An Overview on Flow Fluctuations at STAR

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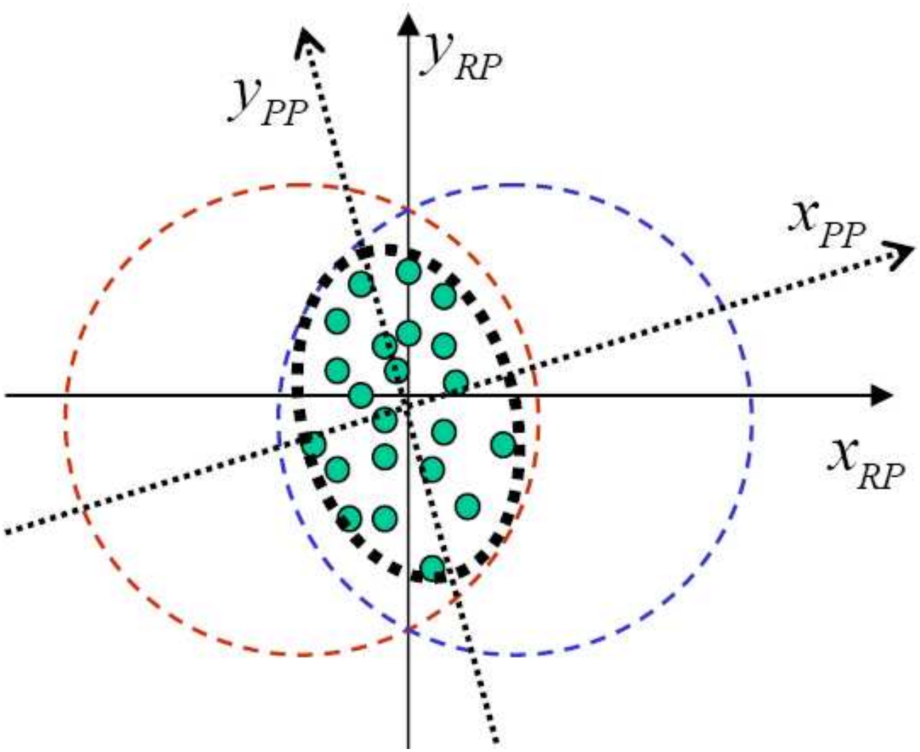
The 2nd Workshop on Initial State Fluctuations and Final State Correlations

Chengdu, China, August 11-14

Outline

- Introduction
- 2- and 4- particle cumulants and their implication on flow fluctuations/nonflow
- Isolate flow, nonflow and flow fluctuations
- Triangular flow
- Summary

Participant/Reaction Plane



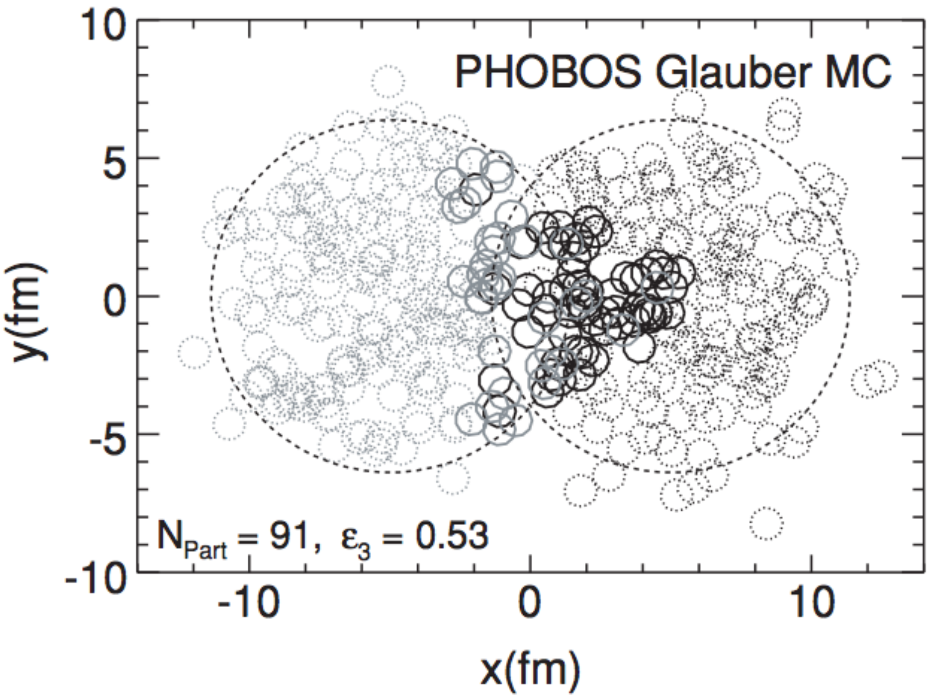
- **RP: the reaction plane**
  - Defined by the impact parameter
  - Initial geometry: ε_{std}
- **PP: the participant plane**
  - Defined by the major axis of the created system
  - Initial geometry: ε_{part}

S. A. Voloshin, A. M. Poskanzer, A.Tang and G.Wang, PLB, 659 (2008), 537-541

The fluctuation in initial eccentricity of the participant zone -> flow fluctuations

Note: flow fluctuations can be due to different reasons, we focus on the fluctuations related to eccentricity fluctuations

Triangular Flow



B. Alver and G. Roland, PRC81, 054905 (2010)

Event-by-Event fluctuations

Triangular anisotropy in the initial geometry

Triangular anisotropy in the final momentum space

$<v_3^2>^{1/2}$

v_3 is sensitive to the initial collision geometry fluctuations

Flow Methods

- Two-particle:
  - $v_n\{2\}$: each particle with every other particle
  - $v_n\{subEP\}$: each particle with the EP of the other subevent
  - $v_n\{EP\}$ “standard”: each particle with the EP of all the others
  - $v_n\{SP\}$: same as $v_n\{EP\}$, weighted with the magnitude of the Q vector
- Many-particle:
  - $v_n\{4\}$: 4-particle-correlation - 2 * (2-particle-correlation)^2
  - $v_n\{LYZ\}$: Lee-Yang Zeros multi-particle correlation

