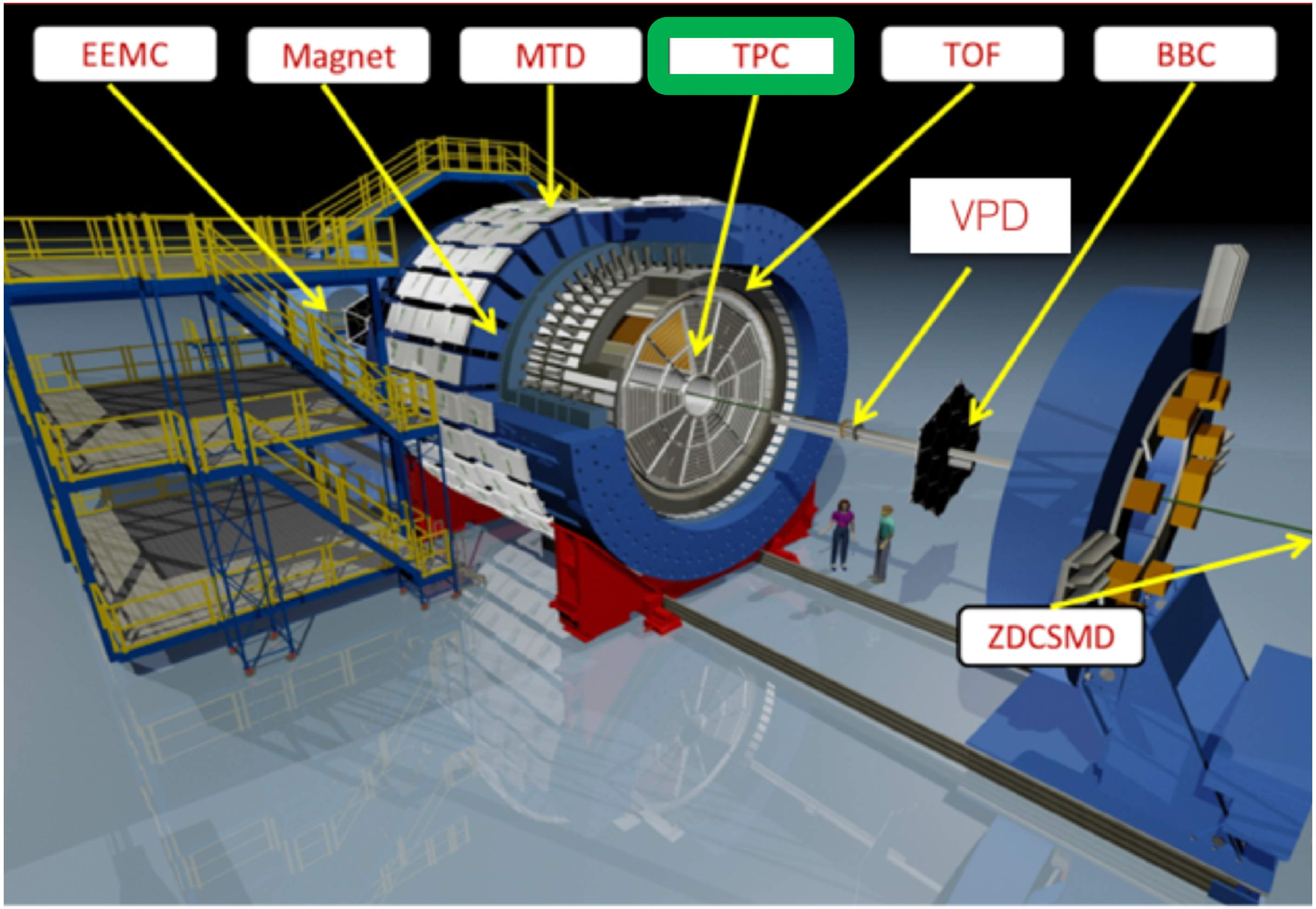
- ✓ Linear response ∝ $\varepsilon_{\mathrm{n}>3}$
- ✓ Mode-coupled response ∝ ε_2 and/or ε_3 and the Event Plane (EP) correlations

The focus of this work:

- ✓ Separate and study the linear and mode-coupled contributions
- ✓ Study the nature of the eccentricity coupling and the EP correlations

Introduction

The Solenoidal Tracker at RHIC



- **Time Projection Chamber**

  Tracking of charged particles with:

  ✓ Full azimuthal coverage

  ✓ $|\eta| < 1$ coverage

Analysis Method

The two- and three-particle correlations:

n= 2,3 k= $n+2$

$|\Delta\eta| > 0.7$

$$C_{k,2n} = \left\langle\left\langle \cos((2+n)\varphi_1^A - 2\varphi_2^B - n\varphi_3^B)\right\rangle\right\rangle \qquad v_n^{Inclusive} = \left\langle\left\langle \cos(n\varphi_1^A - n\varphi_2^B)\right\rangle\right\rangle^{1/2}$$

The four-particle correlations:

$$\langle v_2^4\rangle = \langle\langle\cos(2\varphi_1 + 2\varphi_2 - 2\varphi_3 - 2\varphi_4)\rangle\rangle - 2\,\langle\langle\cos(2\varphi_1 - 2\varphi_2)\rangle\rangle^2 + 2\left\langle\left\langle\cos(2\varphi_1^A - 2\varphi_2^B)\right\rangle\right\rangle^2$$

$$\langle v_2^2 v_3^2\rangle = \langle\langle\cos(3\varphi_1 + 2\varphi_2 - 3\varphi_3 - 2\varphi_4)\rangle\rangle - \langle\langle\cos(2\varphi_1 - 2\varphi_2)\rangle\rangle\,\langle\langle\cos(4\varphi_1 - 3\varphi_2)\rangle\rangle + \left\langle\left\langle\cos(2\varphi_1^A - 2\varphi_2^B)\right\rangle\right\rangle\left\langle\left\langle\cos(3\varphi_1^A - 3\varphi_2^B)\right\rangle\right\rangle$$

