Charge Asymmetry Dependence of π/K Anisotropic Flow in UU and AuAu Collisions at RHIC

Qi-Ye Shou (for the STAR Collaboration)

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SINAP

Charge Separation in HIC

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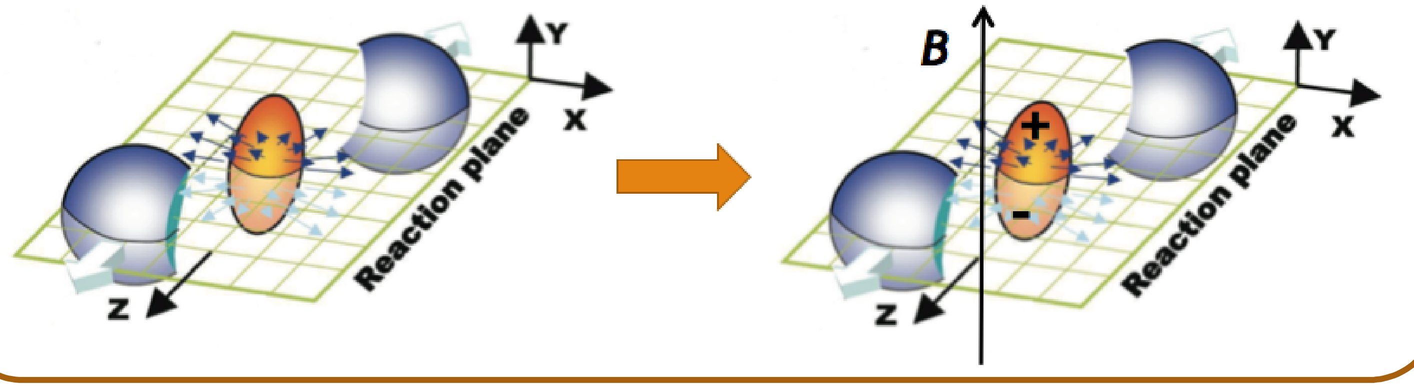

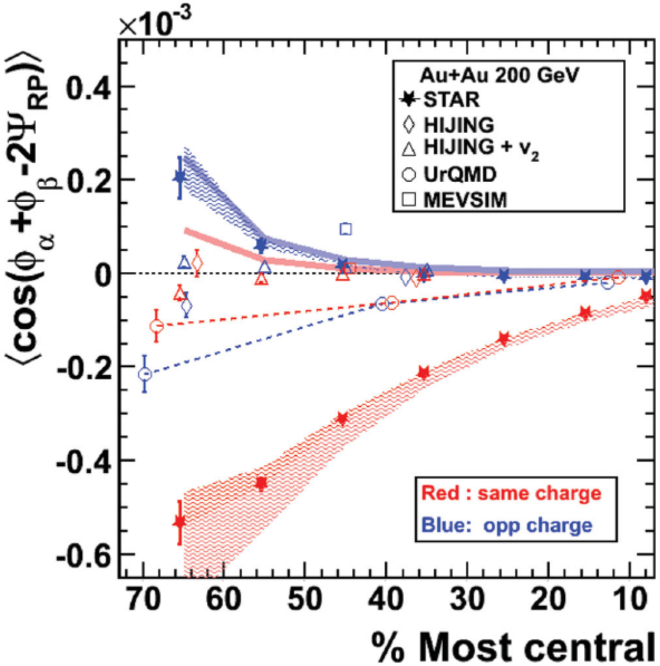

- Charge asymmetry w.r.t. reaction plane as a signature of Local Parity Violation
- Charge separation is believed as a consequence of chiral magnetic effect

More LPV results from STAR,
F. Zhao, ***Λ(K^0_S)-h Azimuthal Correlations with Respect to the Reaction Plane and Searches for CME and CVE***

B. Abelev et al. Phys. Rev. Lett. 103, 251601 (2009)

D. E. Kharzeev, L. D. McLerran, and H. J. Warringa, Nuclear Physics A 803, 227 (2008)

Chiral Magnetic Wave (CMW)

