Azimuthal Anisotropy Measurement by STAR

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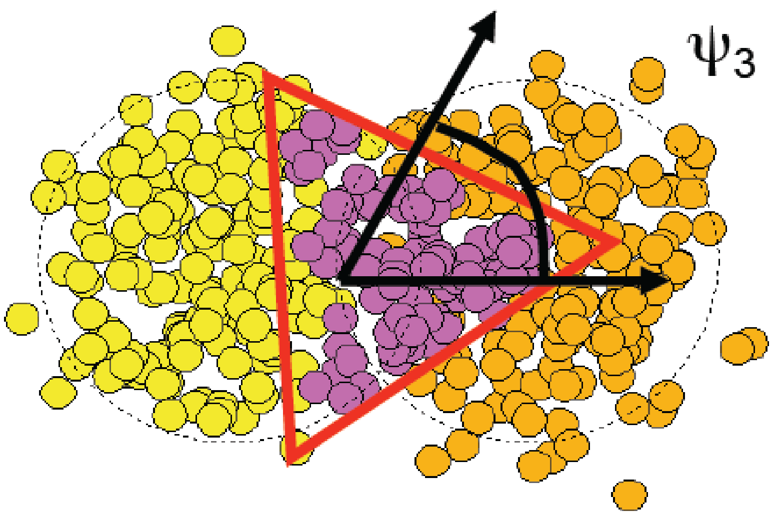
Outline

- Physics motivation
- Beam energy dependence
  - $v_2\{4\}(p_T)$
  - $v_2\{2\}$ and $v_2\{4\}$ difference
- v_3 measurement
  - Centrality, $\Delta\eta$, p_T dependence
- Flow fluctuation and nonflow
  - Isolation of nonflow and flow for v_2 from $\eta-\eta$ cumulant
  - v_2 fluctuation upper limit from $v_2\{2\}$, $v_2\{4\}$
- Summary

Concentrate on AuAu; dAu separate talk F. Wang

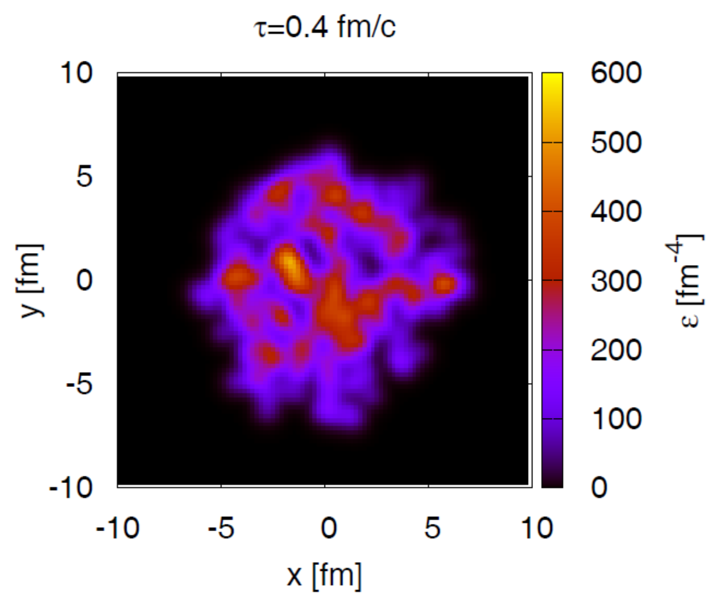
Physics Motivation

Glauber Model



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

Viscous Hydro.

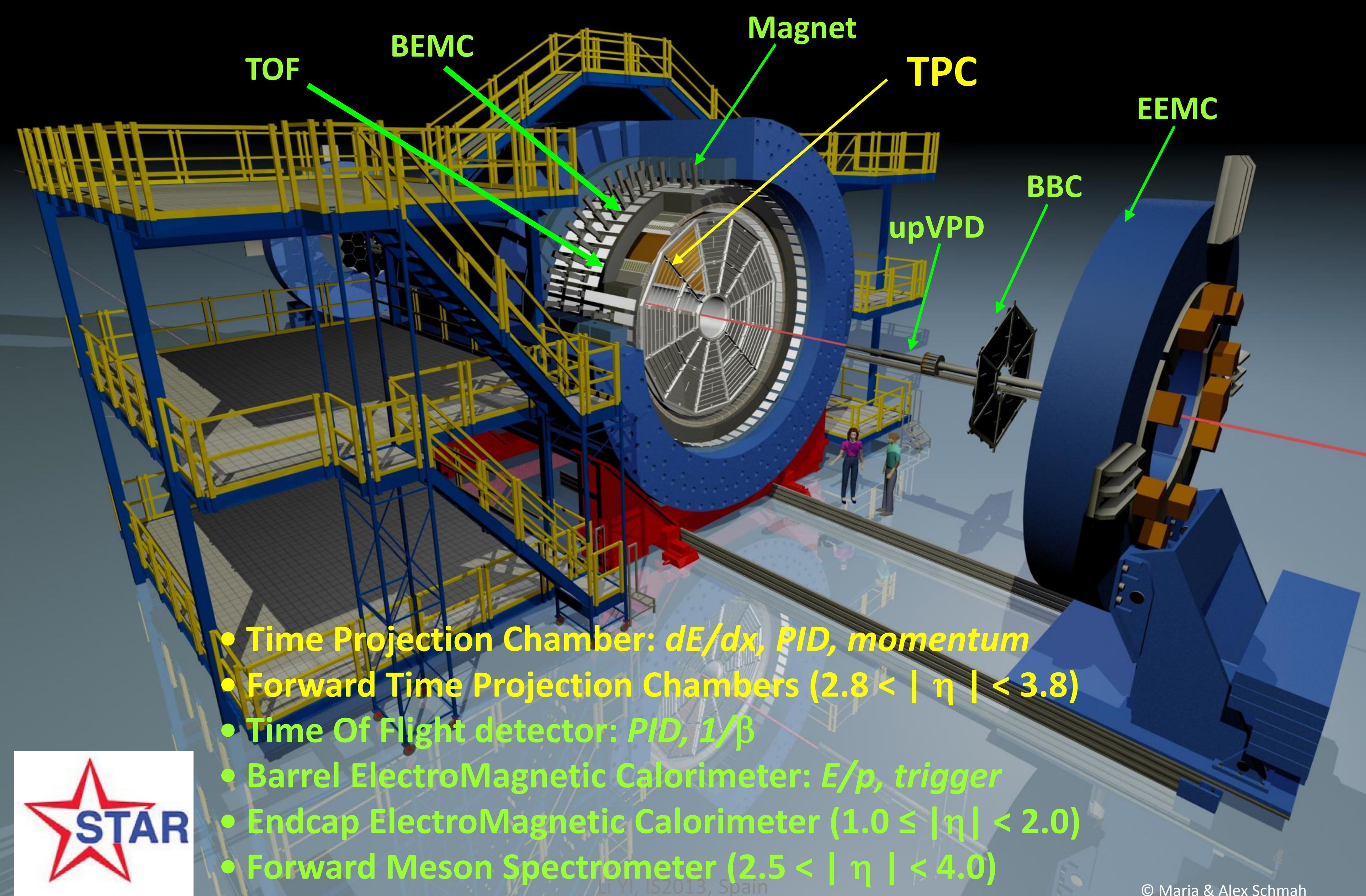


B. Schenke, S. Jeon, C. Gale PRL 106, 042301

- Particle collectivity to probe QGP early stage
- Event-by-event initial state geometry fluctuation
  -> Final state momentum anisotropy, odd harmonics
- Unknown reaction plane, fluctuation of participant plane
  -> Flow + flow fluctuation + nonflow