Assume the orthogonality between linear and non-linear contributions

$$V_k = V_k^{Linear} + V_k^{Non-Linear}$$

- $v_k^{\mathrm{Non-Linear}}$ carry information about:
  - ✓ Viscous effects, EP angular correlations and Eccentricity coupling

$$v_k^{Non-Linear} = \frac{C_{k,2,n}}{\sqrt{\langle v_2^2 v_n^2\rangle}}, = \frac{\langle v_k\, v_2\, v_n\, \cos(k\Psi_k - n\Psi_n - 2\Psi_2)\rangle}{\langle v_2^2 v_n^2\rangle}, \sim \langle v_k\, \cos(k\Psi_k - n\Psi_n - 2\Psi_2)\rangle,$$

$$v_k^{Linear} = \sqrt{(v_k^{\mathrm{Inclusive}})^2 - (v_k^{\mathrm{Non-Linear}})^2}$$

✓ **EP angular correlations**

$$\rho_{k,2n} = \frac{v_k^{\mathrm{Non-Linear}}}{v_k^{\mathrm{Inclusive}}} = \langle\cos(k\Psi_k - 2\Psi_2 - n\Psi_n)\rangle$$

✓ **Eccentricity coupling**

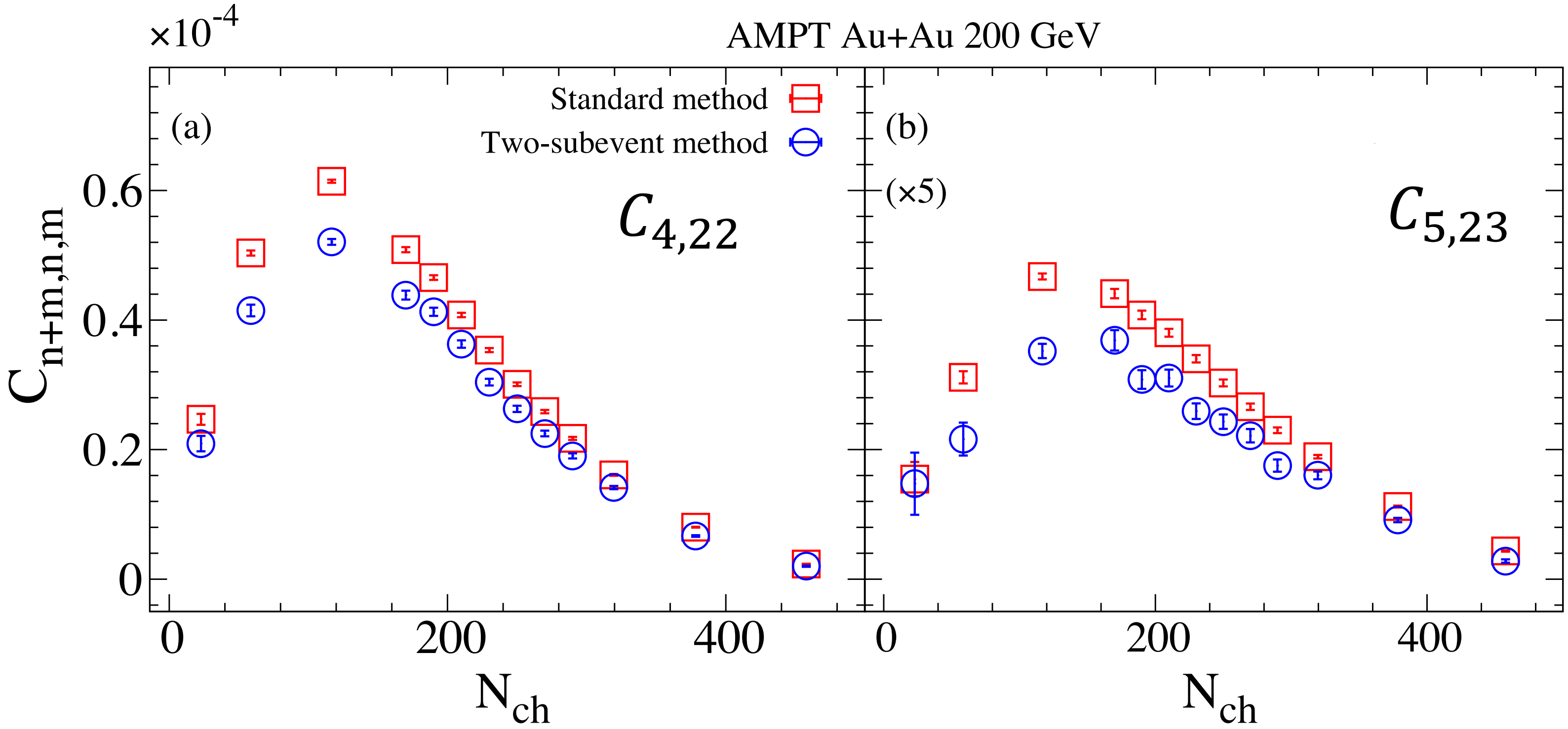
$$\chi_{k,2n} = \frac{v_k^{\mathrm{Non-Linear}}}{\sqrt{\langle v_2^2\, v_n^2\rangle}}$$

Weak viscous effect expected

P.Liu, R.Lacey
PRC 98, 021902 (2018)

