Triangular flow of charged particles in heavy ion collisions from STAR experiment at RHIC

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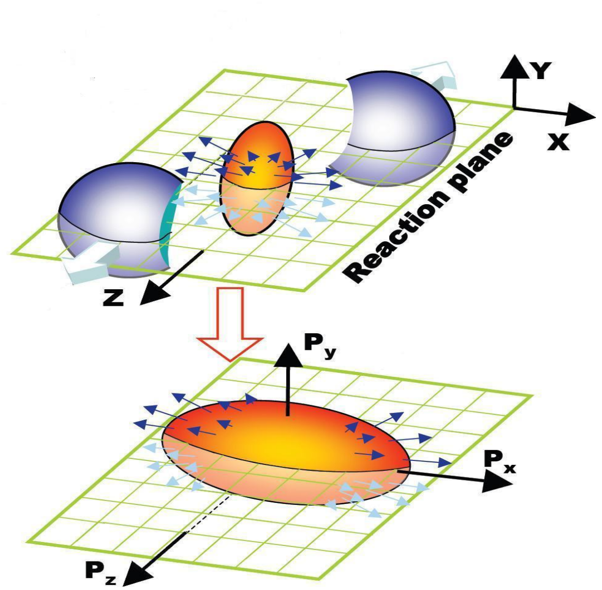
Outline:

- Introduction and Motivation
- STAR experiment
- Analysis Techniques
- Results
- Summary and Outlook

Introduction: Anisotropic flow

Fourier expansion of the particle's azimuthal distribution with respect to the reaction plane is given by:



$$\frac{dN}{d\varphi} \propto \left(1 + 2\sum_{n=1}^{+\infty} v_n \cos\left[n(\varphi - \psi)\right]\right)$$

$$v_n = \left\langle \cos\left[n\left(\varphi - \psi\right)\right]\right\rangle$$

n=1 **Directed Flow**

n=2 **Elliptic Flow**

n=3 **Triangular Flow**

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spatial anisotropy ε_n

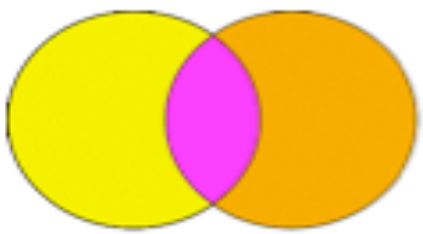
↓ ↓

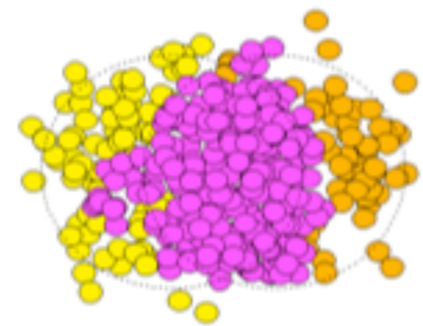
momentum anisotropy v_n

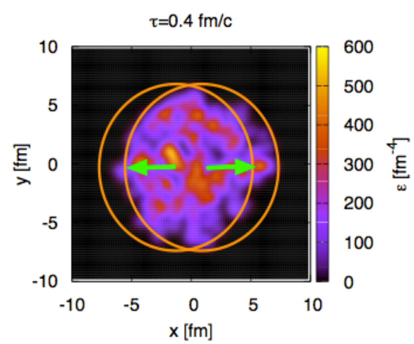
S. A. Voloshin and Y. Zhang, Z. Phys. C 70, 665 (1996), J.-Y. Ollitrault, Nucl. Phys. A590, 561c (1995), A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C 58, 1671–1678 (1998)

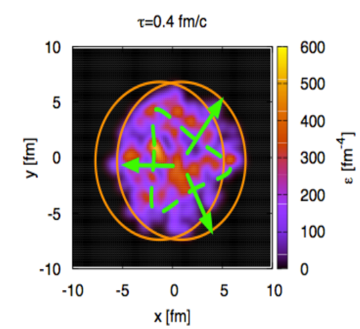
Motivation: Changing Picture

Until recently higher order odd harmonics were overlooked









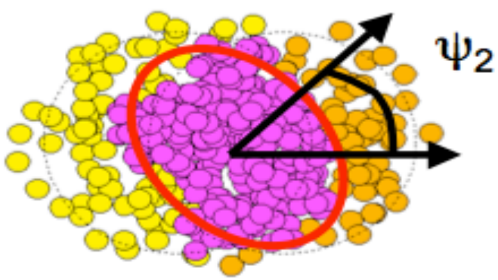
Higher order odd harmonics = 0
(v_3=0)

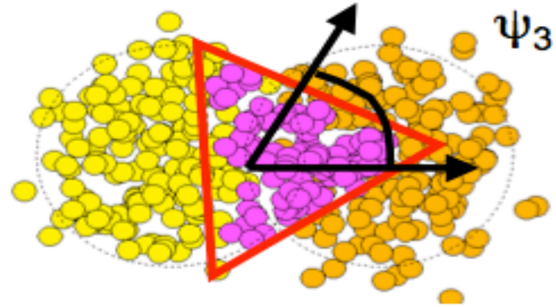
Higher order odd harmonics ≠ 0

Fluctuations imply odd terms aren't necessarily zero

B. Schenke et. Al. Phys. Rev. Lett. 106, 042301 (2011), Takahashi et al, PRL 103, 242301 (2009), Hama et al, arXiv:0911.0811, B.Alver et al, arXiv:0805.4411

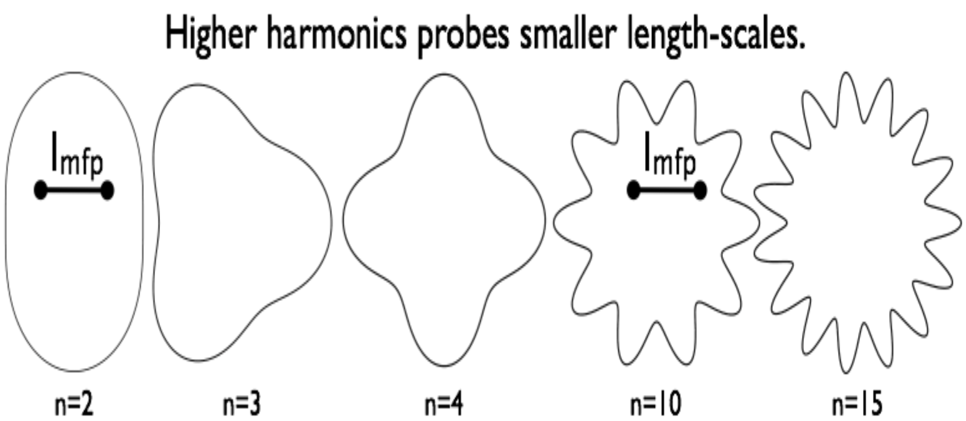
Motivation: Participant Eccentricity





$$\varepsilon_2^2 = \frac{\left\langle r^2 \cos(2\varphi) \right\rangle^2 + \left\langle r^2 \sin(2\varphi) \right\rangle^2}{\left\langle r^2 \right\rangle^2}$$