- Different sensitivities to nonflow and fluctuations

Review of azimuthal anisotropy: S. Voloshin, A. Poskanzer and R. Snelling, arXiv: 0809.2949

Measurements with Cumulants Method

$$v_2\{4\}^2 \approx \langle v_2 \rangle^2 - \sigma_{v_2}^2$$

When $\sigma_{v_2}/\langle v_2 \rangle \ll 1$

Nonflow　Flow fluctuations

$$v_2\{2\}^2 - v_2\{4\}^2 \approx \delta_2 + 2\sigma_{v_2}^2$$

An upper limit to

$$R_{v(2-4)} = \sqrt{\frac{v_2\{2\}^2 - v_2\{4\}^2}{v_2\{2\}^2 + v_2\{4\}^2}}$$

by setting $\delta_2 = 0$. → $\sigma_{v_2}/\langle v_2 \rangle$

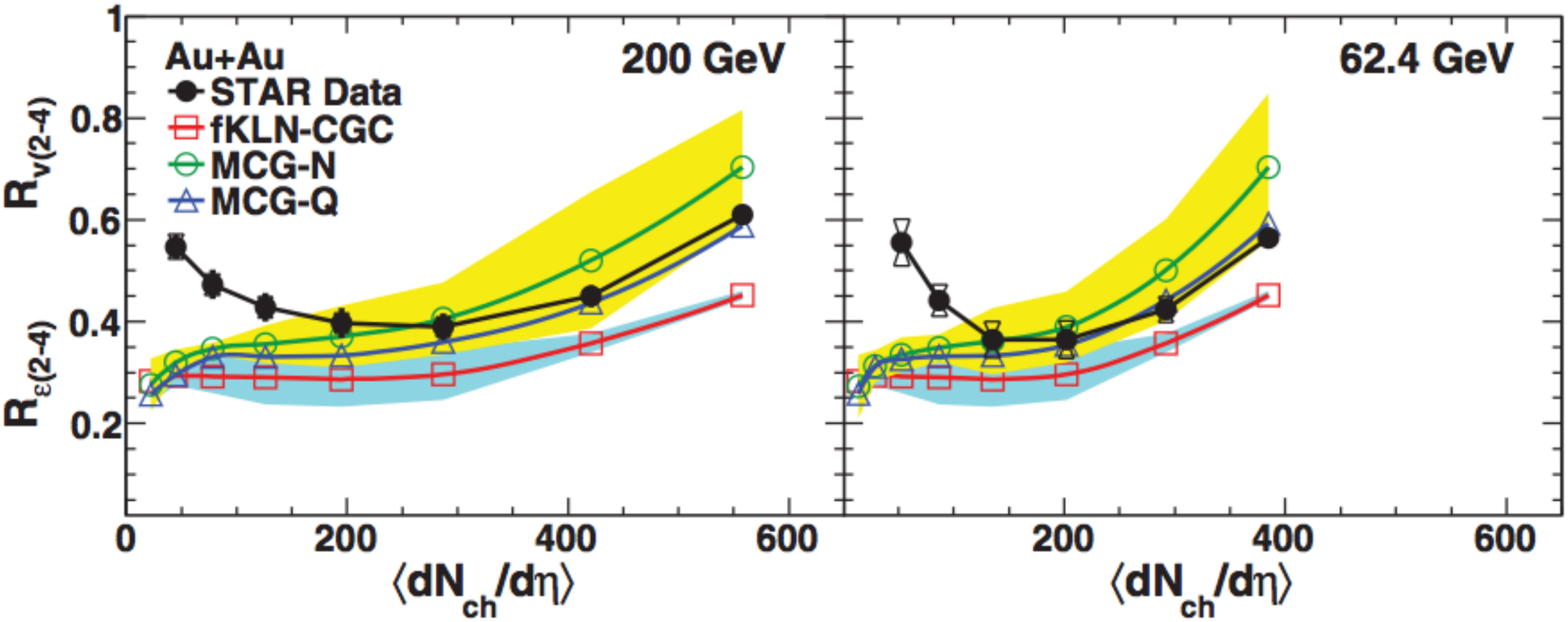
$$R_{\varepsilon(2-4)} = \sqrt{\frac{\varepsilon\{2\}^2 - \varepsilon\{4\}^2}{\varepsilon\{2\}^2 + \varepsilon\{4\}^2}}$$

$\sigma_\varepsilon \ll \varepsilon$ → $\sigma_\varepsilon/\langle \varepsilon \rangle$

$$\sigma_{v_2} \approx \langle v_2 \rangle \frac{\sigma_\varepsilon}{\varepsilon} \longrightarrow \delta_2 \approx v_2\{2\}^2 - v_2\{4\}^2 \left(\frac{\varepsilon^2 + \sigma_\varepsilon^2}{\varepsilon^2 - \sigma_\varepsilon^2} \right)$$