The short-range non-flow contributions in the three-particle correlations

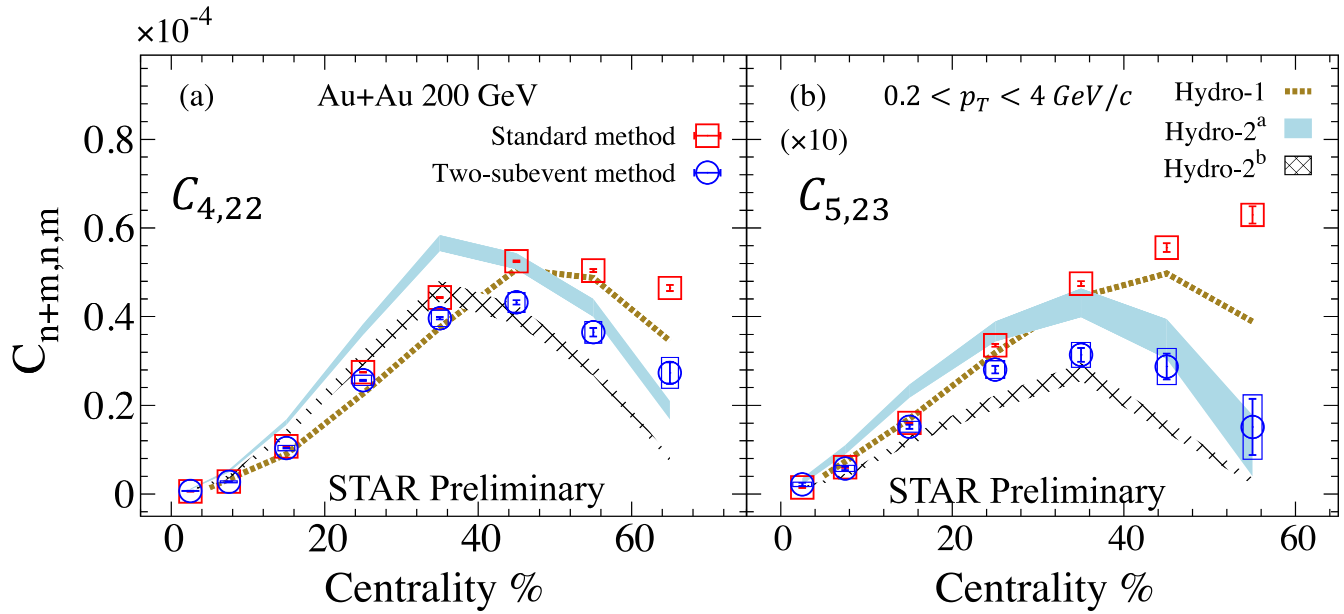
Three-particle correlations, $C_{4,22}$ and $C_{5,23}$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV using the AMPT model



- ➢ Two-subevents reduce the short-range non-flow effect on in the three-particle correlations

Results

Three-particle correlations, $C_{4,22}$ and $C_{5,23}$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV compared with different hydrodynamic simulations.



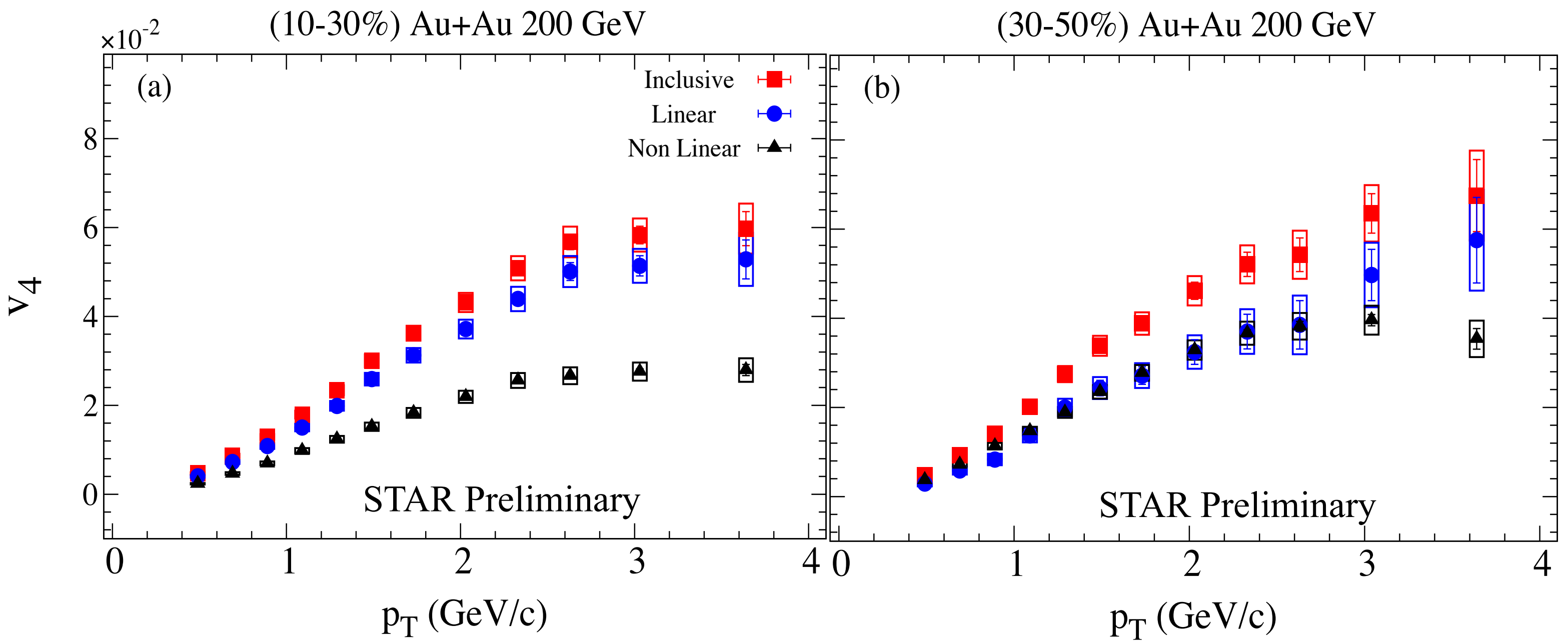
	Hydro−1	Hydro−2$^{a/b}$
η/s	0.05	0.12
Initial conditions	TRENTO Initial conditions	IP-Glasma Initial conditions
Contributions	Hydro + Direct decays	(a) Hydro + Hadronic cascade (b) Hydro only

- (1) P. Alba, et al. PRC 98 , 034909 (2018)
- (2) B.Schenke, C.Shen, and P.Tribedy PRC 99, 044908 (2019)

- Two-subevents reduce the short-range non-flow effect on in the three-particle correlations
- However both models fit the v_n they need additional constrains in order to describe the 3-particle correlations.