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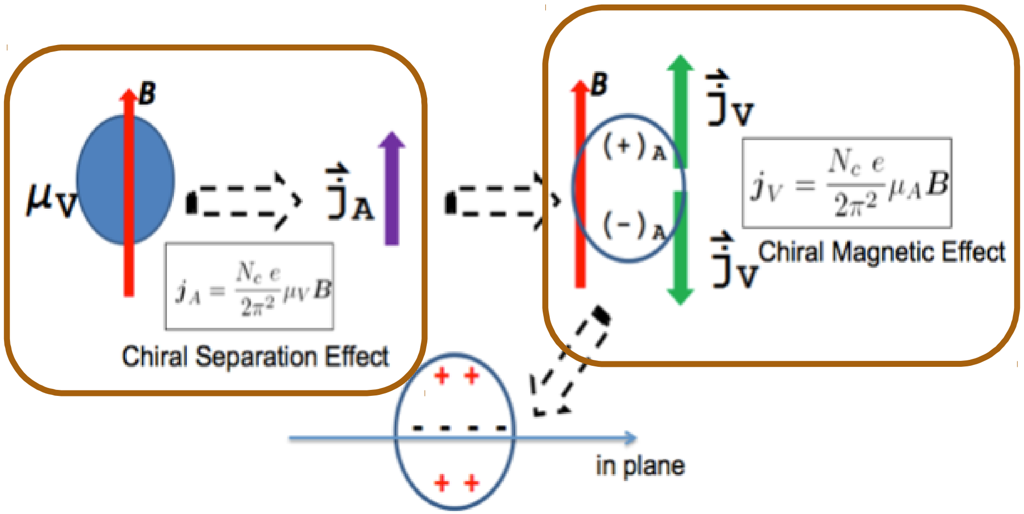
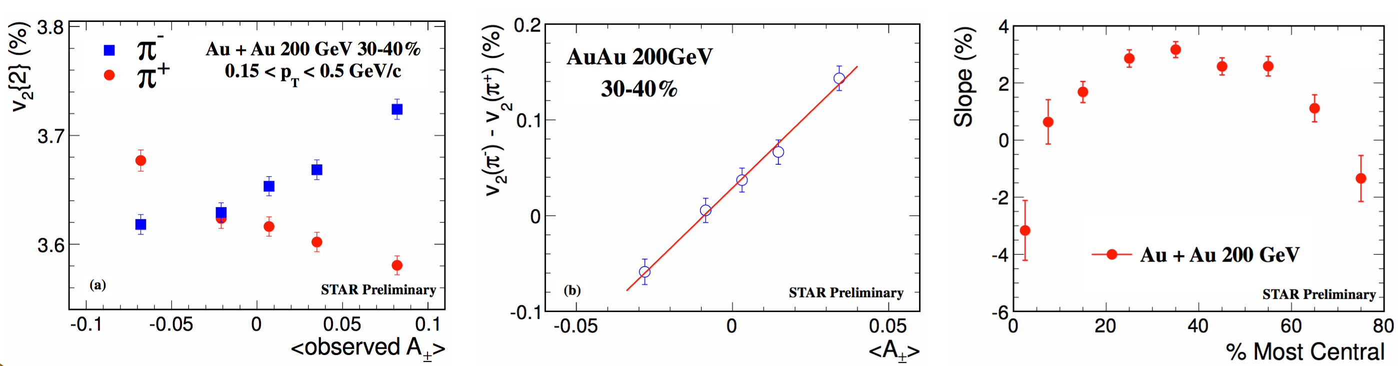


$$\frac{dN_\pm}{d\phi} = N_\pm[1 + 2v_2\cos(2\phi)]$$
$$\approx \bar{N_\pm}[1 + 2v_2\cos(2\phi) \mp A_{ch} r\cos(2\phi)]$$
$$\Delta v_2^{CMW} \equiv v_2(\pi^-) - v_2(\pi^+) \approx r A_{ch}$$

$$A_{ch} = \frac{N_+ - N_-}{N_+ + N_-}$$
$$r = 2q_e/\bar{\rho}_e$$



Measurements consistent with the expectation of CMW

Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, Phys. Rev. Lett. 107, 052303 (2011)