Estimate the contribution to v_2 fluctuations from eccentricity fluctuations

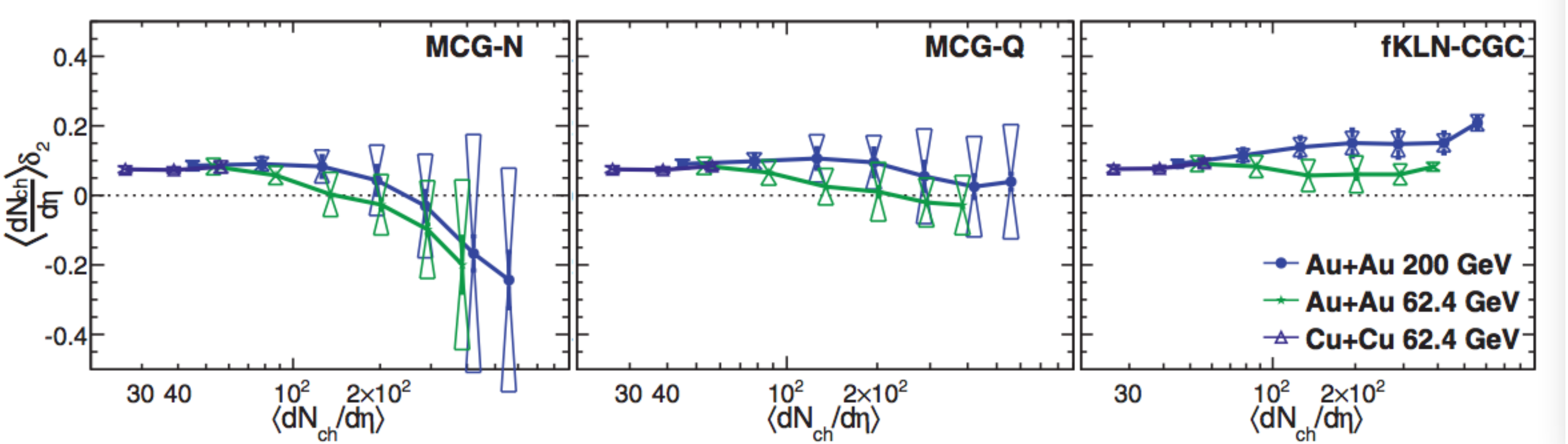
Upper Limit on Relative Fluctuations



STAR: PRC86, 014904(2012)

- In peripheral collisions, data exceeds the eccentricity model
  - Larger nonflow contribution in this region
- fKLN-CGC model lies below the upper limit
- MCG-N and MCG-Q models reach the upper limit in the central collision
  - Nonflow would be small

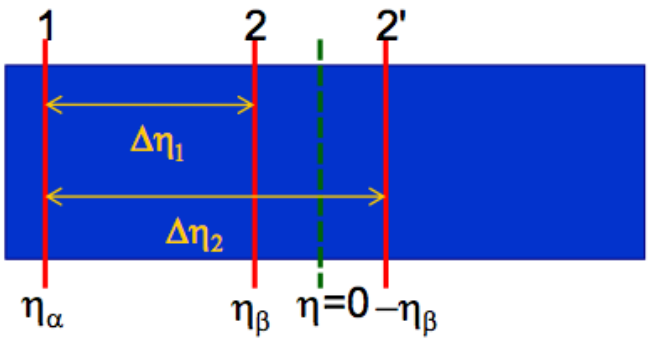
Nonflow



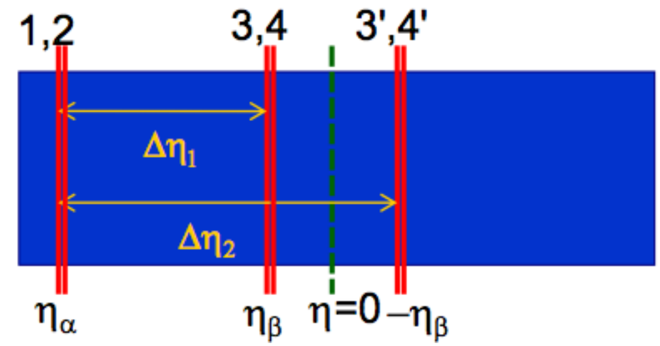
STAR: PRC86, 014904(2012)

- Nonflow scaled by the number of mean charged hadrons to cancel out the combinatorial 1/Multiplicity dependence
- The nonflow is systematically larger at 200 GeV than 62.4 GeV
- MCG-N model leaves almost no room for fluctuations beyond those from the initial eccentricity fluctuations
- fKLN-CGC model leaves the most room for fluctuations beyond initial eccentricity fluctuations

Isolate Nonflow and Fluctuations



Two pairs of 2-particle cumulants:
The first pair is one particle η_α, another particle η_β. The second pair is one particle η_α, another particle $-\eta_\beta$.



Two pairs of 4-particle cumulants:
The first pair is two particle η_α, another two particle η_β. The second pair is two particle η_α, another two particle $-\eta_\beta$.

L. Xu et al, : PRC86, 024901(2012)

$$\mathcal{V}\{\eta_\alpha,\eta_\beta\} = \nu(\eta_\alpha)\nu(\eta_\beta) + \sigma(\eta_\alpha)\sigma(\eta_\beta) + \sigma'(\Delta\eta) + \delta(\Delta\eta)$$

'flow' — flow fluct. — Δη-dep fluct. — Δη-dep nonflow

$$\Delta\mathcal{V}\{2\} = \mathcal{V}\{-\eta_\alpha,-\eta_\beta\} - \mathcal{V}\{-\eta_\alpha,\eta_\beta\} = \Delta\sigma' + \Delta\delta$$

$$\nu(-\eta_\beta) = \nu(\eta_\beta) \quad \sigma(-\eta_\beta) = \sigma(\eta_\beta)$$

- 4-particle cumulant:

$$\mathcal{V}^{1/2}\{\eta_\alpha,\eta_\alpha,\eta_\beta,\eta_\beta\} = \nu(\eta_\alpha)\nu(\eta_\beta) - \sigma(\eta_\alpha)\sigma(\eta_\beta) - \sigma'(\Delta\eta)$$