Results

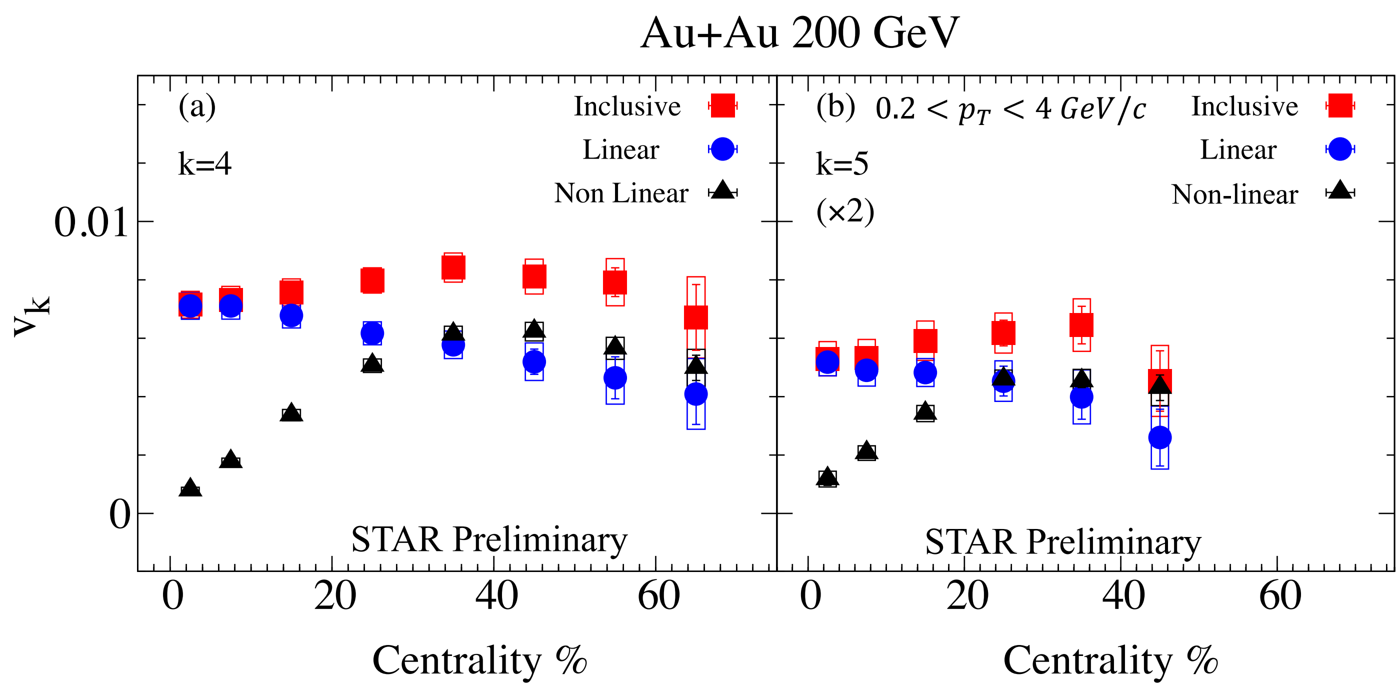
The p_T-differential dependence of the inclusive, linear and non-linear v_4 for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are shown



- ➢ The inclusive, linear and non linear v_4 shows a characteristics p_T dependence
- ➢ The linear v_4 term dominates in central collisions

Results

Centrality dependence of the inclusive, linear and non-linear v_n (n=4,5) for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