Hongwei Ke (for the Star Collaboration) 2012 J. Phys.: Conf. Ser. 389 012035

CMW Draw Lots of Theoretical Attention

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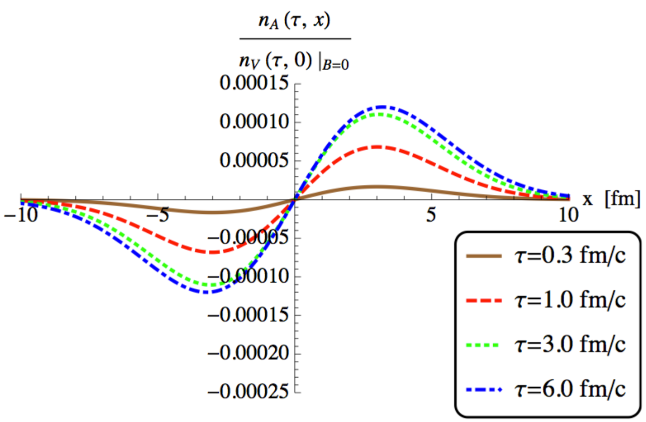
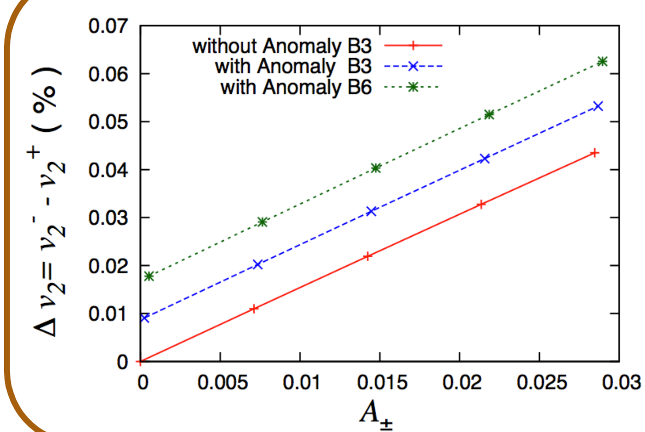


Expanding QCD

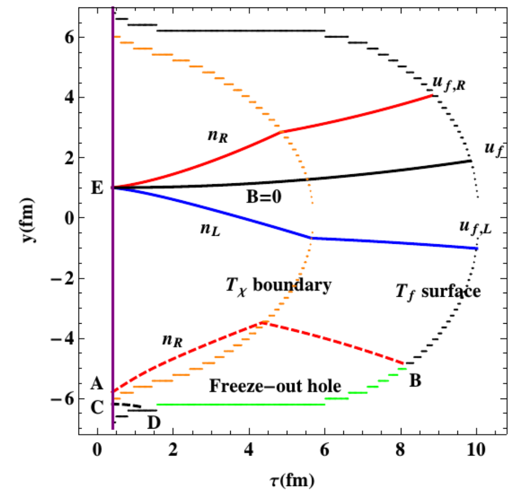
Signal is very small, but can be enhanced if early asymmetries in the axial charge distribution exists

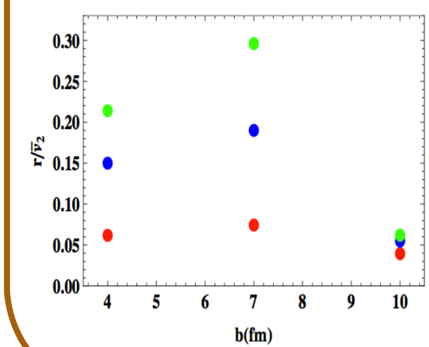


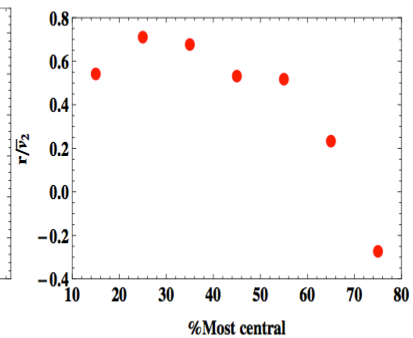
Hydro calculation

The intercept, instead of the slope, is sensitive to anomalous transport effects (CMW)