Few-particle correlation, unrelated to participant plane

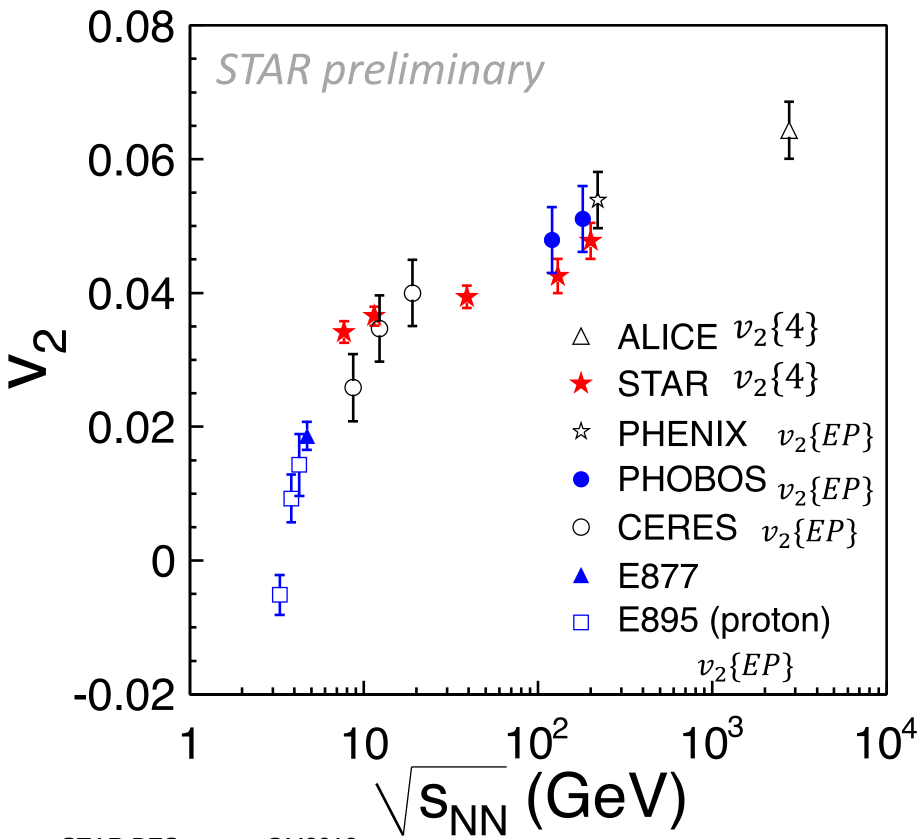
The Solenoidal Tracker At RHIC (STAR)



- Time Projection Chamber: *dE/dx, PID, momentum*
- Forward Time Projection Chambers (2.8 < | η | < 3.8)
- Time Of Flight detector: *PID, 1/*β
- Barrel ElectroMagnetic Calorimeter: *E/p, trigger*
- Endcap ElectroMagnetic Calorimeter (1.0 ≤ |η| < 2.0)
- Forward Meson Spectrometer (2.5 < | η | < 4.0)

STAR

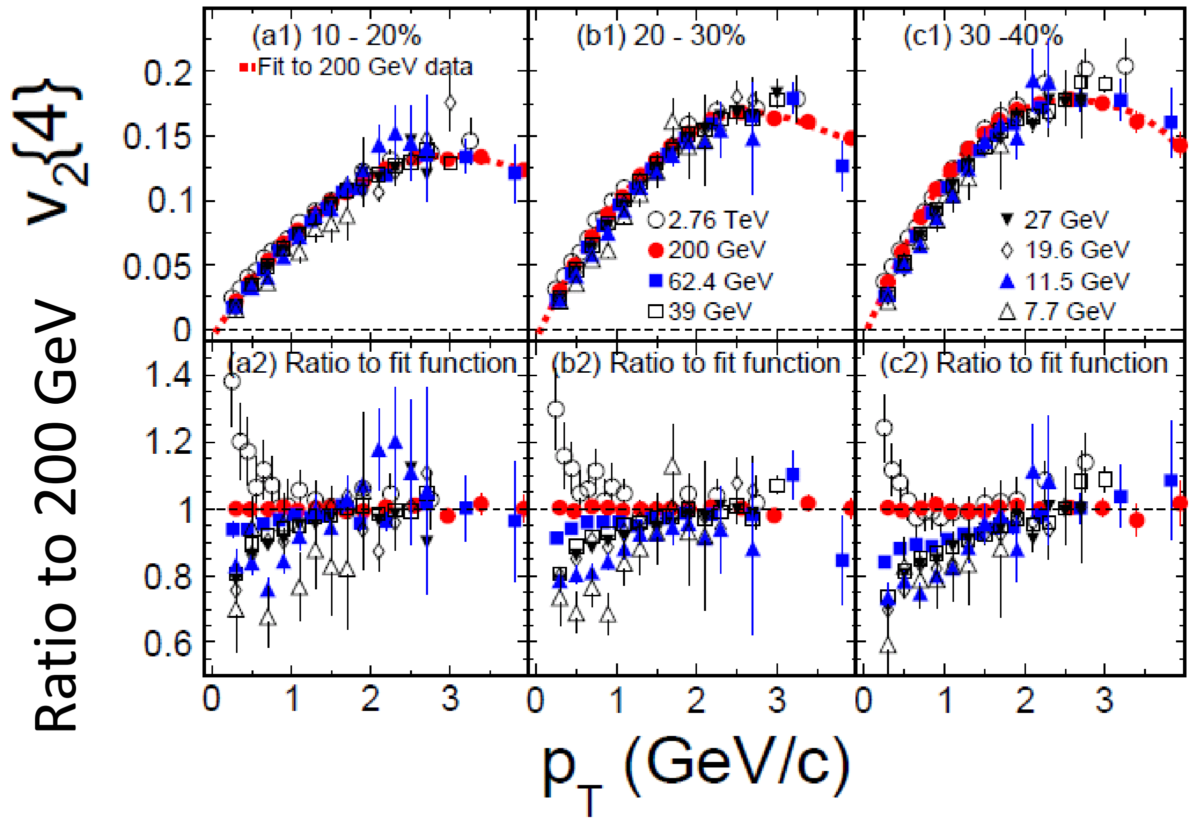
v_2 Beam Energy Dependence



- v_2 increases as beam energy.
  - $v_2(p_T)$
  - $\langle p_T \rangle$
  - particle composition