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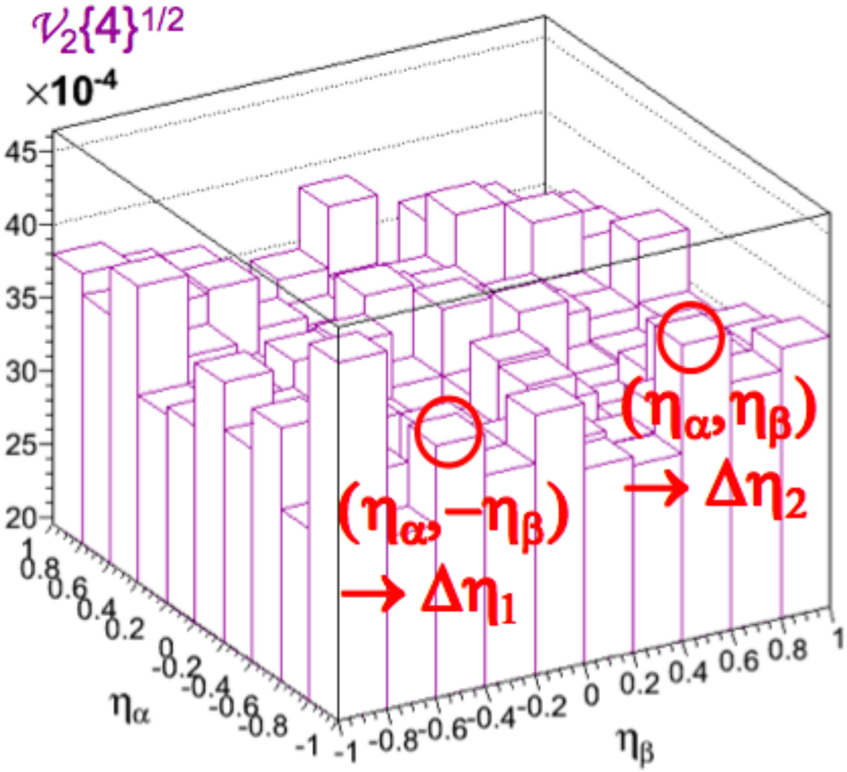
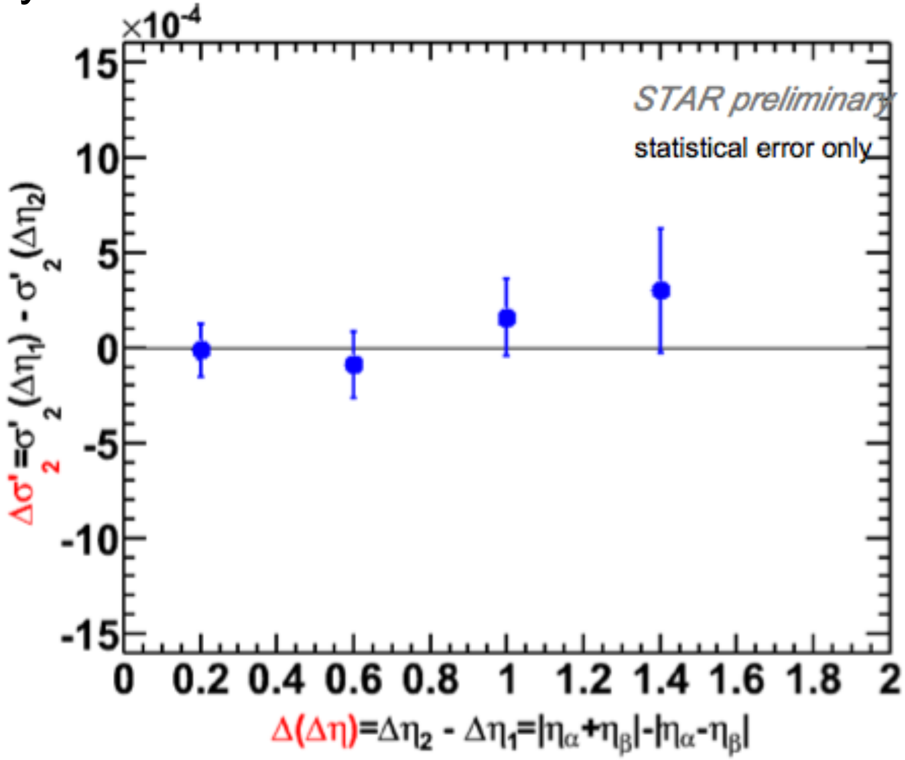
$$\Delta\mathcal{V}\{4\}^{1/2} = -\Delta\sigma'$$