Freezeout condition is important. CMW effect is not small if calculated realistically





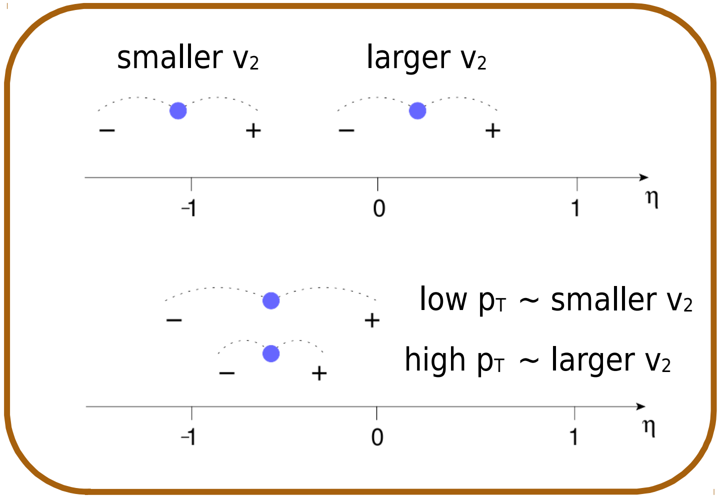


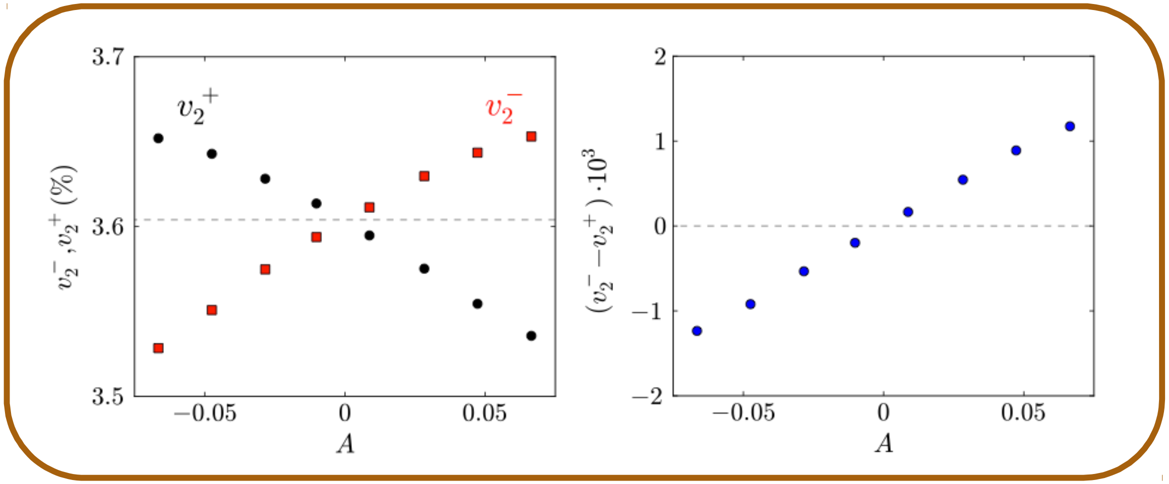
M. Hongo, Y. Hirono and T. Hirano, arxiv:1309.2823

S. F. Taghavi, U. A. Wiedemann, arxiv:1310.0193

H-U Yee, Y. Yin, arxiv 1311.2574

One Possible Explanation
Local Charge Conservation





- Hydro model + Local charge conservation at freeze-out
- slope(Δv_2) / slope(Δv_3) ~ 3
- The η window depedence

A. Bzdak, P. Bozek, Physics Letters B 726 (2013) 239-243

What This Study Provides ...