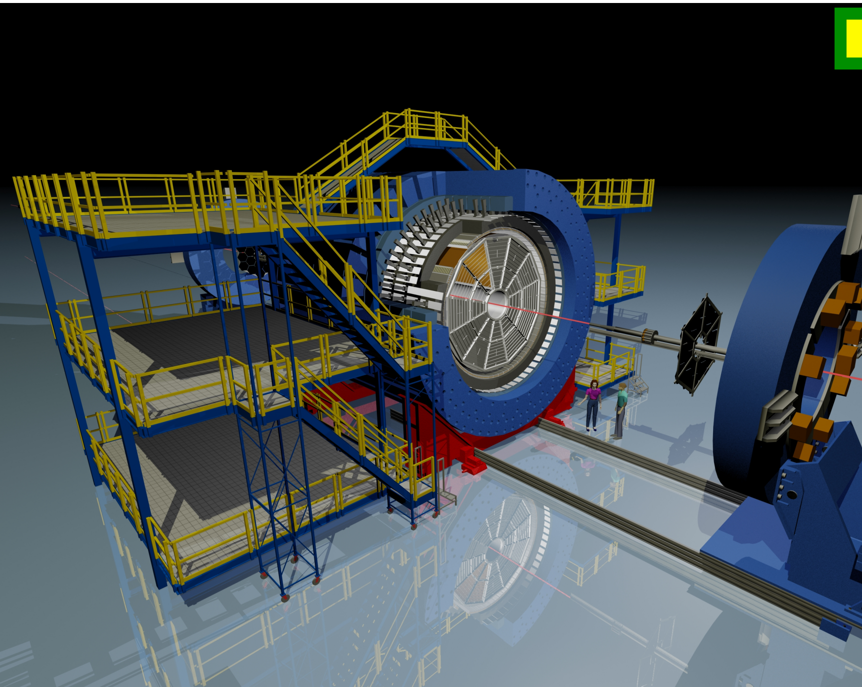
$$\varepsilon_3^2 = \frac{\left\langle r^2 \cos(3\varphi) \right\rangle^2 + \left\langle r^2 \sin(3\varphi) \right\rangle^2}{\left\langle r^2 \right\rangle^2}$$

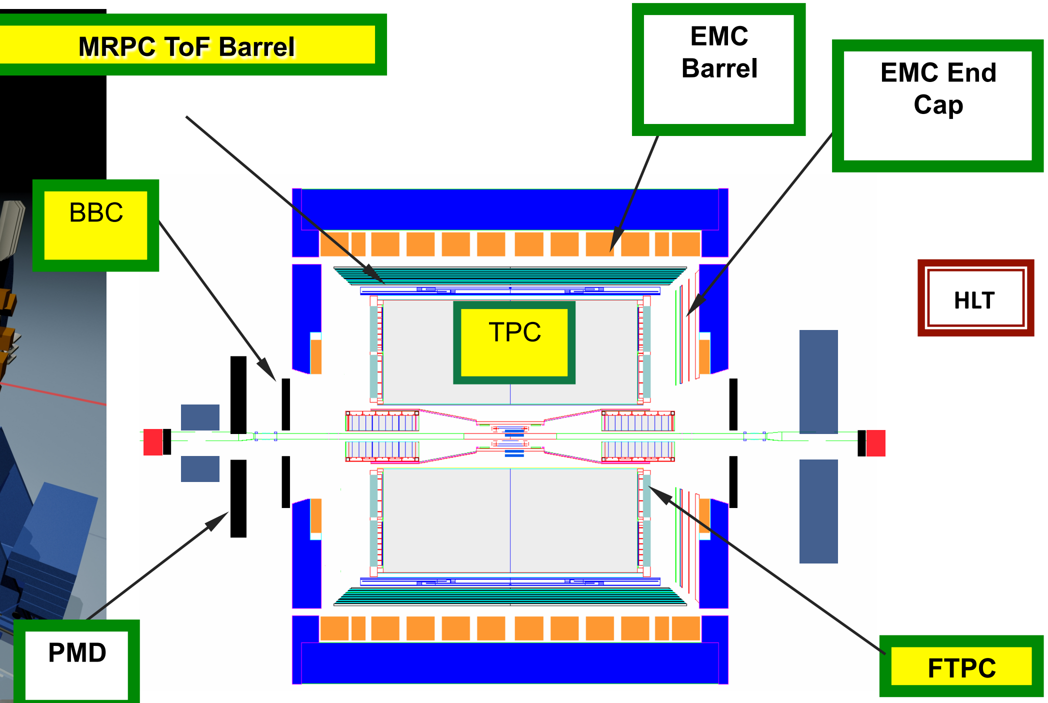


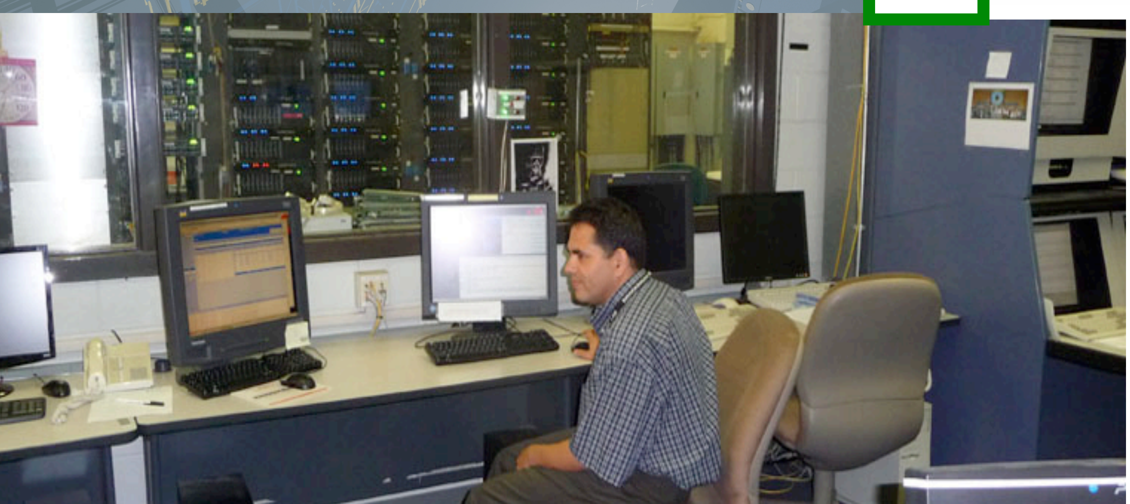
- Triangular anisotropy in initial geometry can be quantified by "participant triangularity" analogous to participant eccentricity.
- v_3 is sensitive to initial state fluctuations and hydrodynamic evolution

B. Alver and G. Roland, Phys. Rev. C 81, 054905 (2010), Derek Teaney and Li Yan, Phys. Rev. C 83, 064904 (2011)

STAR Experiment







- Time Projection Chamber(TPC) ($|\eta| < 1.0$) is main tracking detector at STAR at midrapidity
- Forward TPC (FTPC) ($2.5 < |\eta| < 4.0$) also provides tracking at forward rapidity.
- Full azimuthal coverage.