Δη-dependent Fluctuations

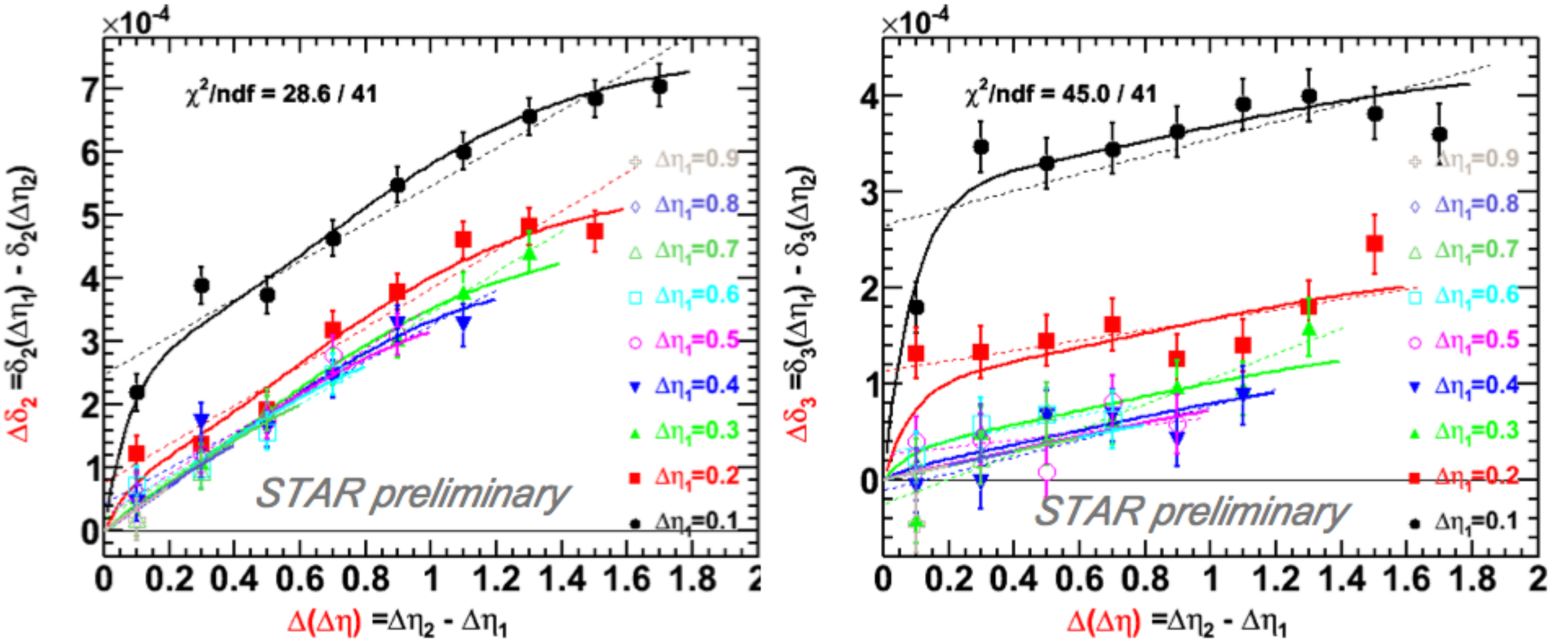
Centrality: 20-30%





➢ Flow fluctuation appears independent of Δη

Δη-dependent Nonflow



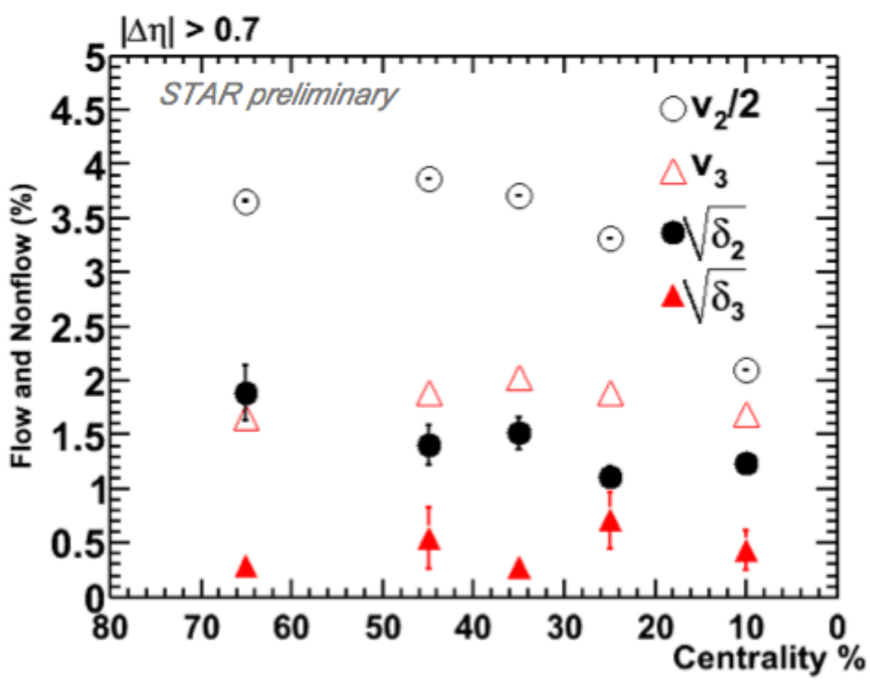
$$\Delta\delta(\Delta\eta_1,\Delta\eta_2) = a(e^{-\Delta\eta_1/b} - e^{-\Delta\eta_2/b}) + A(e^{-\Delta\eta_1^2/2\sigma^2} - e^{-\Delta\eta_2^2/2\sigma^2})$$

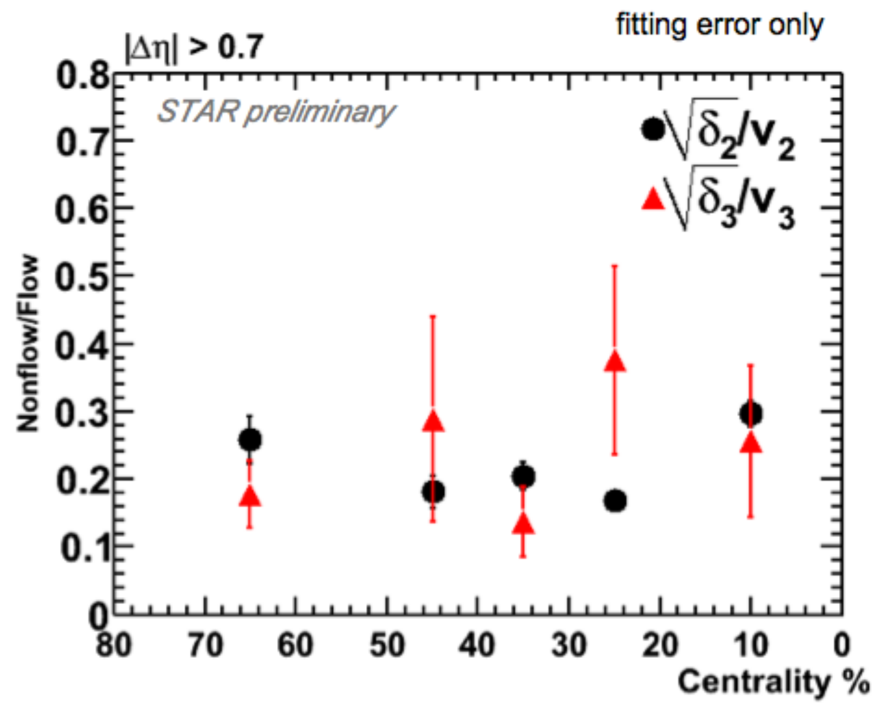
$$\delta(\Delta\eta) = ae^{-\Delta\eta/b} + Ae^{-\Delta\eta^2/2\sigma^2}$$