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Ingredients for various consistency checks:

- **The measurement in UU collisions**
  different geometry setup
- **The slope of $\Delta v_2(A_{ch})$ for kaons**
  other particle species with different Δv_2
- **The measurement of $\Delta v_3(\pi)$ as a function of A_{ch}**
  test for Hydro + Local charge conservation at freeze-out

Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, Phys. Rev. Lett. 107, 052303 (2011)

RHIC-STAR

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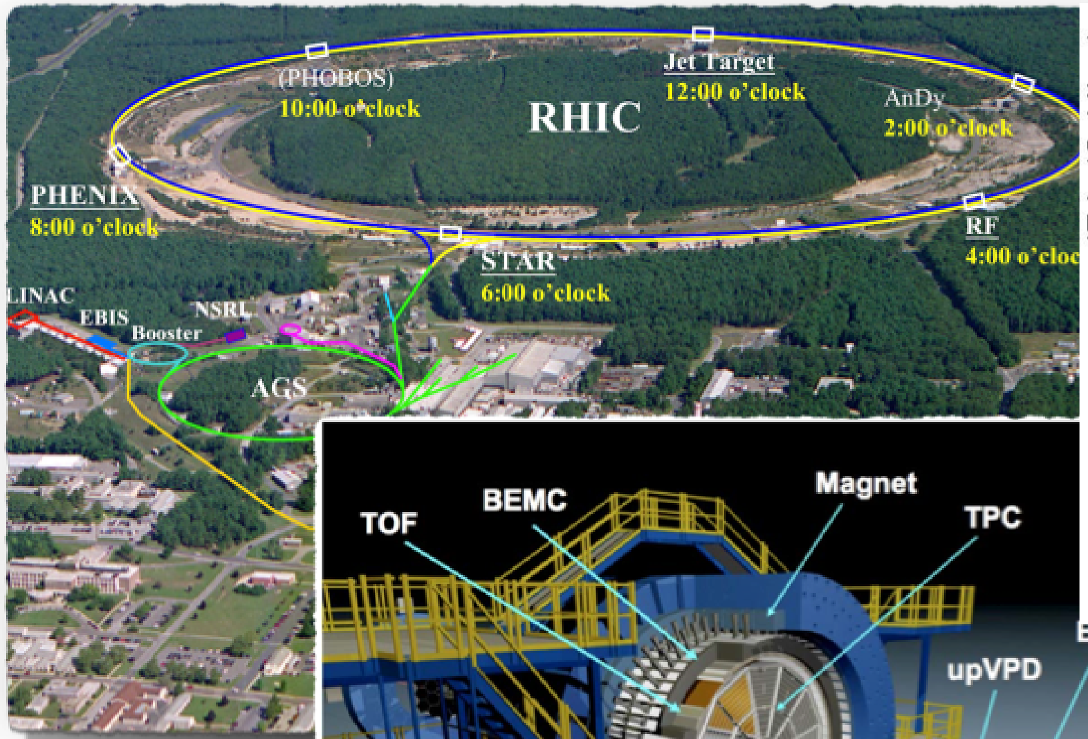