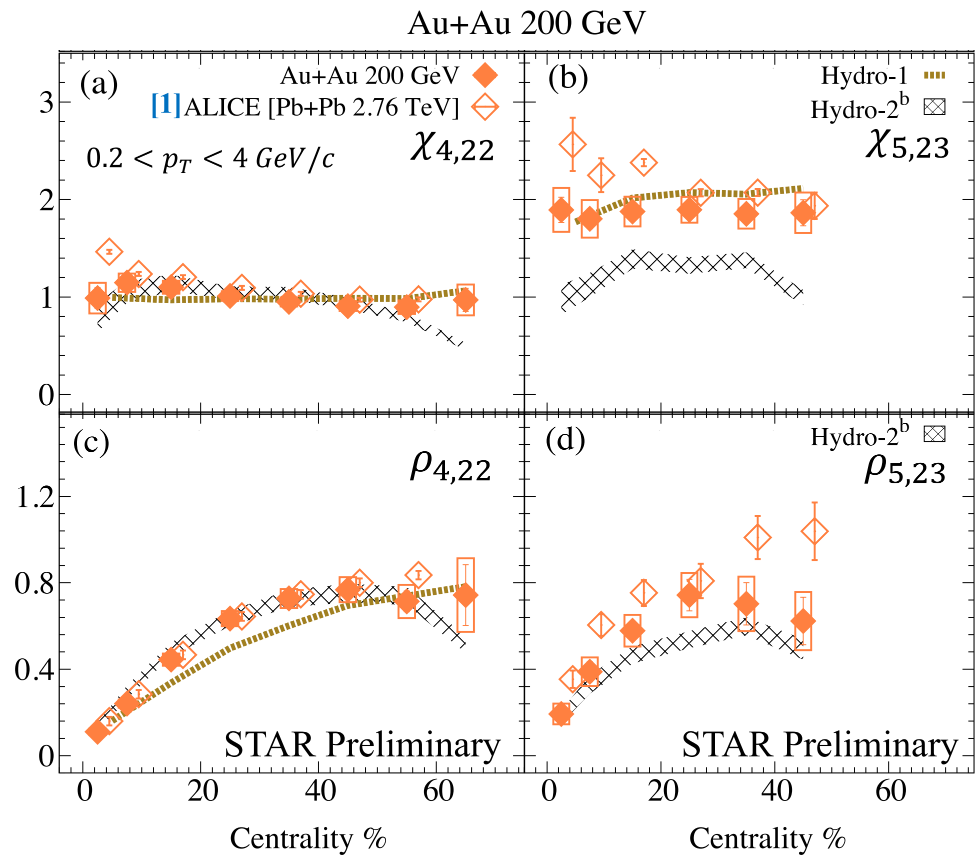


- The linear v_n (n=4,5) terms dominate in central collisions

Results

Centrality dependence of the non-linear mode-coupling coefficients, $\chi_{4,22}$ and $\chi_{5,23}$ and the EP angular correlations $\rho_{4,22}$ and $\rho_{5,23}$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

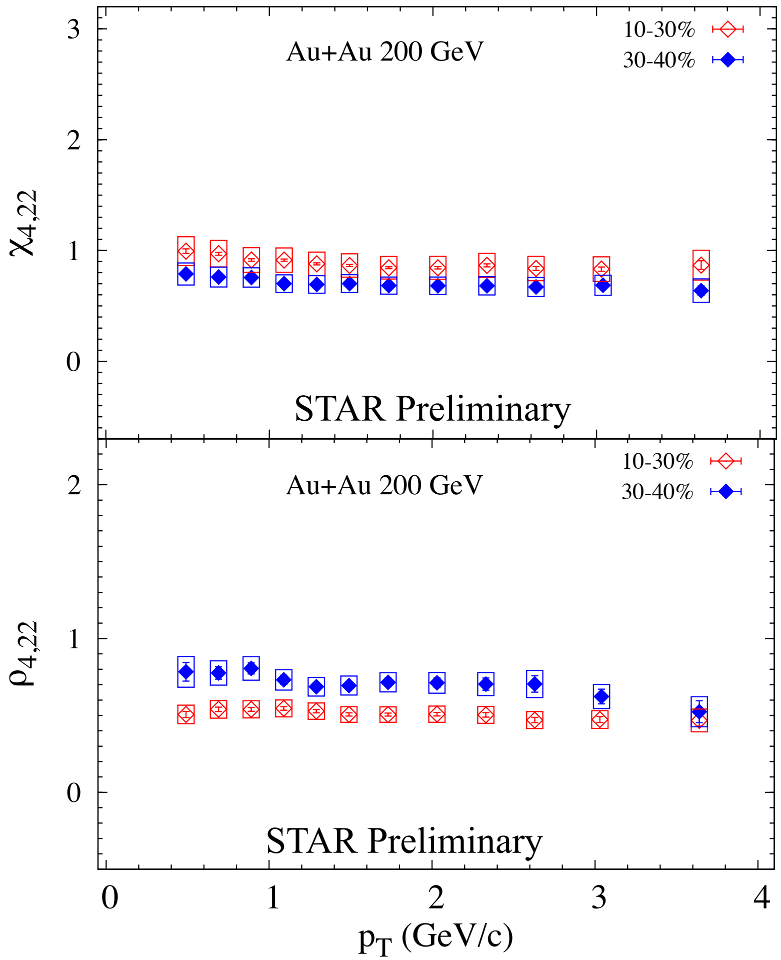
- $\rho_{k,nm}$ and $\chi_{k,nm}$ show a weak beam energy dependence
- $\chi_{k,nm}$ shows a weak centrality dependence (weak viscous effect)
- $\rho_{k,nm}$ shows a strong centrality dependence



[1]ALICE Collaboration
PLB 773 68 (2017)

Results

The p_T-differential dependence of the non-linear mode-coupling coefficients, $\chi_{4,22}$ and the EP angular correlations $\rho_{4,22}$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are shown



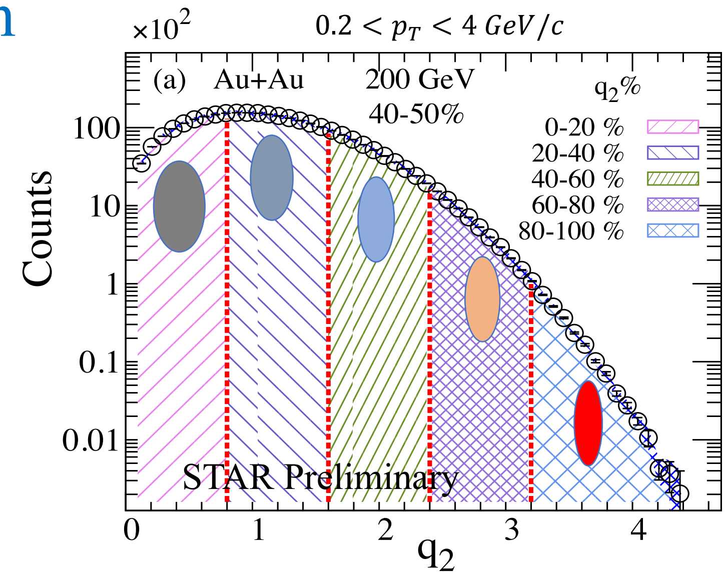
- $\chi_{4,22}$ shows a weak p_T dependence
- $\rho_{4,22}$ shows a weak p_T dependence
  - ✓ Dynamical final-state effects are significantly less than the initial-state effect?