Centrality: 20-30%

- Parameterizing nonflow with Gaus + Exp

Nonflow vs. Centrality

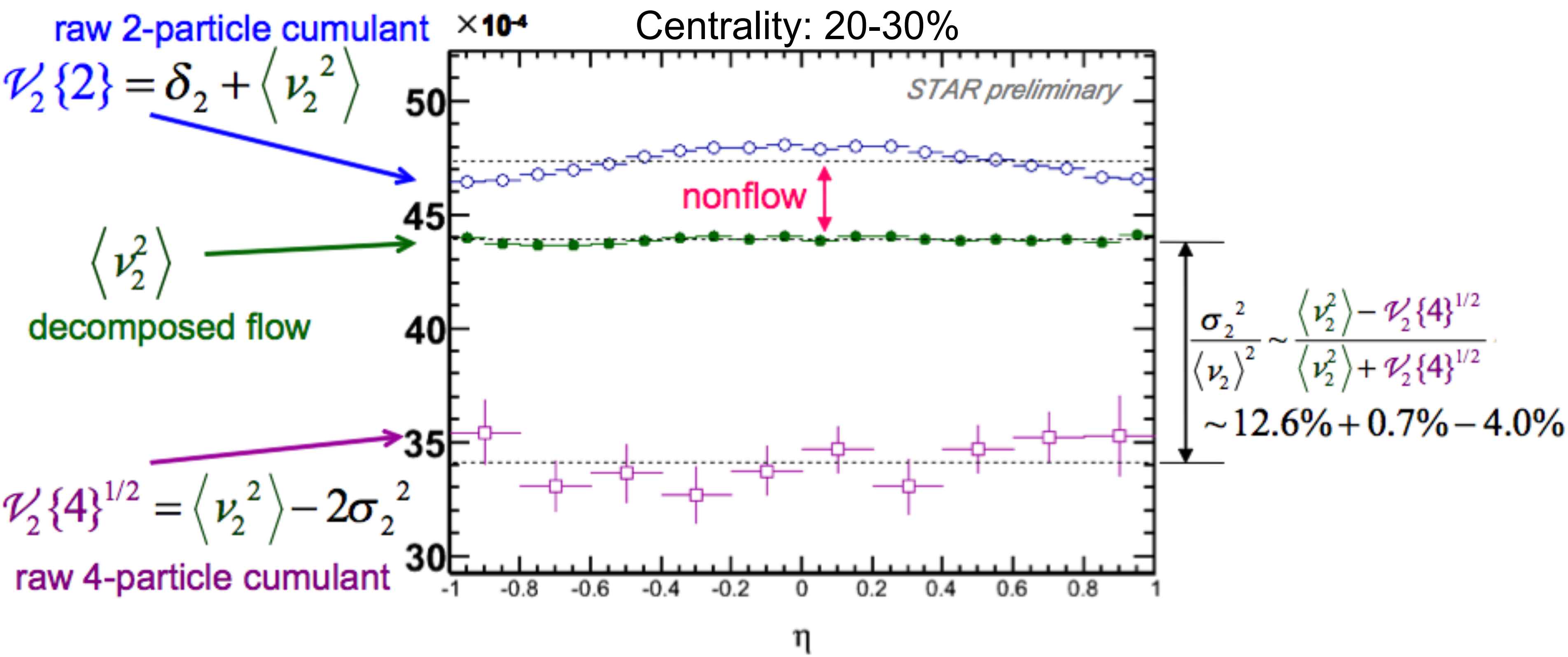




For $|\eta| > 0.7$:

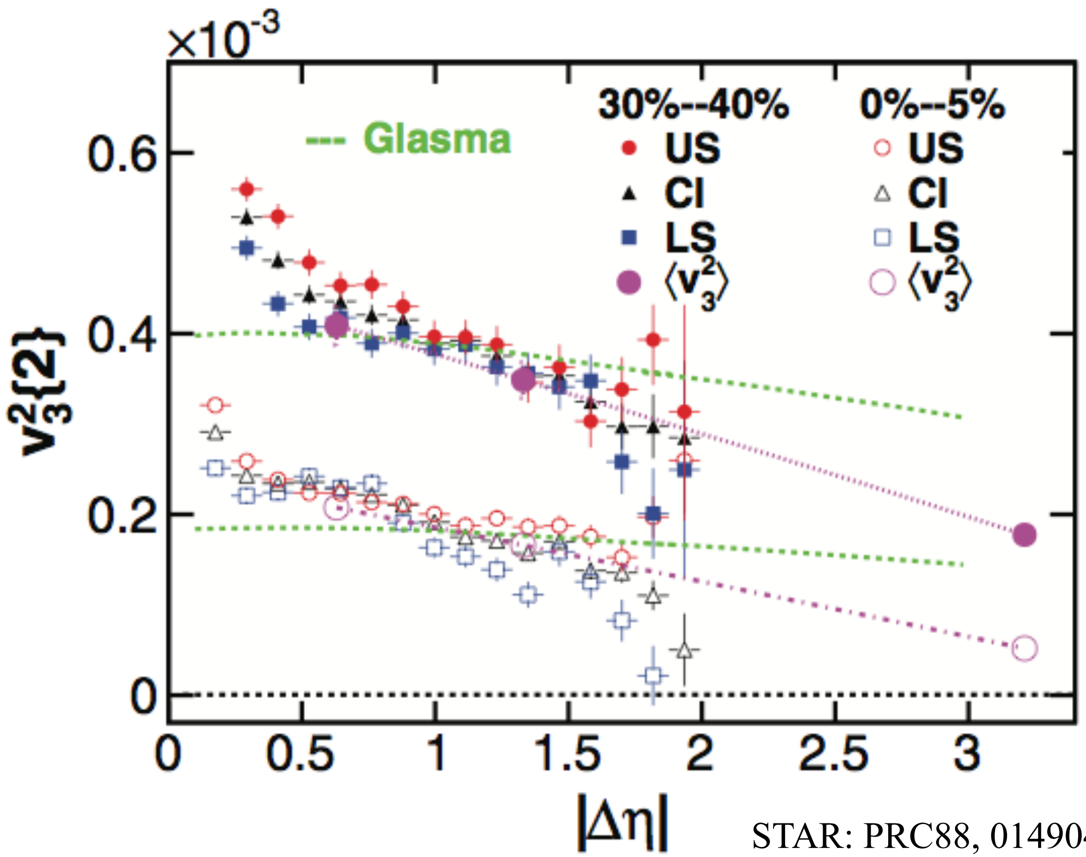
- The decomposed $\sqrt{\langle\delta_2\rangle}/\langle v_2\rangle \sim 20\%$
- $\langle\delta_2\rangle/\langle v_2^2\rangle \sim 4\%$