STAR BES energy QM2012
ALICE: Phys. Rev. Lett. 105, 252302 (2010)
PHENIX: Phys. Rev.Lett. 98, 162301 (2007).
PHOBOS: Phys. Rev.Lett. 98, 242302 (2007).
CERES: Nucl. Phys. A 698, 253c (2002).
E877: Nucl. Phys. A 638, 3c(1998).
E895: Phys. Rev. Lett. 83, 1295 (1999).
STAR 130 and 200 GeV: Phys. Rev. C 66,873 034904 (2002); Phys. Rev. C 72,790 014904 (2005)

$v_2\{4\}$ (p_T) Beam Energy Dependence

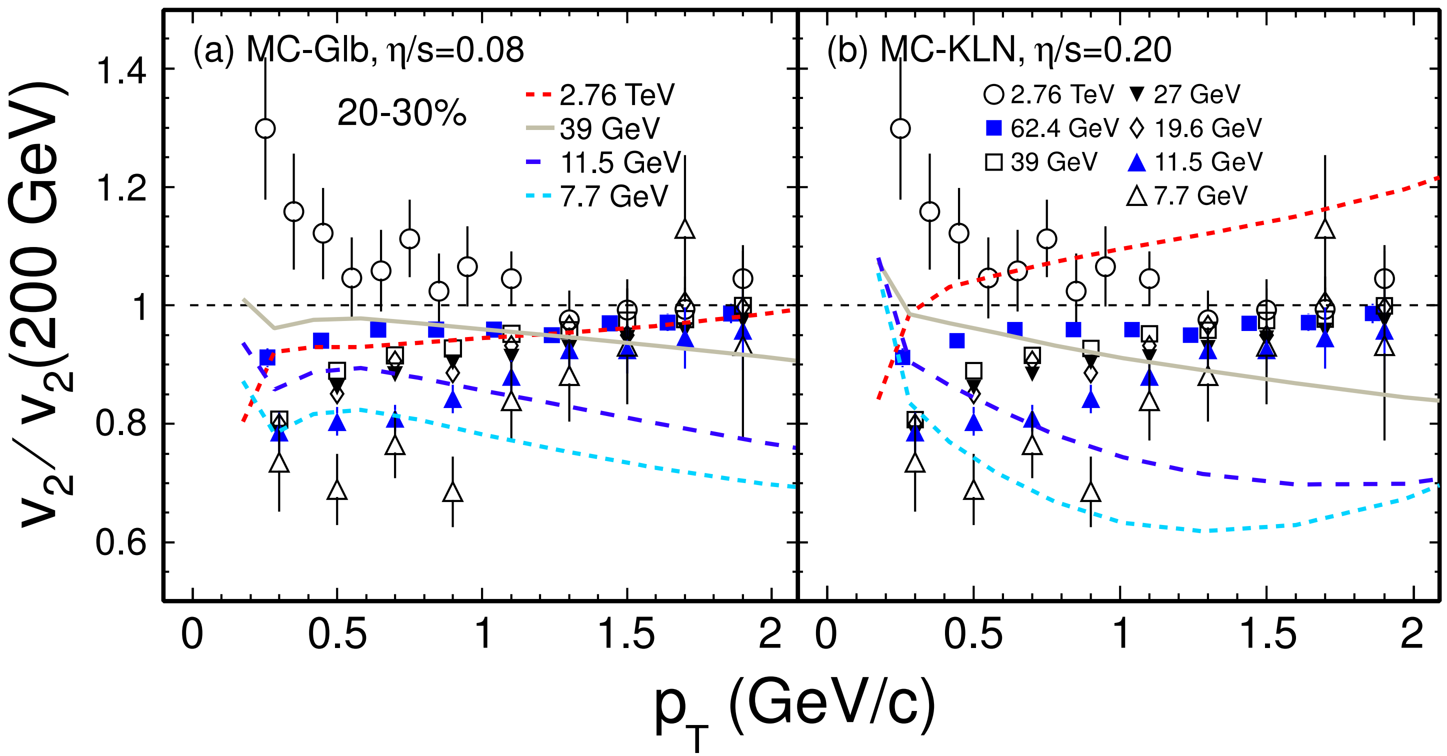


- $v_2(p_T)$ indeed same w/ ± 30%
  < 10% below 1 GeV/*c*
- ‹v_2› increase mainly due to ‹p_T›

v_2 syst. err. ~ 7%

STAR: *Phys. Rev. C* ***86*** *(2012) 054908*

$v_2\{4\}$ Comparison with Viscous Hydro



STAR: *Phys. Rev. C **86** (2012) 054908*
Hydro: C. Shen and U. Heinz, Phys. Rev. C 85, 054902(2012)

} Methods may be different

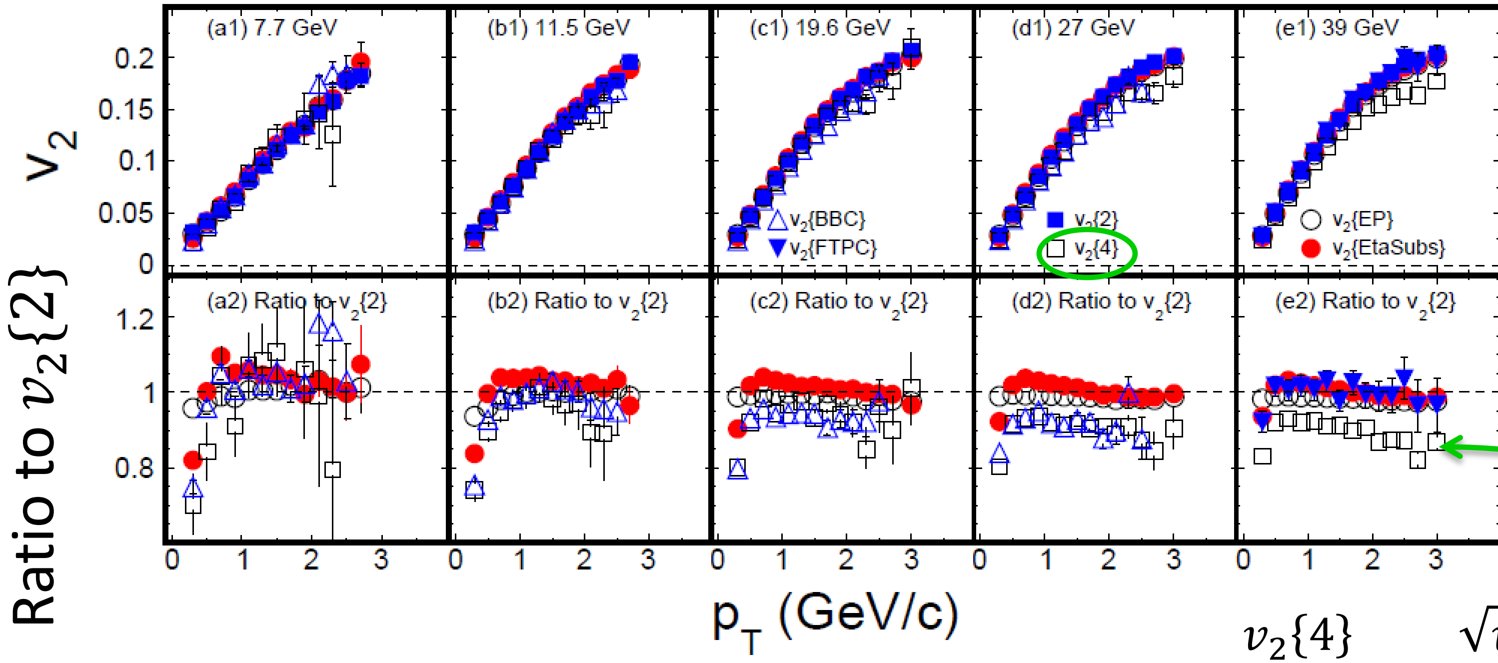
- Viscous hydro with constant η/s and zero net baryon density can not reproduce the trend of experimental data.