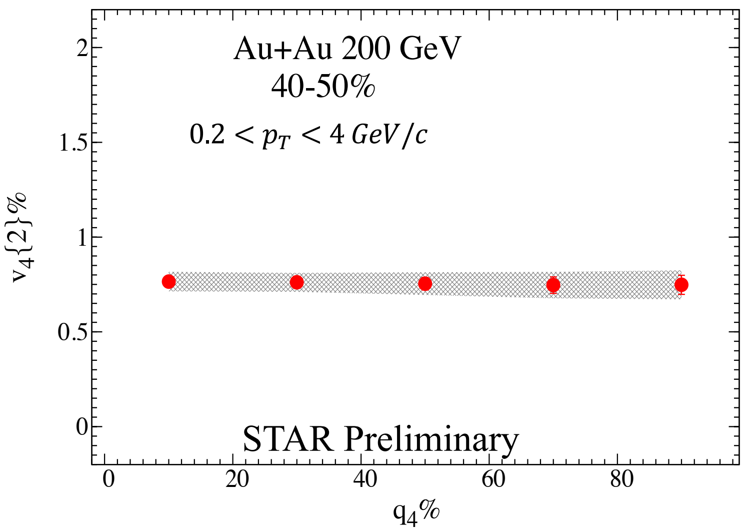
The system size via event shape selection

- Events are further subdivided into groups with different q_2 magnitude:

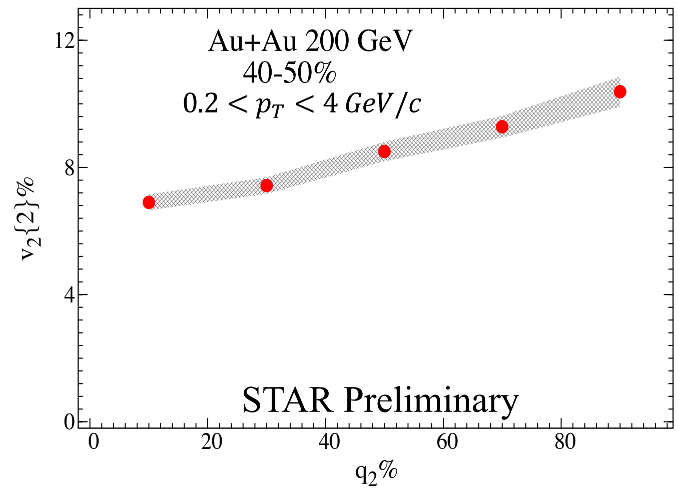
$$Q_{n,x} = \sum_{i=1}^{M} \cos(n\,\varphi_i) \qquad Q_{n,y} = \sum_{i=1}^{M} sin(n\,\varphi_i)$$

$$|Q_n| = \sqrt{Q_{n,x}^2 + Q_{n,y}^2} \qquad q_n = \frac{|Q_n|}{\sqrt{M}}$$





- $v_4\{2\}$ shows no sensitivity to q_4

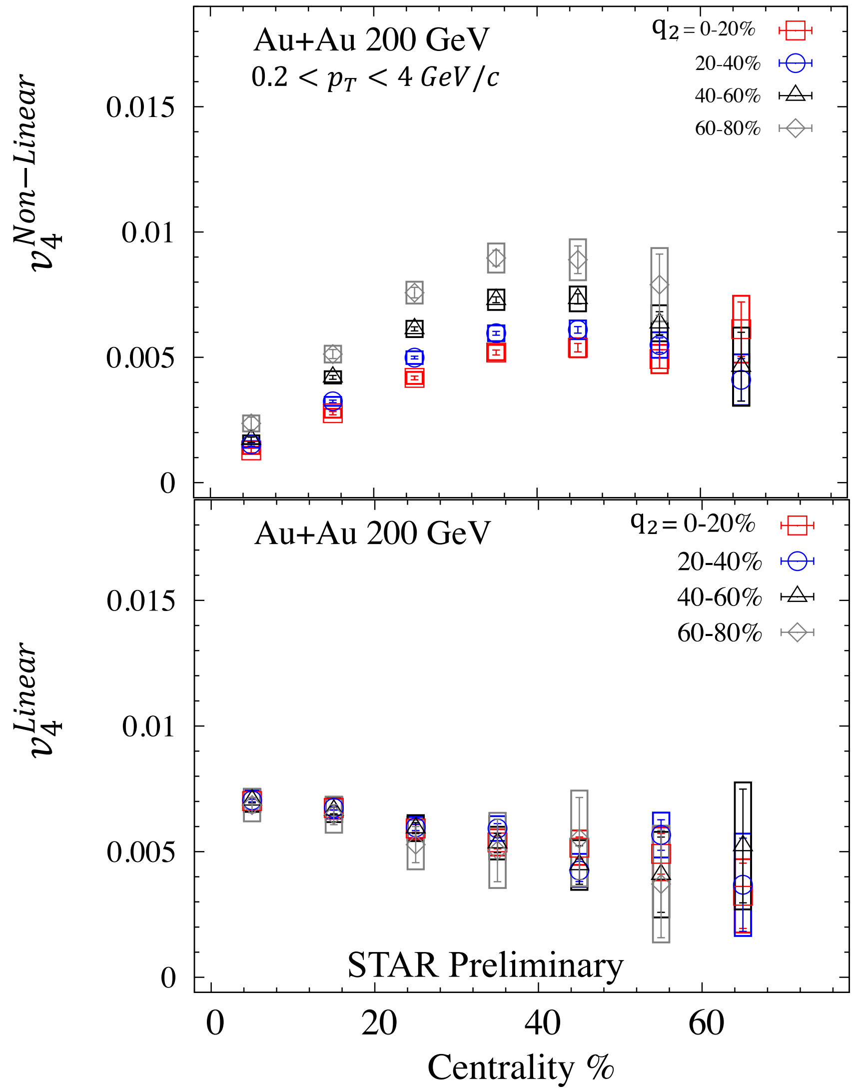


- $v_2\{2\}$ increases linearly with q_2
  q_2 is good event-shape selector

ALICE Collaboration
PRC 93, 034916 (2016)