Method of Measurement :

Cumulant Method:

1.Two particle correlation

- a. Q-Cumulant
- b. Cumulant with η gap

2. Multi-particle correlation

Event Plane Method:

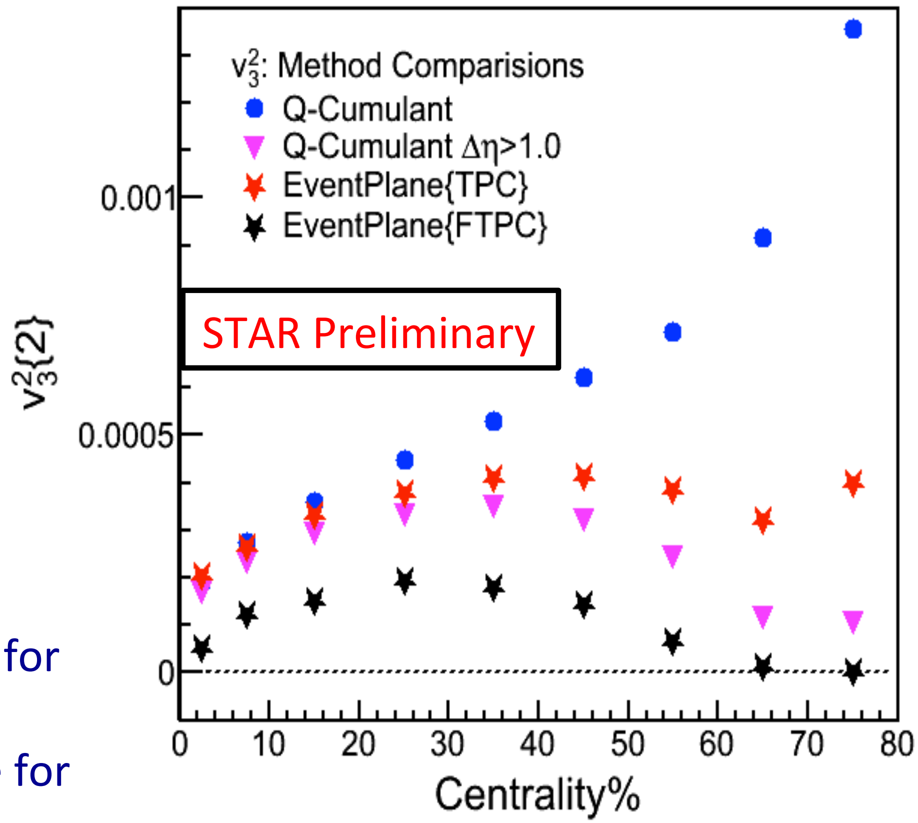
a. TPC event plane

1. Full event plane method
2. Sub Event(η-sub) method

b. FTPC event plane

We used tracks with $0.15<p_T< 2.0$ GeV/c except for p_T dependence study and we apply acceptance correction to our measurements. The results are for Au+Au collisions at 200 GeV.

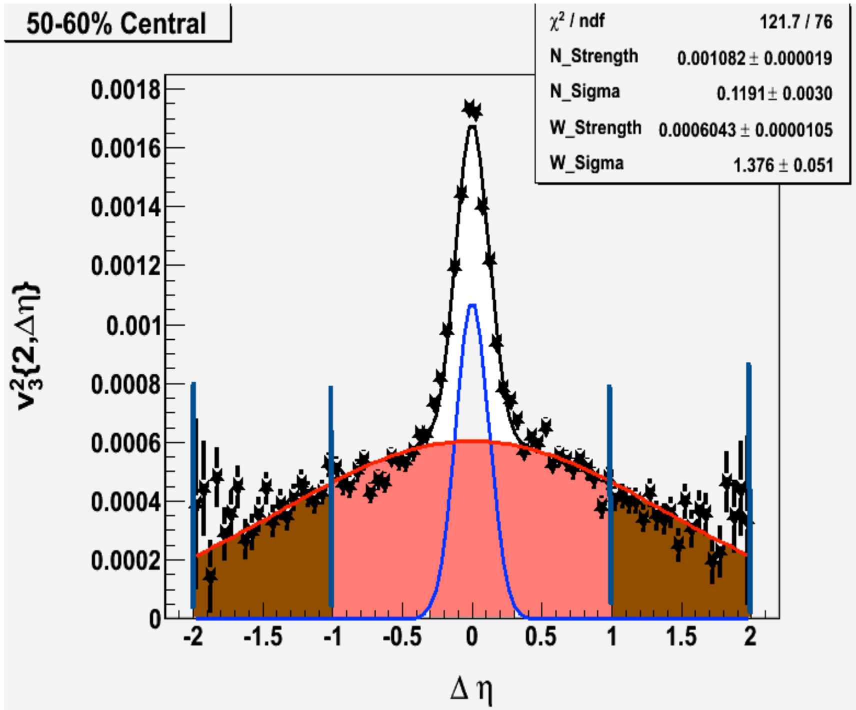
QM2011 : STAR

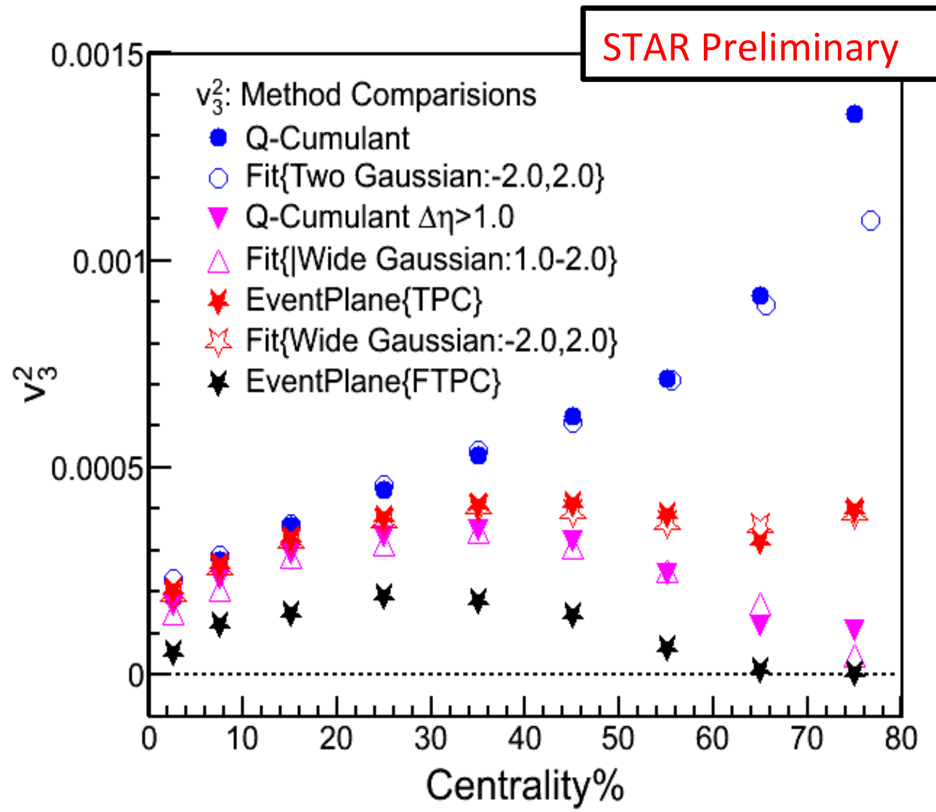


We study two particle correlation with respect to pseudorapidity separation to understand the different results from different method of measurement

For alternative to v_n approach, see D. Kettler (STAR Collaboration), J. Phys. Conf. Ser.270, 012058 (2011)
G. Agakishiev, et al. (STAR Collaboration) arXiv:1109.4380 and references therein