$v_2\{2\}$, $v_2\{4\}$ Beam Energies Dependence

STAR: *Phys. Rev. C* ***86*** *(2012) 054908*

v_2 syst. err. ~ 7%

20-30 % Au+Au

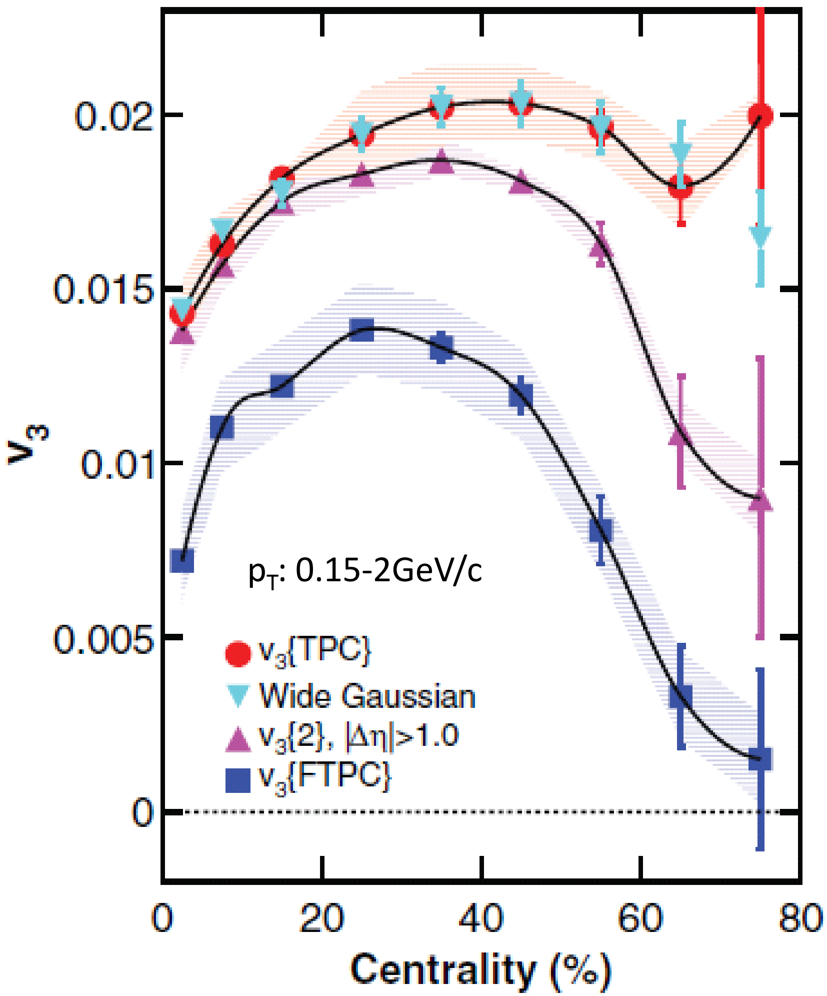


$$\frac{v_2\{4\}}{v_2\{2\}} = \frac{\sqrt{v^2 - \sigma^2}}{\sqrt{v^2 + \sigma^2 + \delta}}$$

- $v_2\{4\}/v_2\{2\}$ is closer to 1 at the lower collision energies, indicating smaller nonflow and/or fluctuation.

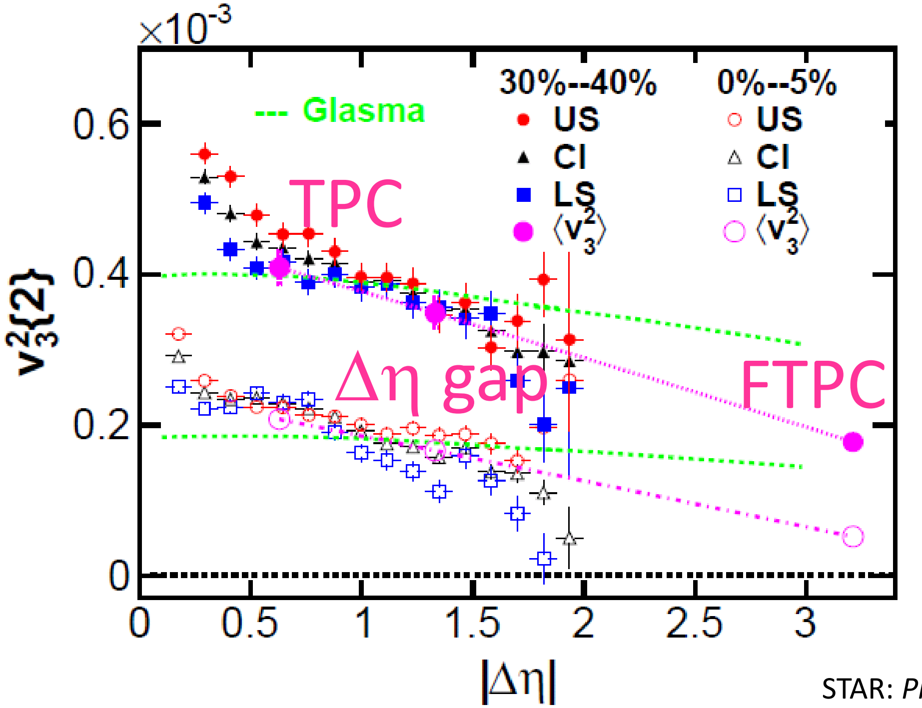
AuAu@200GeV v_3 Centrality Dependence

STAR: *Phys. Rev. C* ***88*** *(2013) 14904*



- v_3 centrality dependence.
- v_3 depends on methods. Need to look at Δη window for methods.