Results

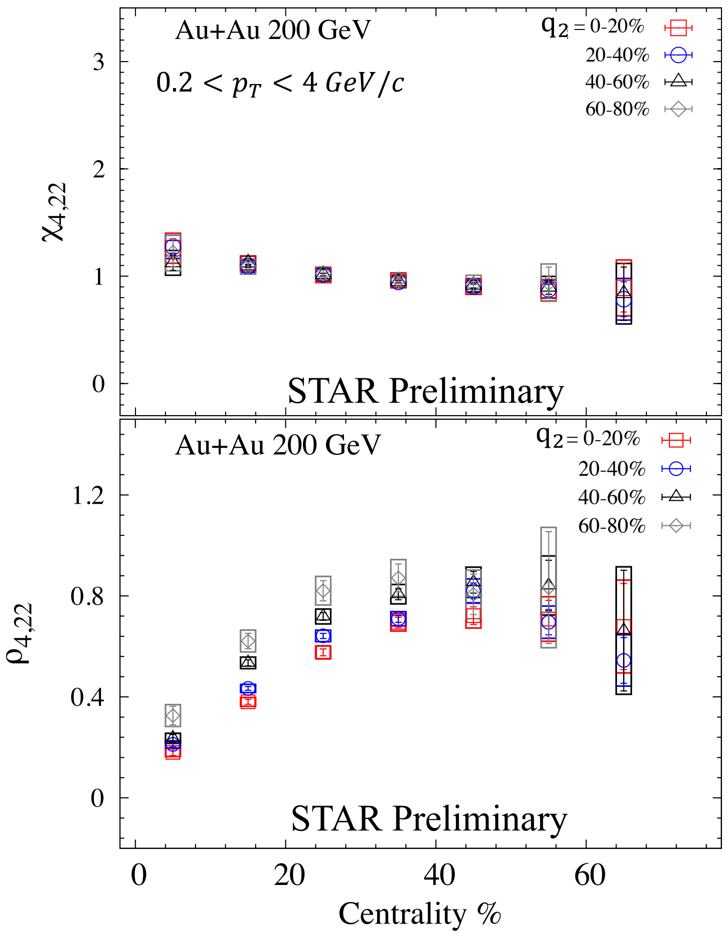
Centrality dependence of the linear and non-linear v_4 for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with different event shape selections (q_2%)



- The Non-linear v_4 increases with q_2 selections
- The Linear v_4 shows a weak sensitivety to q_2 selections

Results

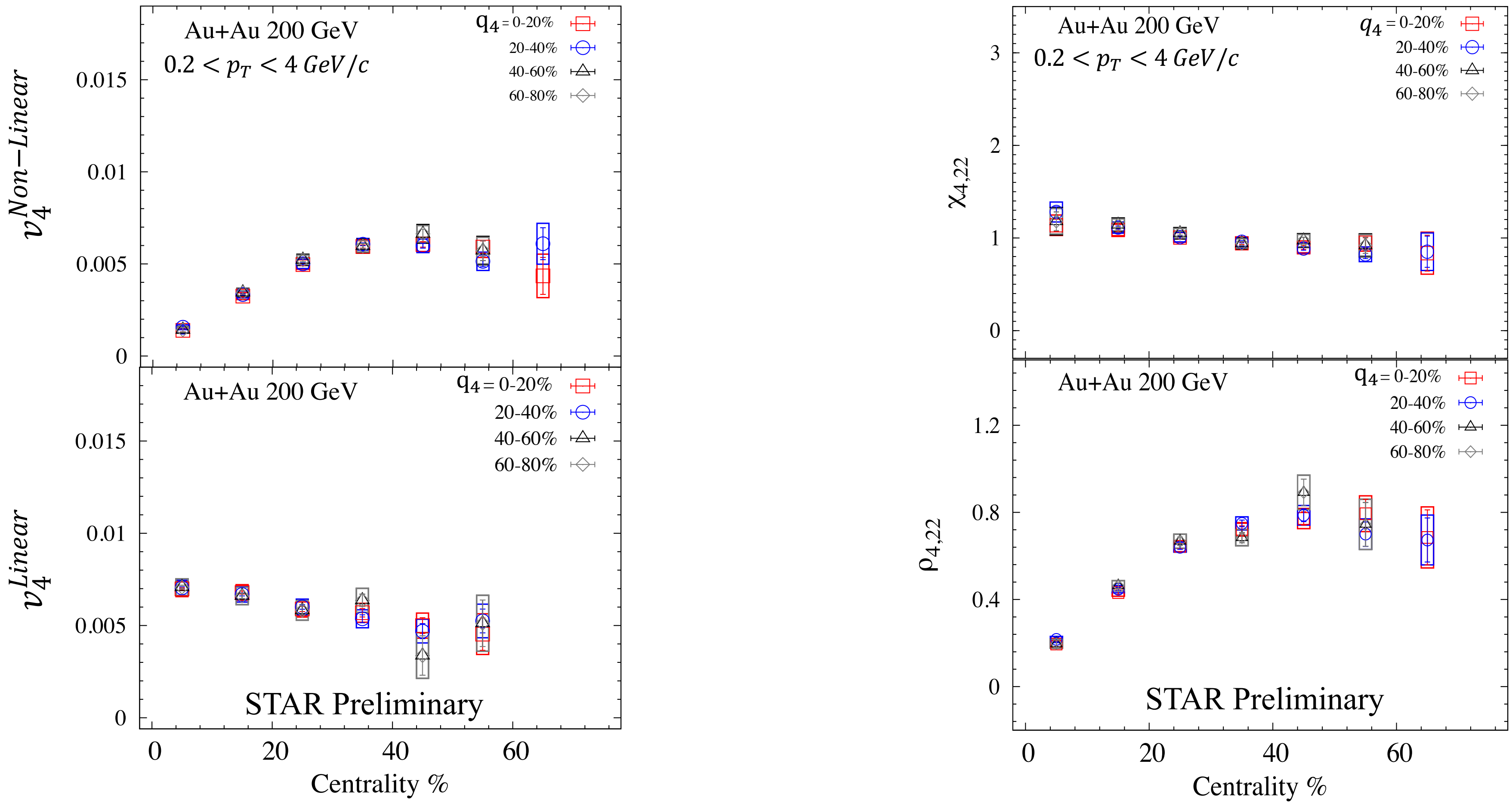
Centrality dependence of the $\rho_{4,22}$ and $\chi_{4,22}$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with different event shape selections (q_2)