Triangular flow: Method of Measurement





- Narrow Gaussian: Short range Non Flow.
- Wide Gaussian: Flow+ Flow Fluctuations

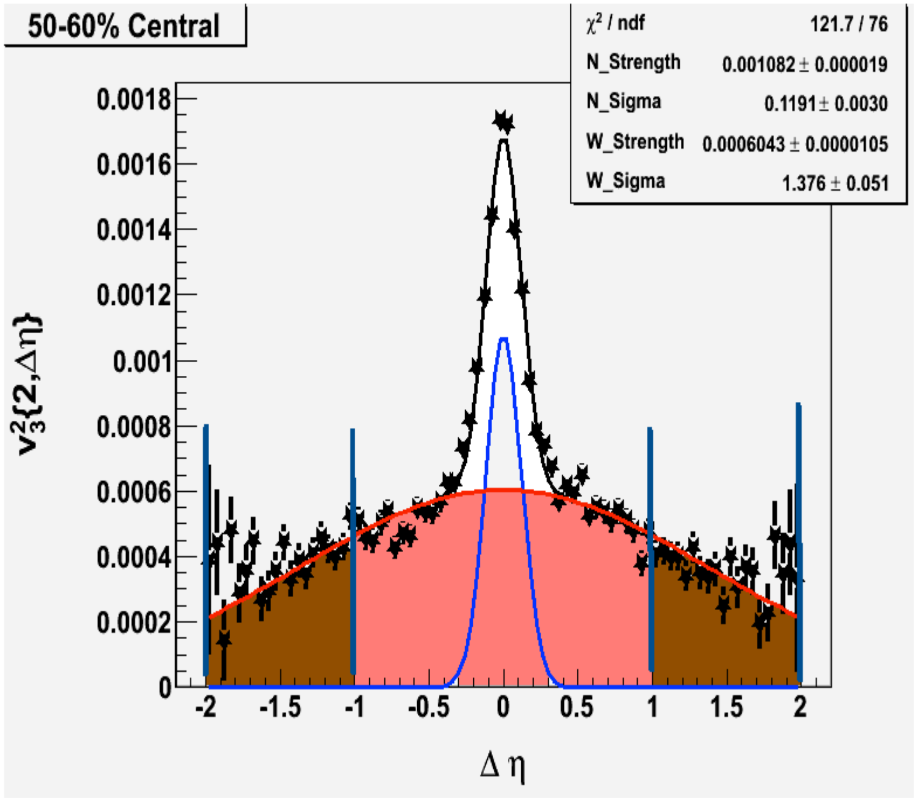
+(Long range Non flow)

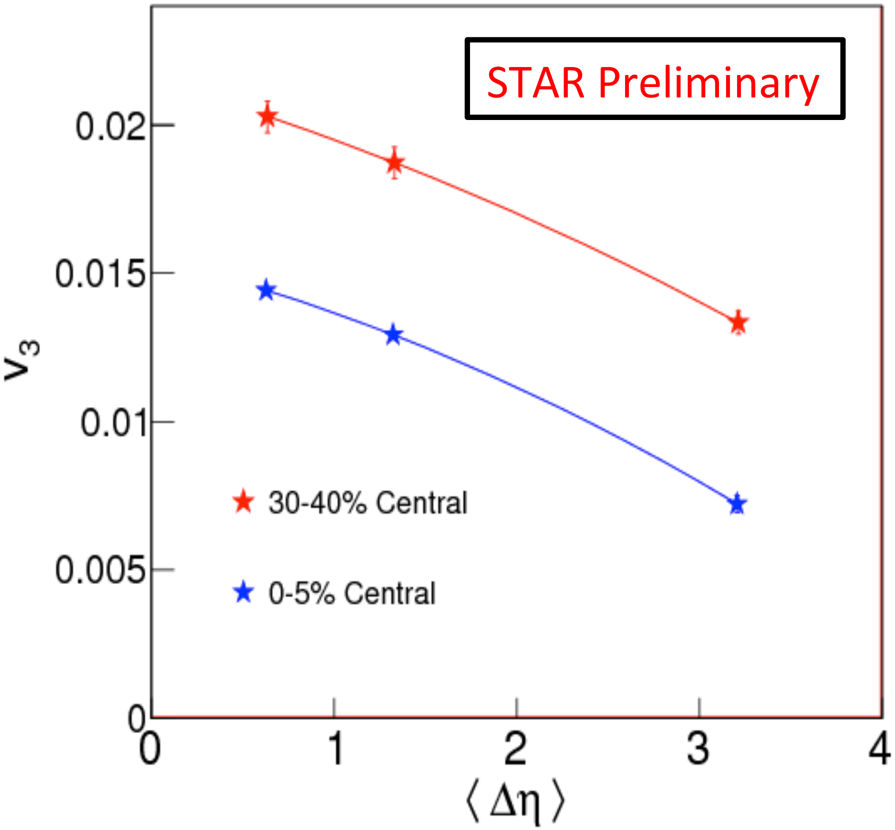
$$v_3^2\{2,\Delta\eta\} = \langle \cos 3\Delta\phi \rangle$$

$$v_3^2 = \frac{\int_{\Delta\eta=a}^{\Delta\eta=b} v_3^2\{2,\Delta\eta\}\frac{dn}{d(\Delta\eta)}d(\Delta\eta)}{\int_{\Delta\eta=a}^{\Delta\eta=b} \frac{dn}{d(\Delta\eta)}d(\Delta\eta)}$$

- The wide Gaussian is used to measure v_3 in the range $|\Delta\eta| < 2$ in our study.
- The differences in different methods are due to different Δη window used to measure v_3.