v_3 Measurement $\Delta\eta$ Dependence

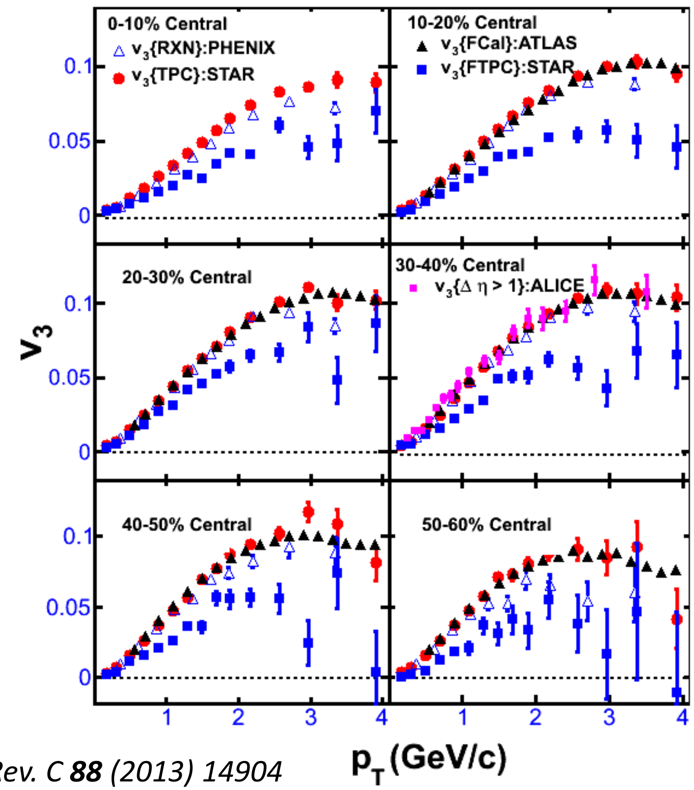


AuAu@200GeV

STAR: *Phys. Rev. C* ***88*** *(2013) 14904*

- Strong $\Delta\eta$-dependence
  Nonflow, and/or fluctuation from event plane decorrelation?
- Model comparisons have to use same $|\Delta\eta|$

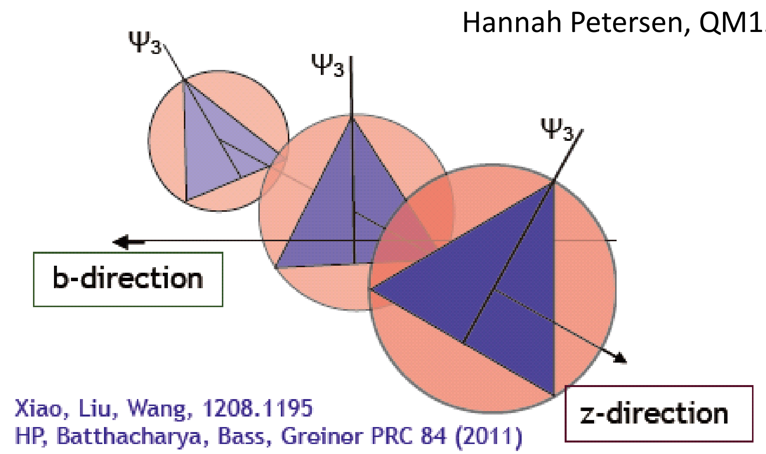
v_3 Comparison with other Experiment



Phys. Rev. C ***88*** *(2013) 14904*

	|η|	<Δη>
STAR TPC	< 1.0	0.63
STAR FTPC	< 1.0	3.21
PHENIX	< 0.35	≈1.9
ALICE	< 0.8	> 1.0
ATLAS	< 2.5	> 0.8

EP decorrelation:



- $$v_3 \approx \frac{\langle \cos 3(\phi - \Psi_{EP}) \rangle}{\sqrt{2\langle \cos 3(\Psi_{EP}^{A} - \Psi_{EP}^{B}) \rangle}}$$

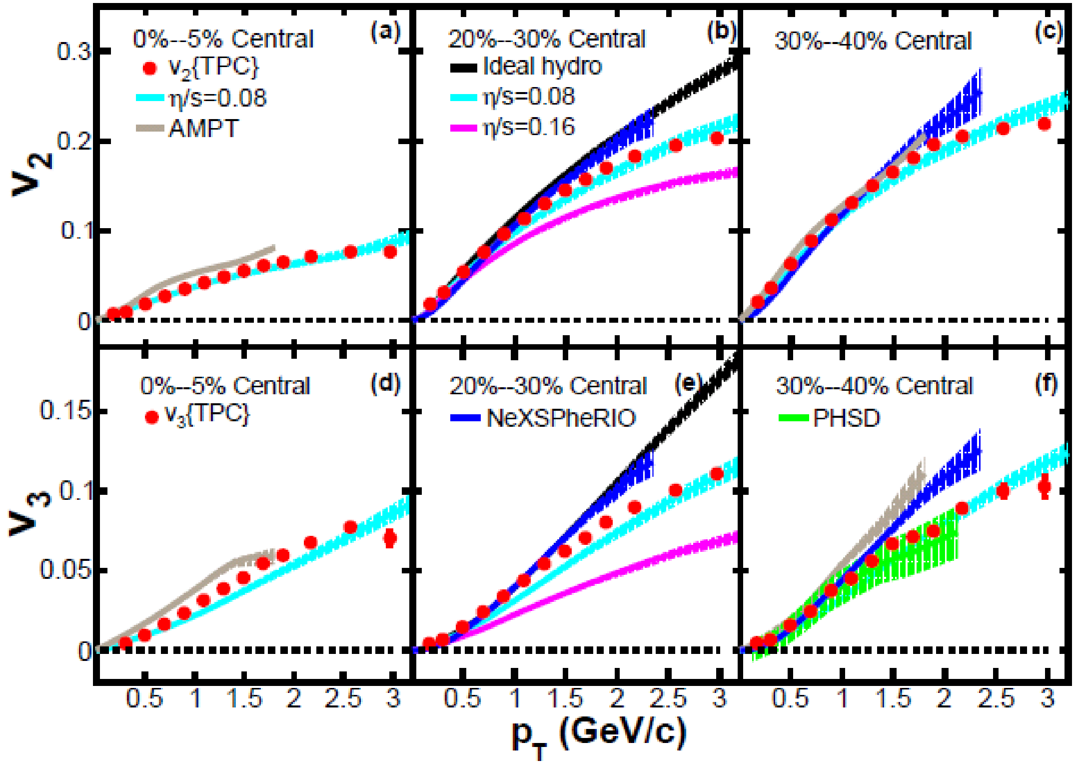
  ϕ, Ψ_{EP}: $\Delta\eta$

  $\Psi_{EP}^{A}, \Psi_{EP}^{B}$: $\Delta\eta_{EP}$

  STAR TPC: ϕ, EP are both in TPC
  STAR FTPC: ϕ TPC, EP FTPC
  PHENIX: ϕ central arms, EP RXN
- $v_3(p_T)$ same between RHIC and LHC.