Flow Fluctuations



- The decomposed flow seems independent of η
- $\sigma_2^2/\langle v_2 \rangle^2 \sim 13\%$

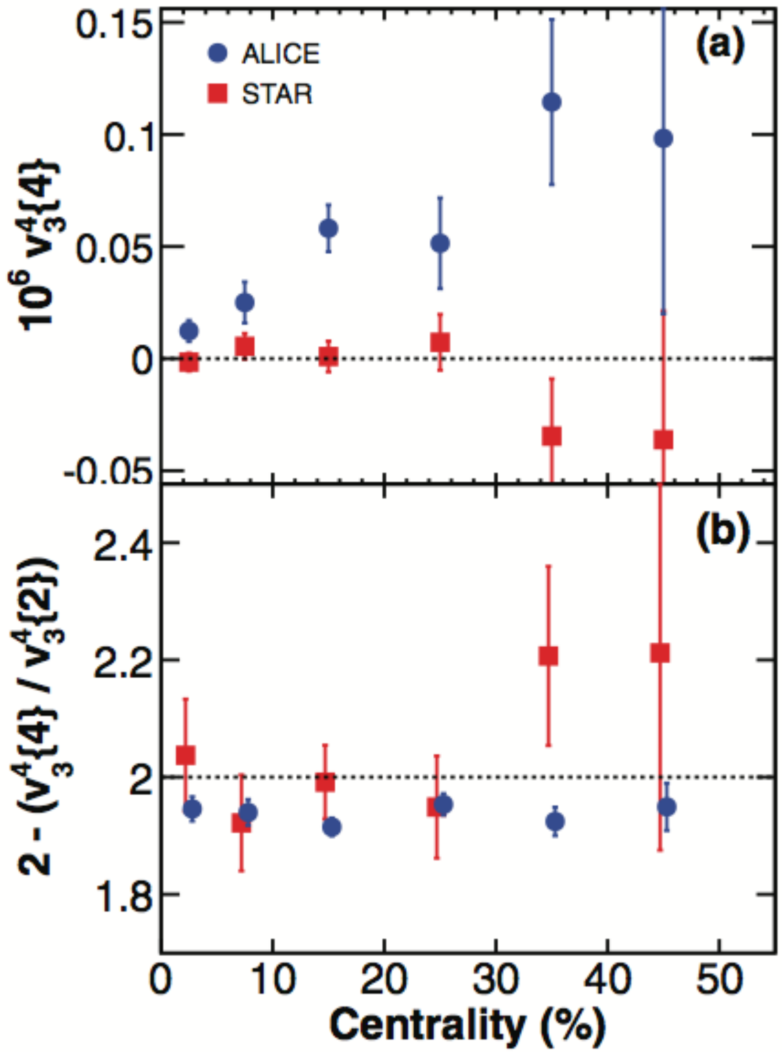
η-gap Dependent v_3



STAR: PRC88, 014904(2013)

- v_3 strongly depends on the η-gap
- The glasma model shows decrease trend with Δη, but not as much as data
- One have to compare results to models with approximately the same Δη as the experiment

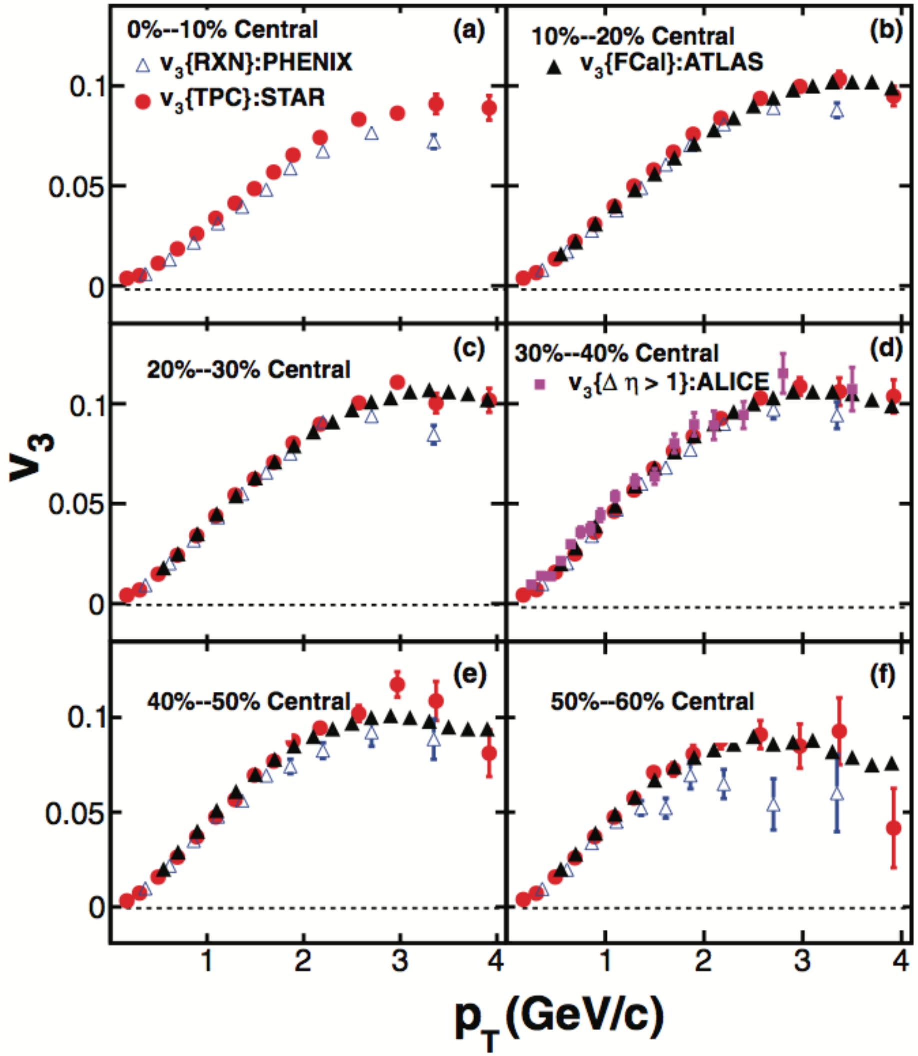
4-particle Cumulants v_3



STAR: PRC88, 014904(2013)