Two particle correlation with respect to pseudorapidity separation



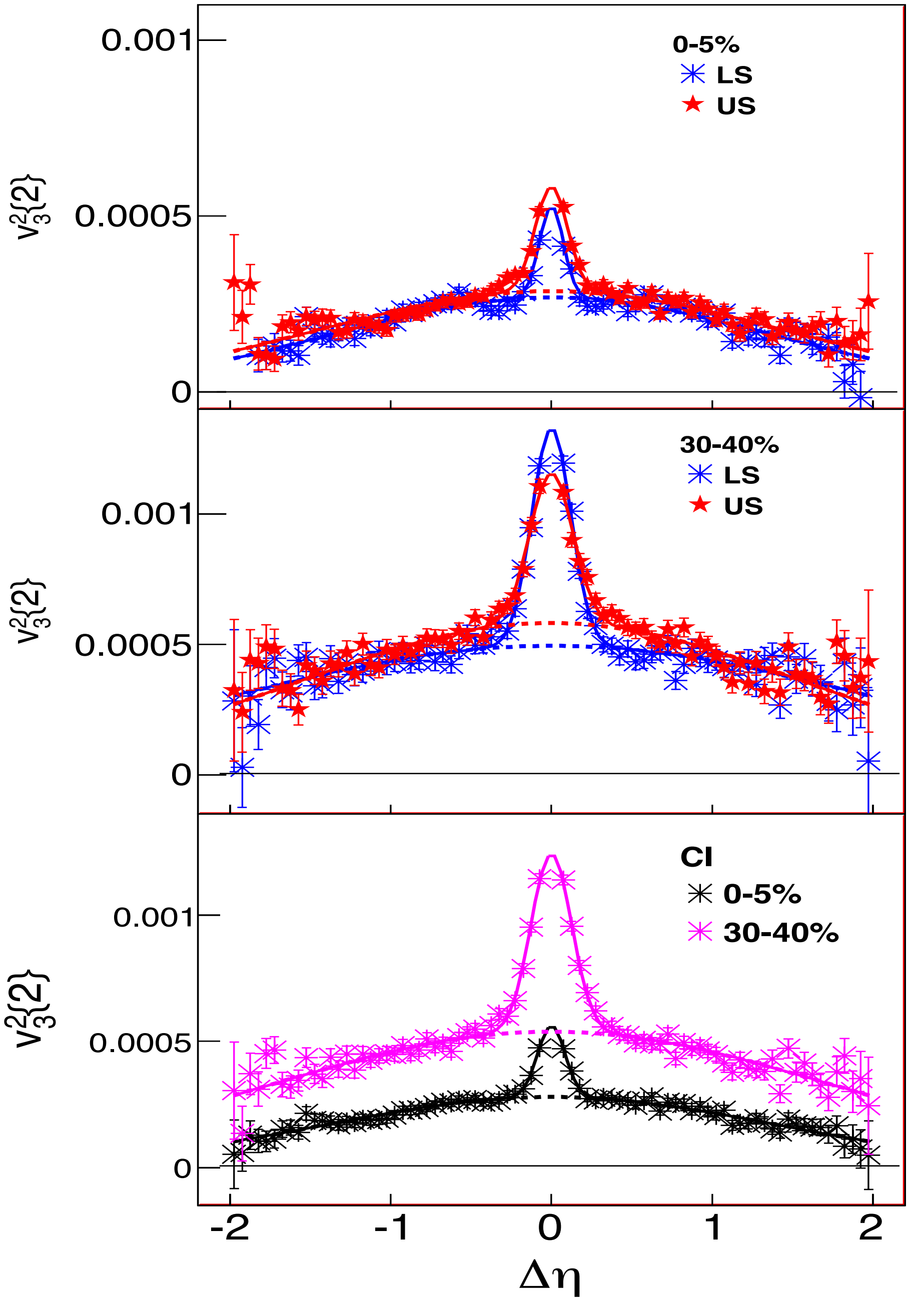


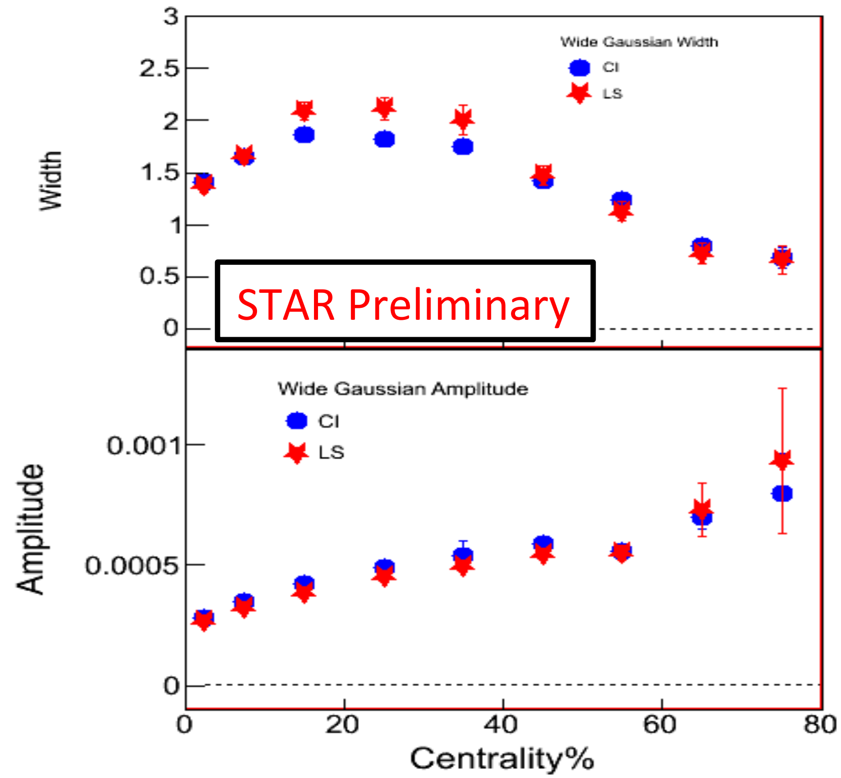
- Triangular flow depends on the Δη window used to measure it and v_3 decreases with mean Δη:

1. Non Flow contribution decreases with larger Δη separation.
2. Initial state density correlations may drop with Δη .

Petersen, Greiner, Bhattacharya & Bass, arXiv:1105.0340, Dusling, Gelis, Lappi & Venugopalan, Nucl. Phys. A 836, 159 (2010), Piotr Bozek and Wojciech Broniowski, arXiv:1204.3580

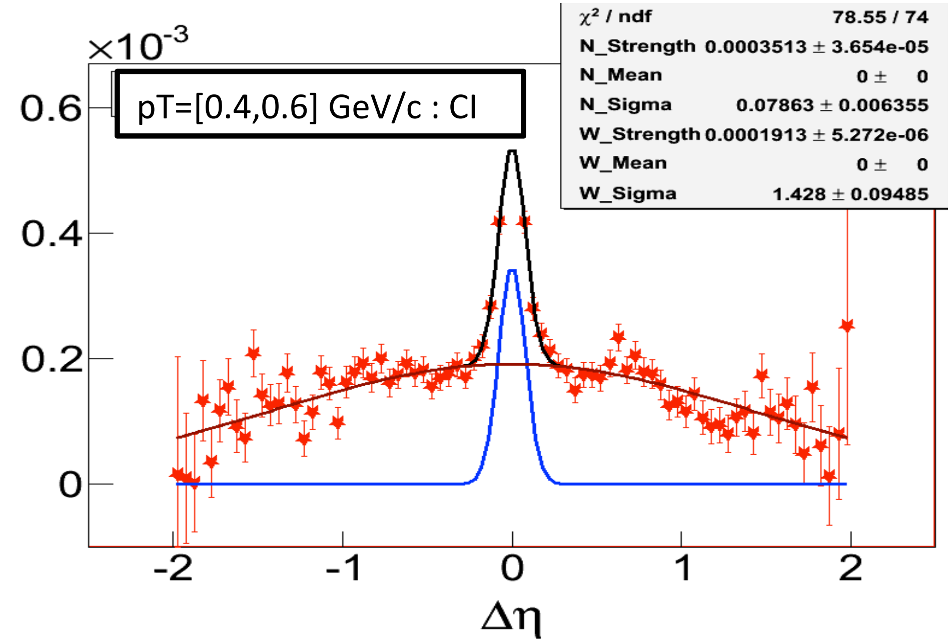
Two particle correlation with respect to pseudorapidity separation