$v_3(p_T)$ Comparison with Models

AuAu@200GeV



STAR: *Phys. Rev. C* ***88*** *(2013) 14904*

Qualitative agreement with data:

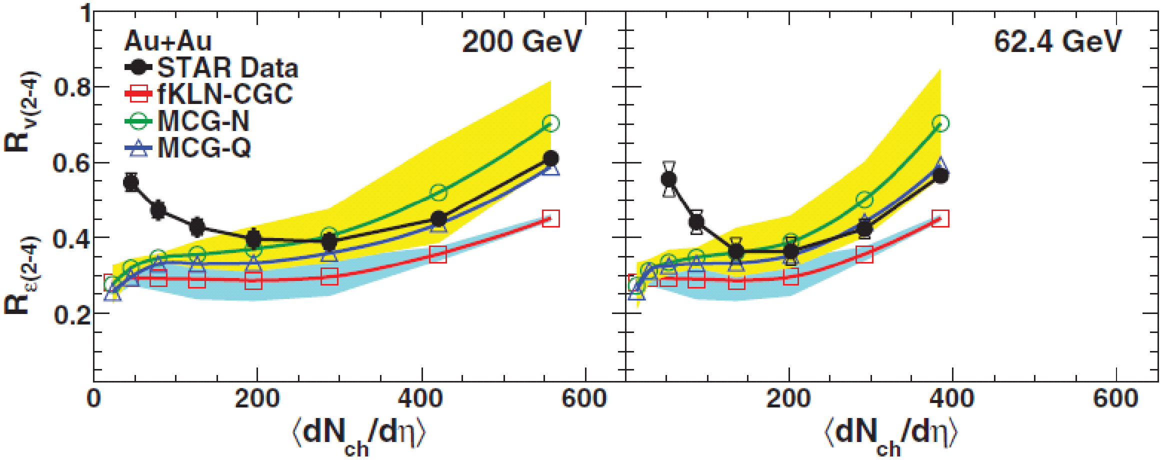
- η/s = 0.08 hydro w/ Glauber initial condition
- NeXSPheRIO at low p_T
- PHSD mid central collision

Model|Δη|?

v_2 Flow Fluctuation Upper Limit

Upper limit for $\frac{\sigma_2}{v_2}$

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

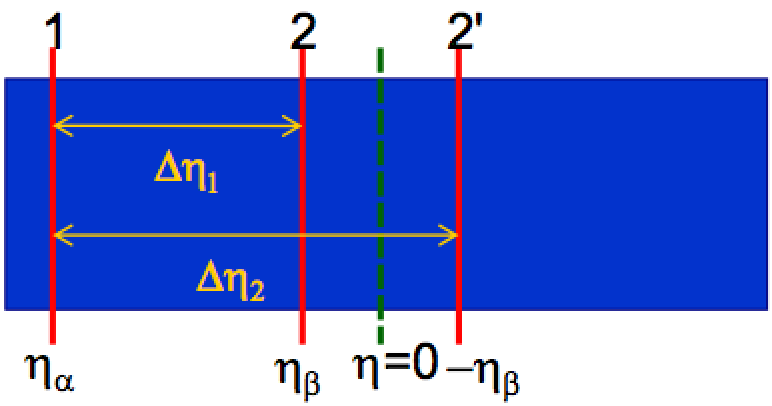


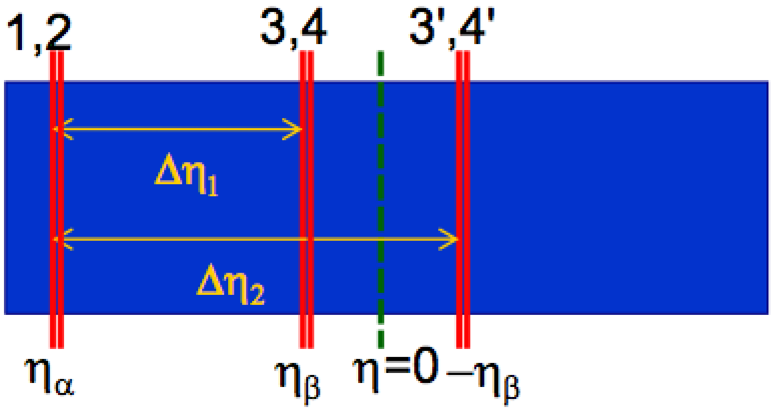
STAR: *Phys. Rev. C* ***86*** *(2012) 014904*

- Compare models to data fluctuation upper limit
- Models have eccentricity fluctuations only. Data may have other fluctuation sources.
- Premature to conclude which ε model is favored.

Isolation of Flow and Nonflow

using 2- and 4-Particle η–η Cumulants





Xu, LY et al, : PRC86, 024901(2012)

$$V_2\{\eta_\alpha,\eta_\beta\} = v(\eta_\alpha)v(\eta_\beta) + \sigma\,(\eta_\alpha)\sigma(\eta_\beta) + \sigma'(\Delta\eta) + \delta(\Delta\eta)$$

$$v(\eta_\beta) = v(-\eta_\beta), \sigma(\eta_\beta) = \sigma(-\eta_\beta)$$

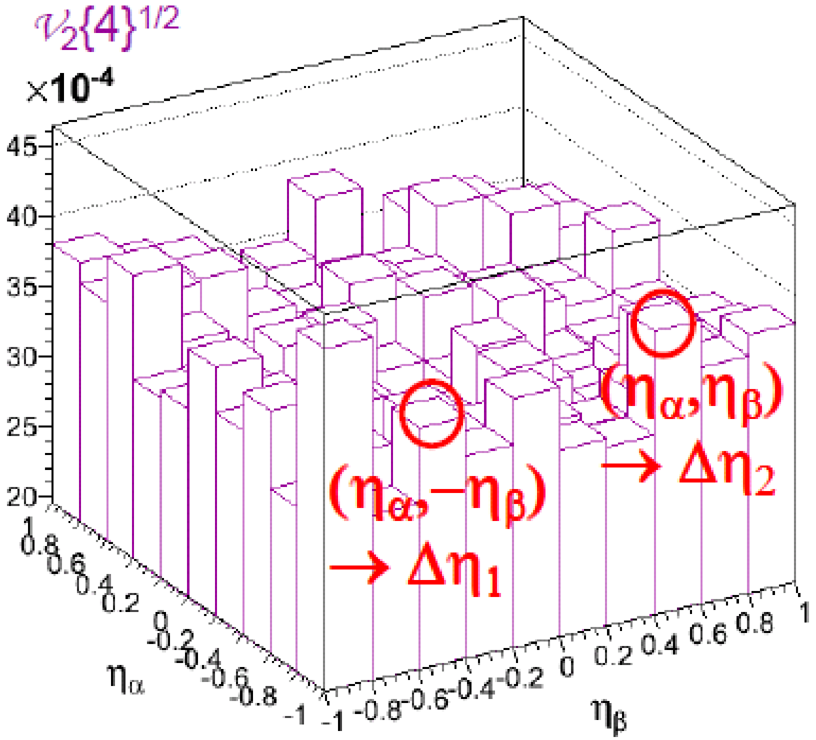
$$V_4\{\eta_\alpha,\eta_\alpha,\eta_\beta,\eta_\beta\}^{1/2} = v(\eta_\alpha)v(\eta_\beta) - \sigma\,(\eta_\alpha)\sigma(\eta_\beta) - \sigma'(\Delta\eta)$$