- 4-particle cumulants suppress nonflow and Gaussian fluctuations
- STAR data consistent with just nonflow + Gaussian fluctuations

RHIC and LHC

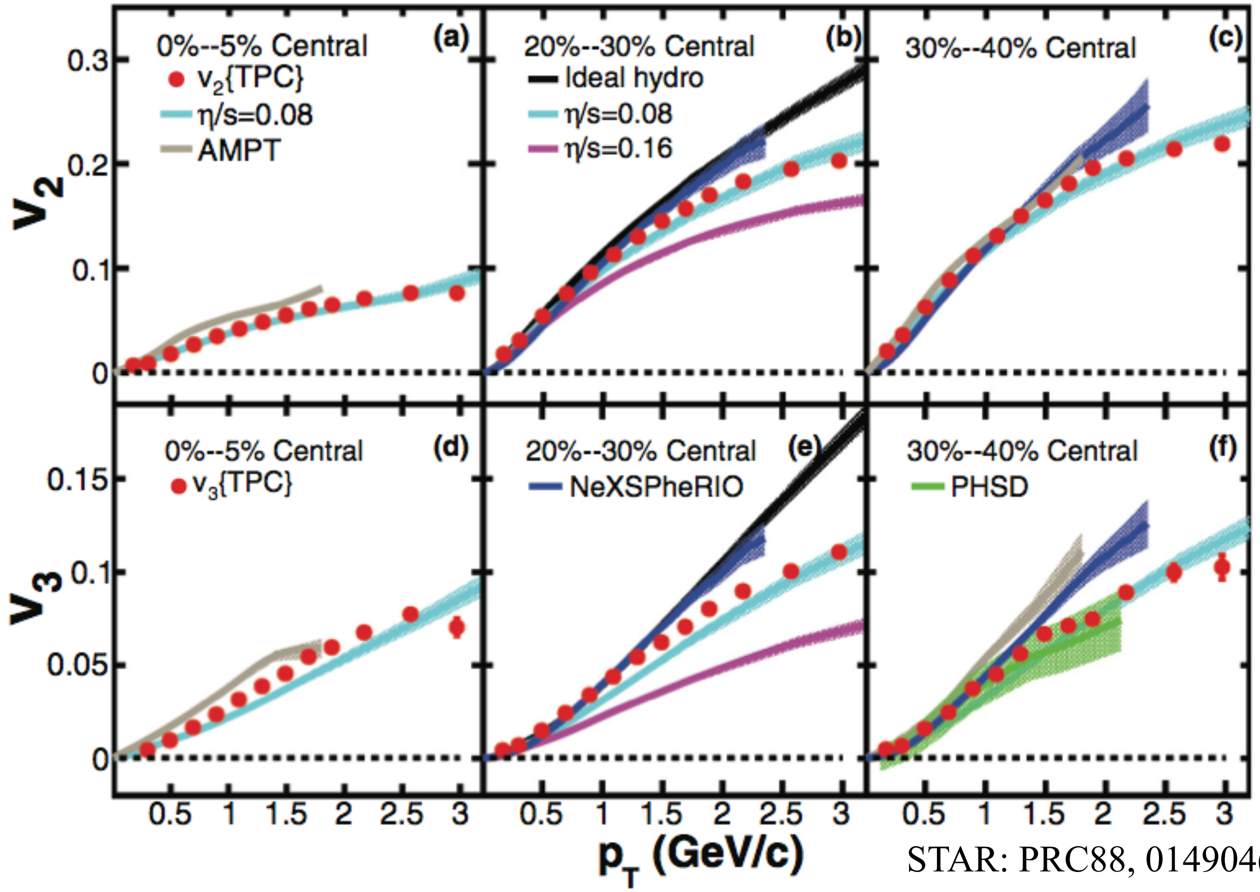


STAR: PRC88, 014904(2013)

- The v_3\{TPC\} values agree with ALICE and ATLAS, as well as PHENIX, despite different $\Delta\eta$

	|η|	<Δη>	
STAR	<1.0	0.63	200 GeV
PHENIX	<0.35	≈1.9	
ALICE	<0.8	>1.0	2.76 TeV
ATLAS	<2.5	>0.8	

Comparison to Hydro



STAR: PRC88, 014904(2013)

- The initial conditions in the models come from MC-Glauber
- NeXSPheRIO model reproduce the data well for 20-30% and 30-40% at pT < 1 GeV/c
- Both v_2 and v_3 are better described by η/s ~ 0.08

Summary

- **MCG models reach the estimate upper limit of flow fluctuations for central Au+Au collisions, while the fKLN-CGC model falls within the limit**
- **The nonflow implied by the fluctuations in the MCG models leave less room for nonflow or other sources of fluctuations**
- **Isolation of nonflow and flow fluctuations using 2- and 4-particle cumulants between η bins**
  - **Nonflow estimate ~4% in v_2^2**
  - **Flow fluctuations estimate ~ 13% in v_2^2**

AuAu@200, 20-30%

- **The glasma model including fluctuations similarly shows decrease trend in the Δη dependence of v_3**
  - **v_3 is likely mainly due to Δη dependent fluctuations**
- **Similar as v_2, v_3 is better described by hydro model with η/s ~ 0.08 (MCG initial conditions)**