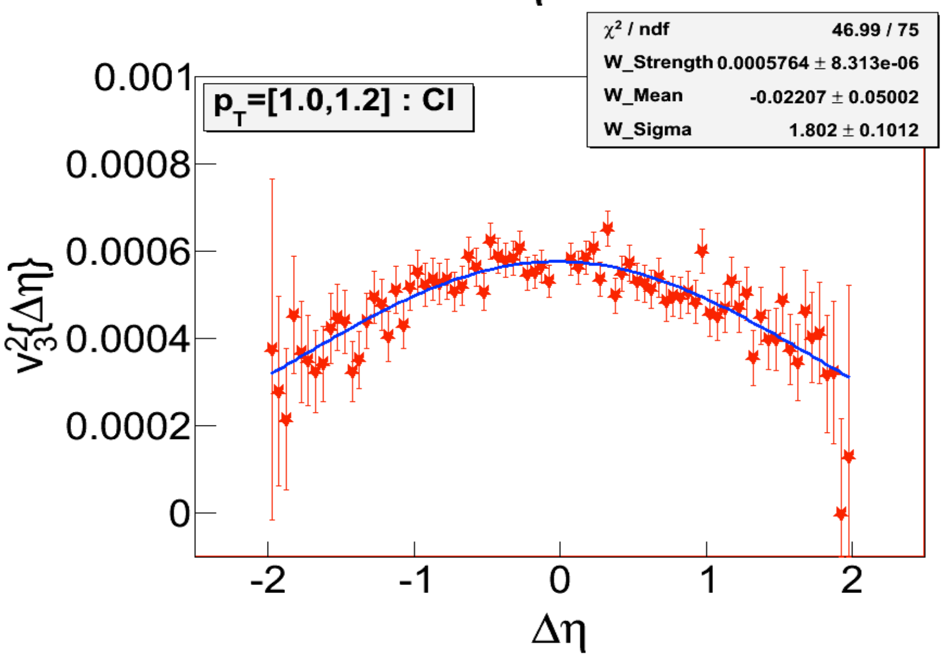


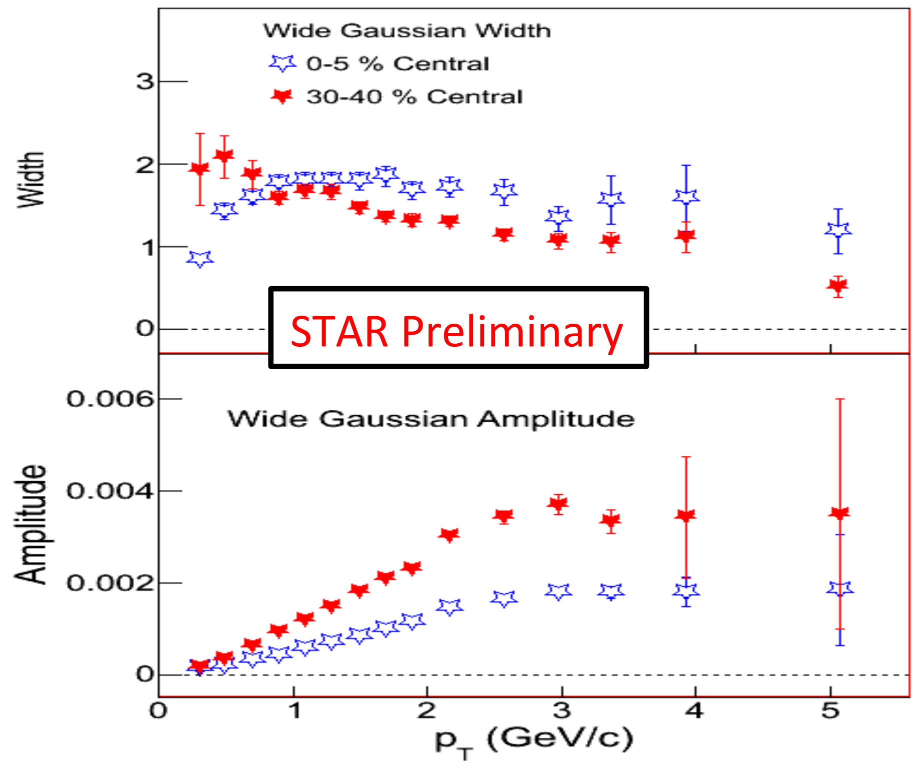


- We study like sign(LS), unlike sign(US) and charge independent(CI) correlations
  - –Different sensitivity to Non Flow
- Wide Gaussian width and amplitude show Centrality dependence