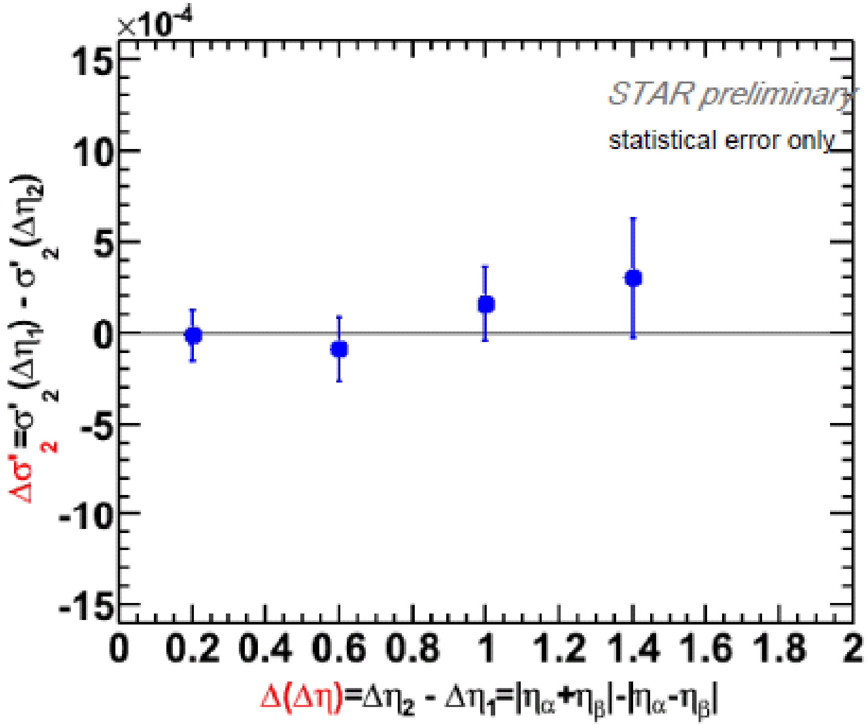
$$\Delta V\{2\} = V\{\eta_\alpha,\eta_\beta\}\text{-}V\{\eta_\alpha,-\eta_\beta\} = \Delta\sigma' + \Delta\delta$$

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

$\Delta\eta$-dependence $\sigma'(\Delta\eta)$

AuAu@200GeV 20-30%

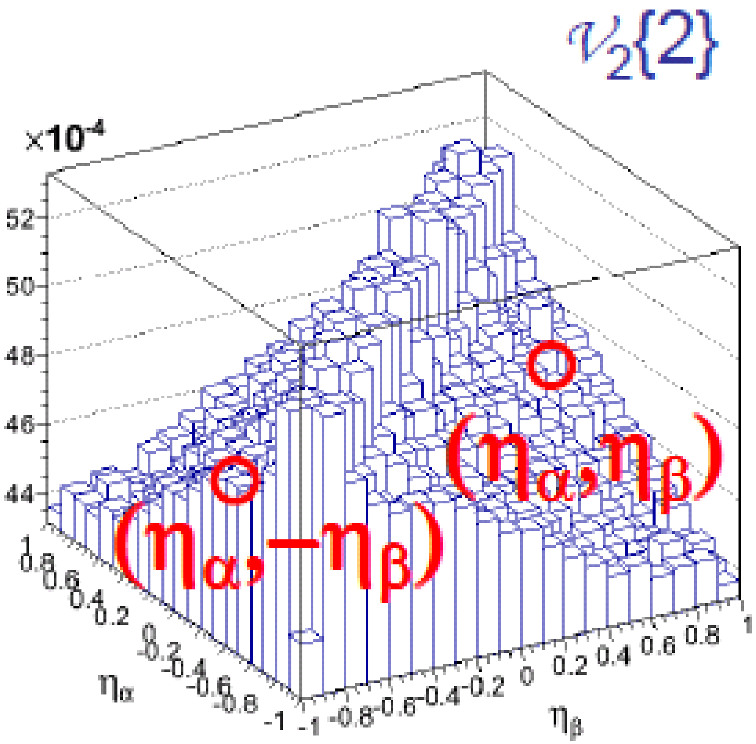


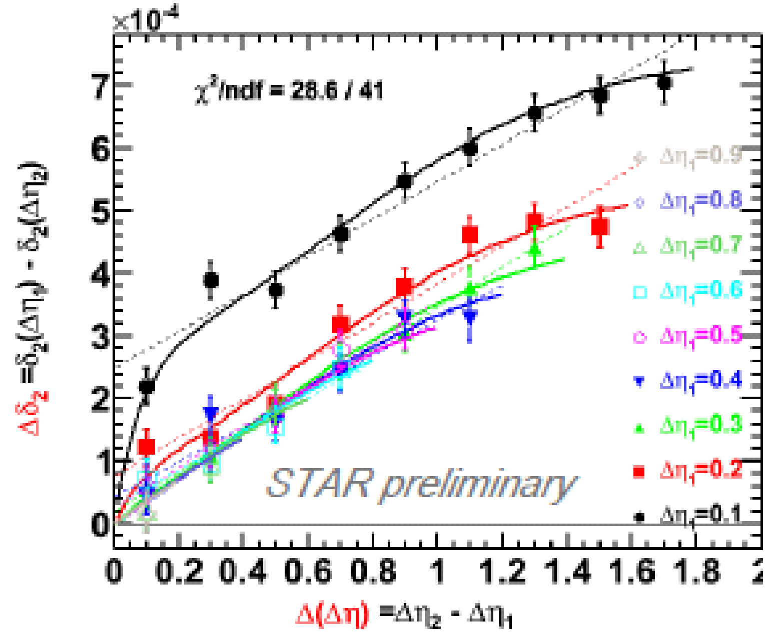


$$\Delta V\{4\}^{1/2} = -\Delta\sigma'$$

- Flow fluctuation appears independent of $\Delta\eta$.