- The $\chi_{4,22}$ shows a weak sensitivety to q_2 selections
- The $\rho_{4,22}$ increases with q_2 selections

Results

Centrality dependence of the linear and non-linear v_4 and the assosatied $\rho_{4,22}$ and $\chi_{4,22}$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with different event shape selection (q_4)



- Linear and non linear v_4 and the assosatied $\rho_{4,22}$ and $\chi_{4,22}$ show weak sensitivety to q_4 selections

Conclusion

The linear and mode-coupled contributions to the higher-order anisotropic flow coefficients v_4 and v_5, have been studied using two- and multi-particle correlations in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

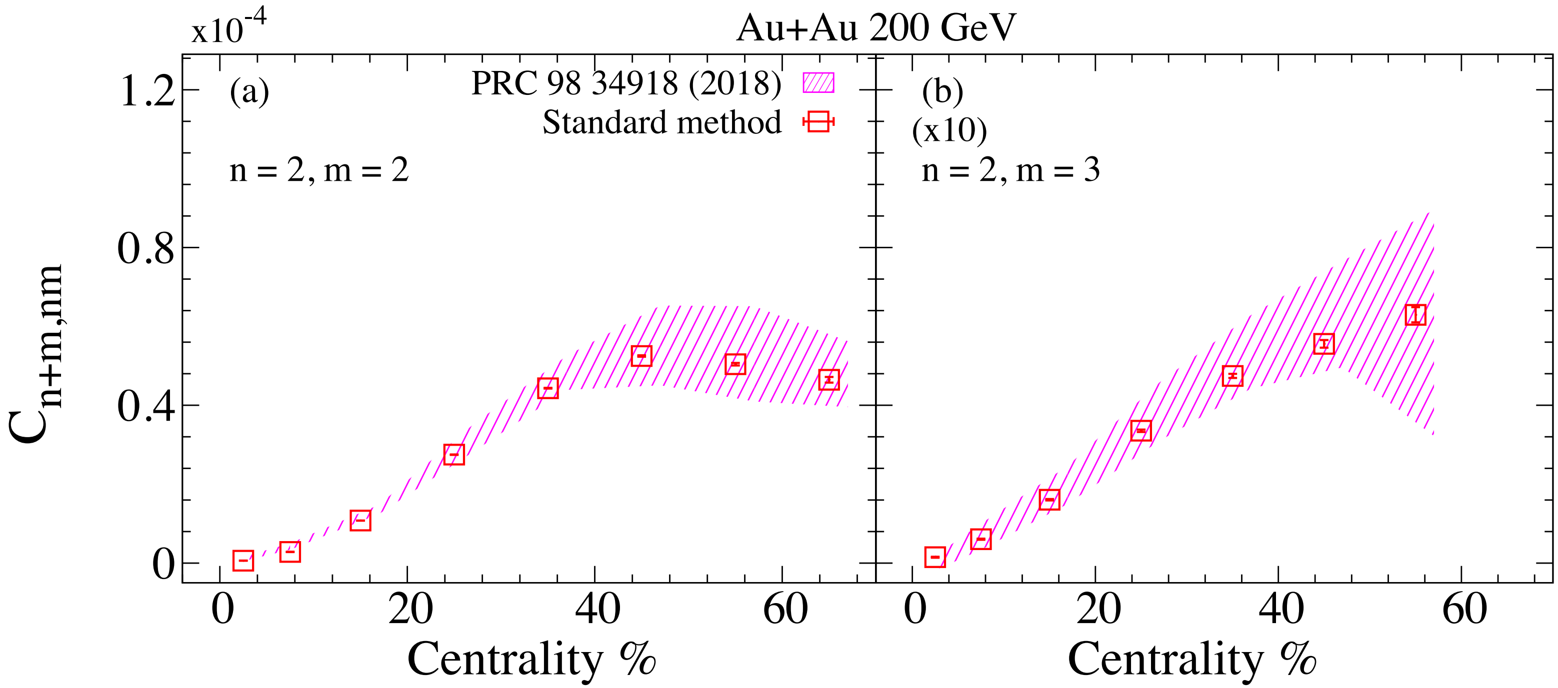
- ➢ Two-subevents reduce the short-range non-flow effect on in the three-particle correlations
- ❖ The linear v_n (n=4,5) terms dominate in central collisions
- ❖ The $\chi_{\mathrm{k,nm}}$ show a weak centrality dependence (weak viscous effects)
- ❖ The $\chi_{4,22}$ and $\rho_{4,22}$ show a weak $\mathrm{p_T}$ dependence
  - ✓ Dynamical final-state effect are significantly less than the initial-state effect?

- ❖ The system size via event shape selection
  - ➢ The non-linear v_4 and $\rho_{4,22}$ increase with $\mathrm{q_2}$ selections
  - ➢ The linear v_4, $\chi_{4,22}$ show no sensitivity to $\mathrm{q_2}$ selections
  - ➢ The (Non)Linear v_4, $\chi_{4,22}$ $\rho_{4,22}$ and show no sensitivity to $\mathrm{q_4}$ selections

The integrated and differential measurements, which are compared to viscous hydrodynamic model calculations, will add important constraints for the initial-state models

Thank You

Backup



Good agreement with the STAR published measurements