Two particle correlation with respect to pseudorapidity separation

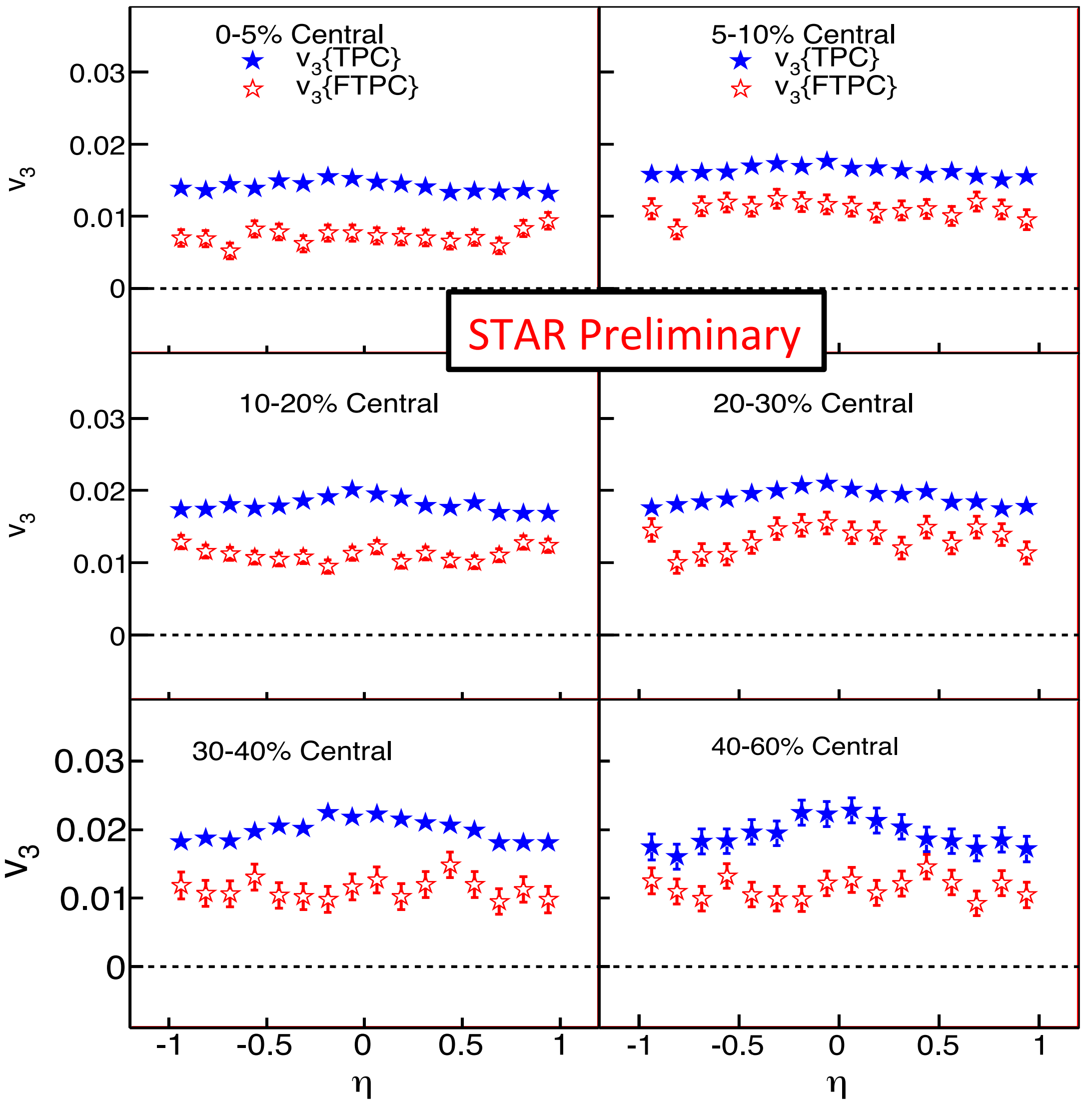






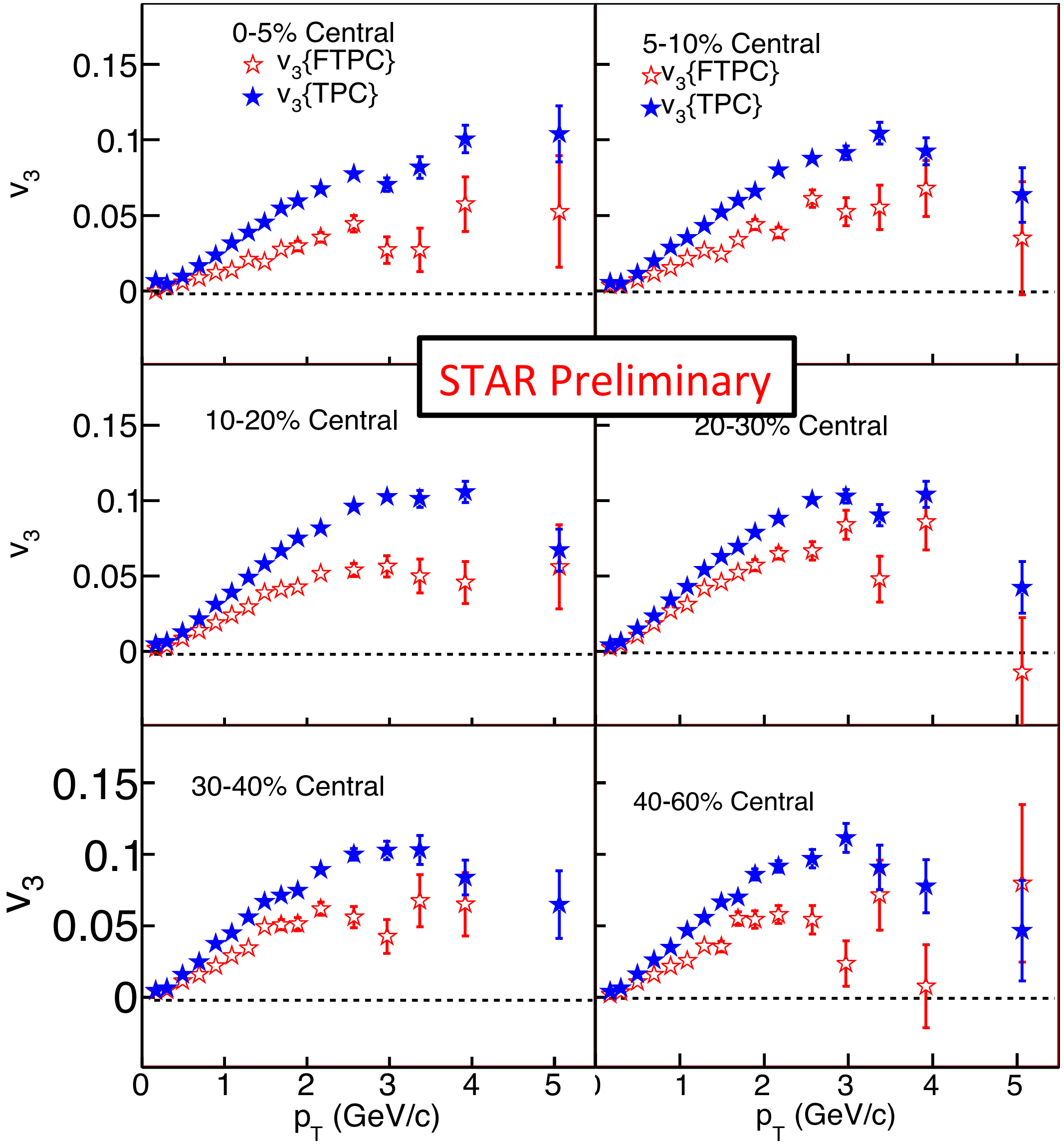
- Above 0.8 GeV/c in p_T narrow Gaussian peak disappears
- Wide Gaussian width and amplitude show centrality dependence as a function of p_T

Triangular flow v_3 : pseudorapidity dependence



- Charged hadron v_3 vs η from different centralities in Au+Au at $\sqrt{s_{NN}}$=200 GeV. The results are from v_3{TPC} and v_3{FTPC} method. The error bars shown are statistical.
- v_3 is symmetric in η.
- No significant η dependence

Triangular flow v_3 : transverse momentum dependence



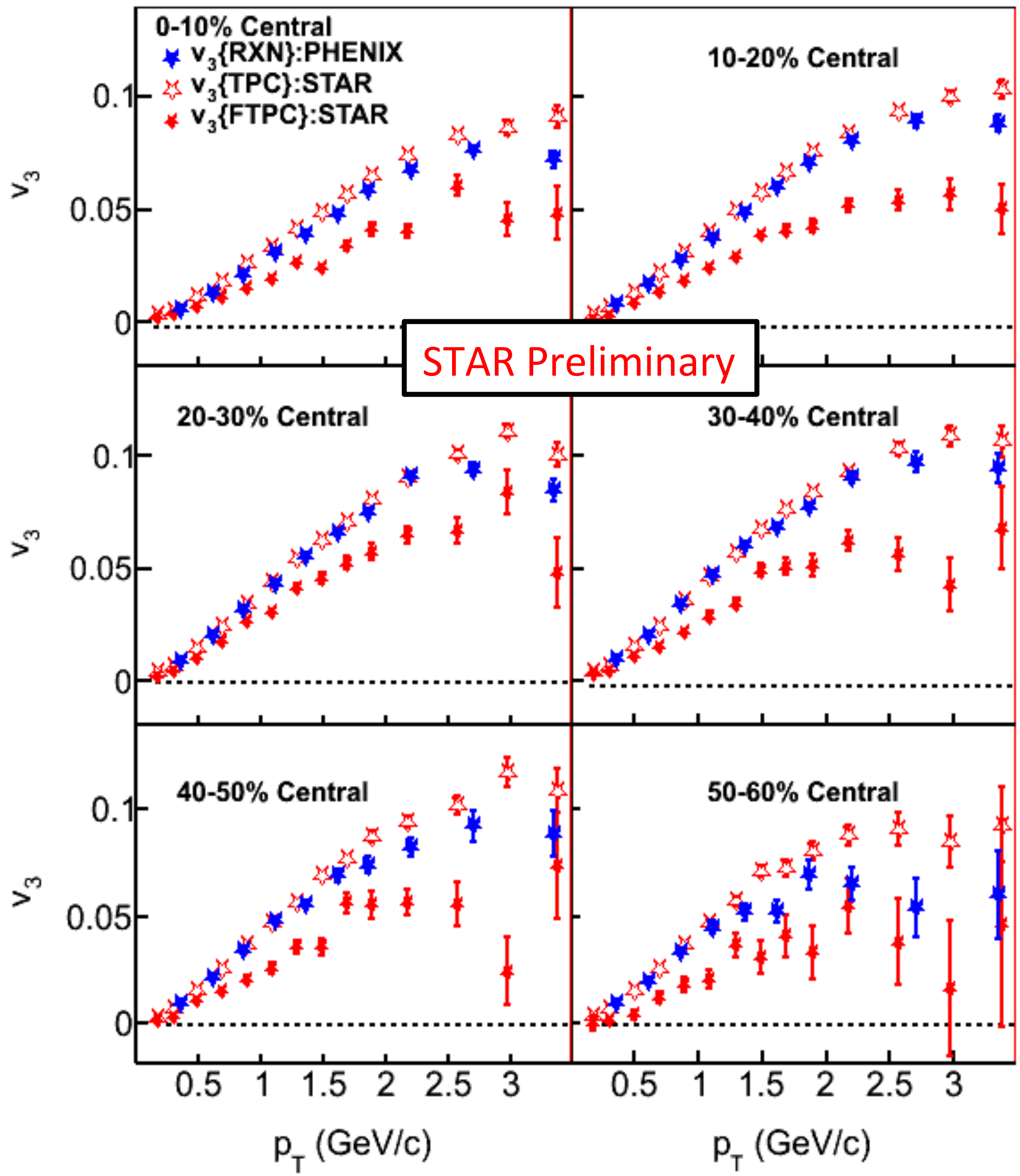
Triangular flow signal depends on the Δη window used to measure it. This may explain the difference between v_3\{TPC\} and v_3\{FTPC\} which may have origin in