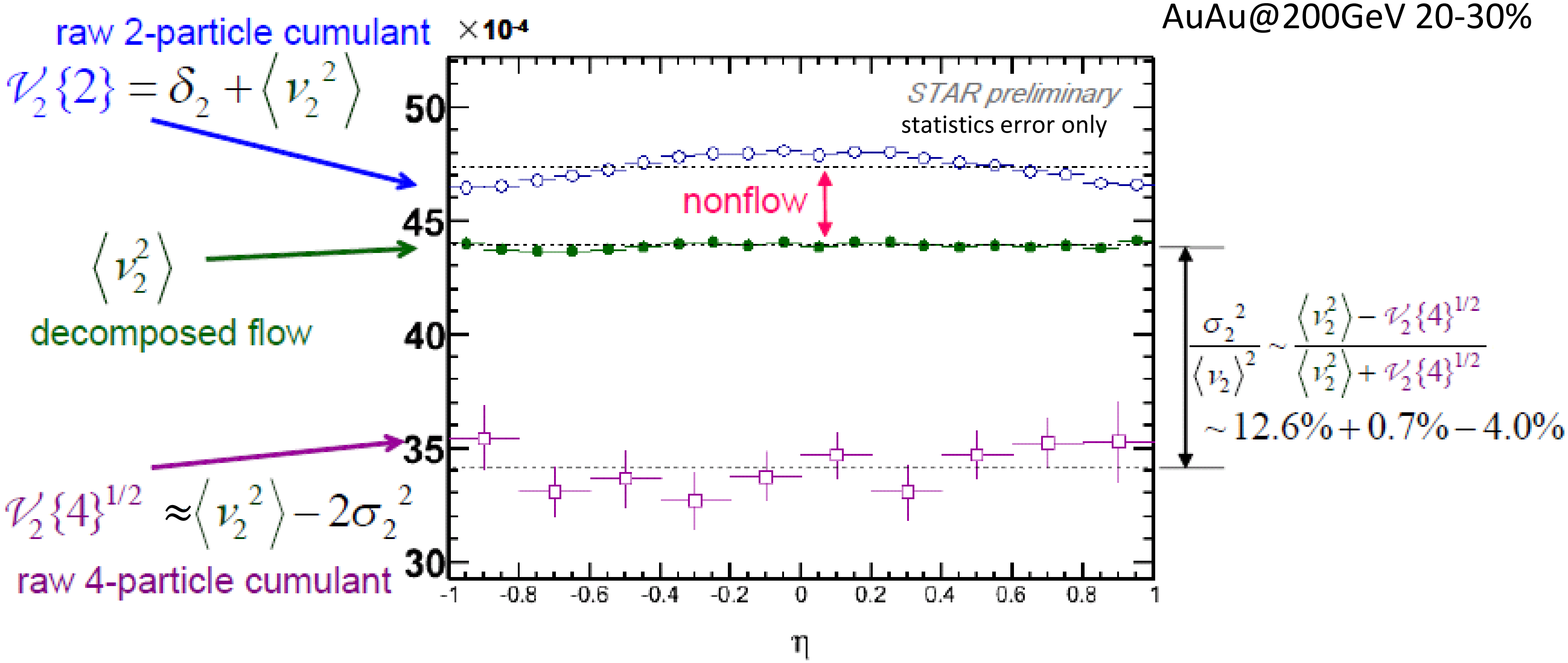
$\Delta\eta$-Dependence $\delta(\Delta\eta)$





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

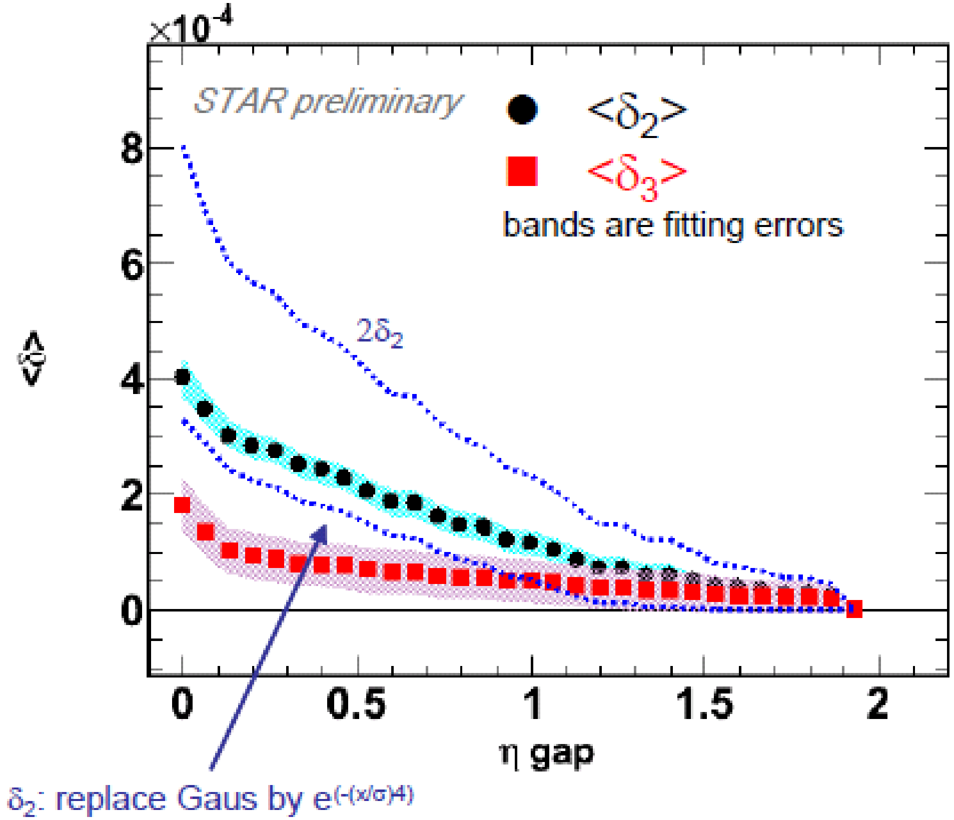
'Flow' vs η



- v_2 flow seems independent of η.
- (Fluctuation/flow)^2 for v_2 ~ 13%

Nonflow δ_n

AuAu@200GeV 20-30%



- δ_n drops as η gap increases.

Summary

- $\langle v_2\{4\}\rangle$ values rise with increasing beam energy

  Possibly related to weaker radial flow at the lower energy, $\langle p_T\rangle$.

- v_3 shows strong $\Delta\eta$ dependence
  - Event plane decorrelation
  - Nonflow

- v_2 in AuAu@200GeV 20-30%:

  Nonflow $\delta_2/ v_2^2 \sim 4\%$

  Flow fluctuation $\sigma_2^2/v_2^2 \sim 13\%$