1. Non Flow contribution decreases with larger Δη separation.

2. Initial state density correlations may drop with Δη .

Petersen, Greiner, Bhattacharya & Bass, arXiv:1105.0340

Triangular flow: Comparisons With PHENIX



- The difference between STAR measurement v_3\{FTPC\} , v_3\{TPC\} and PHENIX measurement v_3\{RXN\} can be understood considering the different Δη window used to measure v_3

PHENIX

RXN : 1.0<|η|<2.8

Measured in : |η|<0.35

STAR

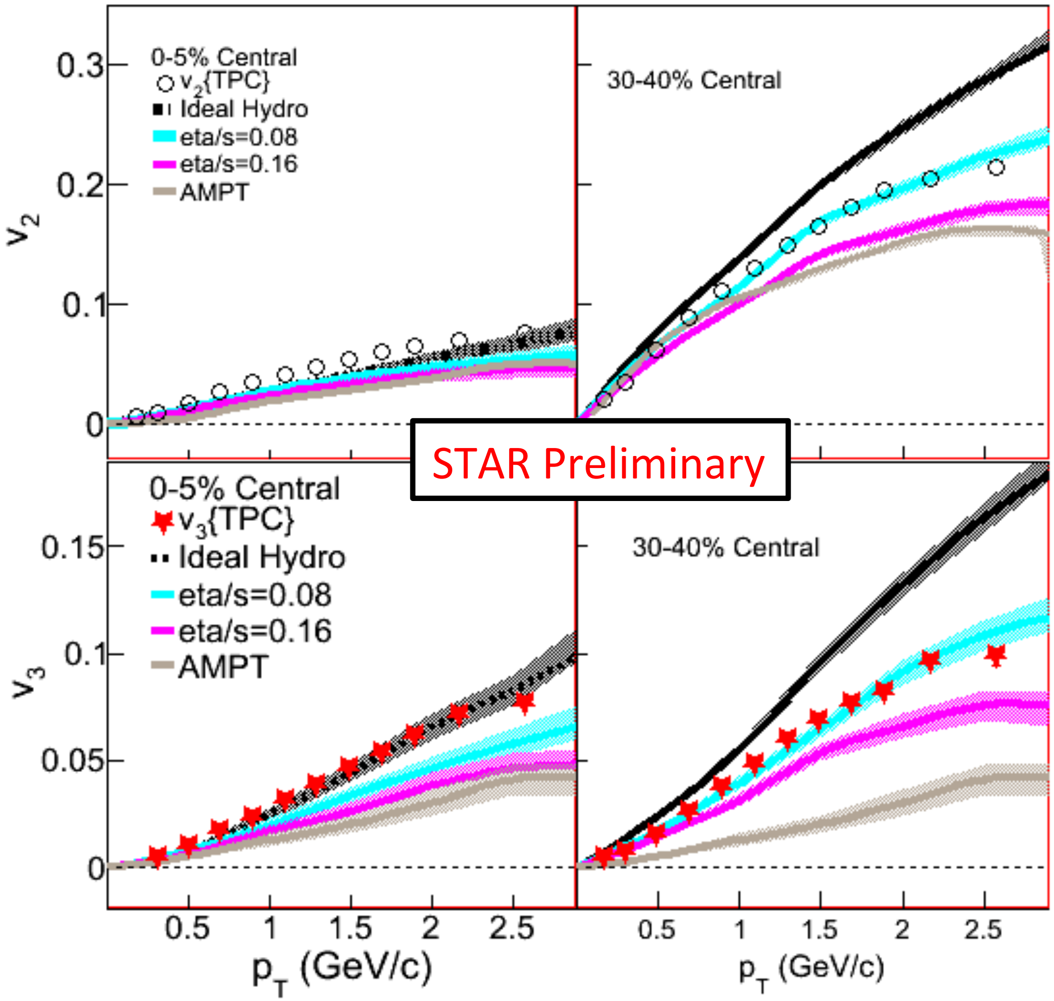
FTPC : 2.5 <|η|< 4.0

TPC : 0.05 <|η|< 1.0

Measured in : |η| <1.0

A. Adare et al. (PHENIX Collaboration),
Phys. Rev. Lett. 107, 252301 (2011)

Triangular flow $v_3(p_T)$:Comparison to models



- Charged hadron v_3 vs p_T from 0-5 %, and 30-40% central Au+Au collision at $\sqrt{s_{NN}}$=200 GeV compared to the hydro and transport model calculations with fluctuating initial conditions(Monte-Carlo Glauber)
- Triangular flow is described by hydro model with a small viscosity setting similar to elliptic flow

B. Alver et. al, Phys. Rev. C 82, 034913 (2010), B. Schenke et. al, Phys. Rev. Lett. 106, 042301 (2011)
M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, Annu. Rev. Nucl. Part. Sci. 57, 205 (2007).

Summary/Outlook:

- Triangular flow (v_3) in Au + Au collisions at 200 GeV as a function of transverse momentum, pseudorapidity and centrality is presented from STAR Experiment.
- Triangular flow depends on the Δη window used to measure it and v_3 decreases with mean Δη.
- The v_3 is almost flat as a function of pseudorapidity and v_3 has centrality dependence.
- The difference between STAR measurement v_3\{FTPC\} , v_3\{TPC\} and PHENIX measurement v_3\{RXN\} can be understood considering the different Δη window used to measure v_3
- In part, origin of v_3 is believed to be the fluctuation giving rise to the triangularity in the initial state and presented data are mostly described by the Hydro and transport model calculation with fluctuating initial conditions.
- Triangular flow measurements provide an extra handle to discriminate between models.
- Triangular flow is described by hydro model with a small viscosity setting similar to elliptic flow