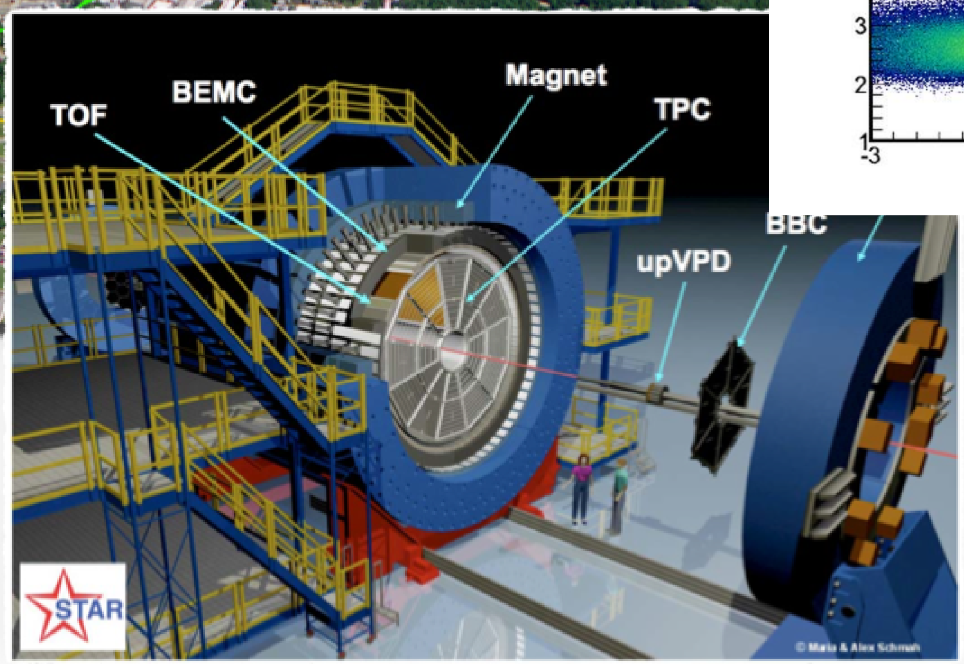

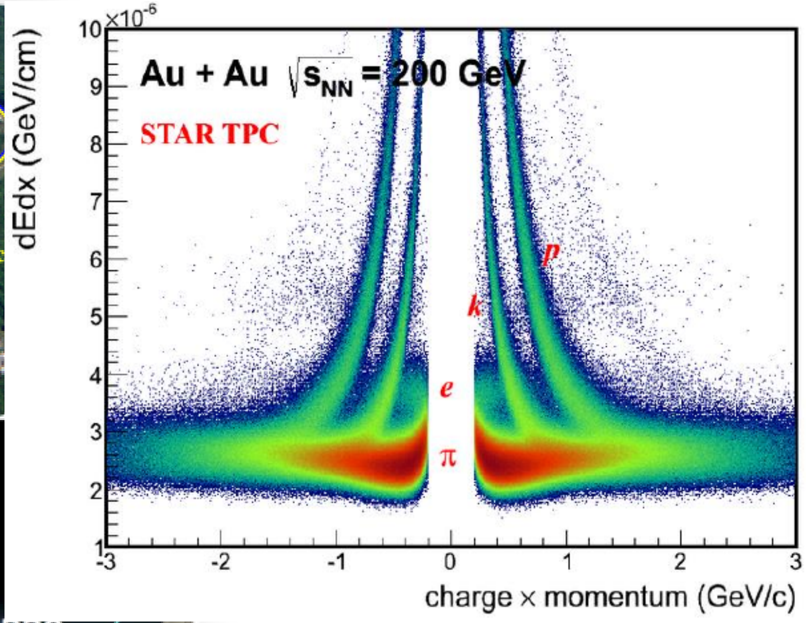

TPC and ToF are used for particle idenification

Data Analysis

Flow Calculation

- Q-cumulant method
- Δη between two correlated particles should be larger than 0.3 to suppress non-flow effect

A. Bilandzic, R. Snellings and S. Voloshin, Phys. Rev. C 83, 044913 (2011)

Data Analysis

Charge Asymmetry

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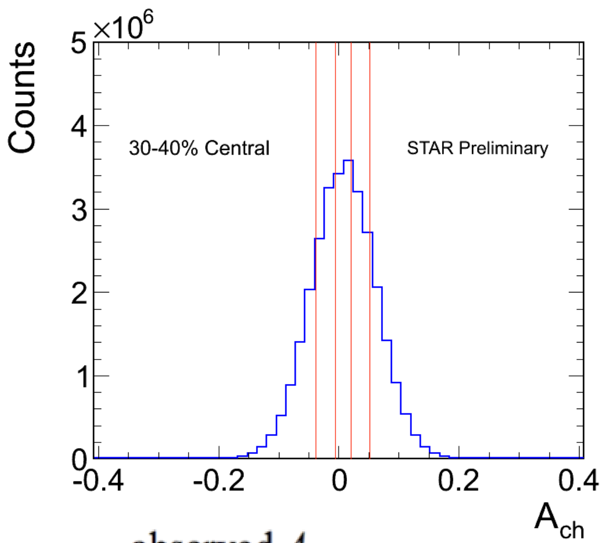
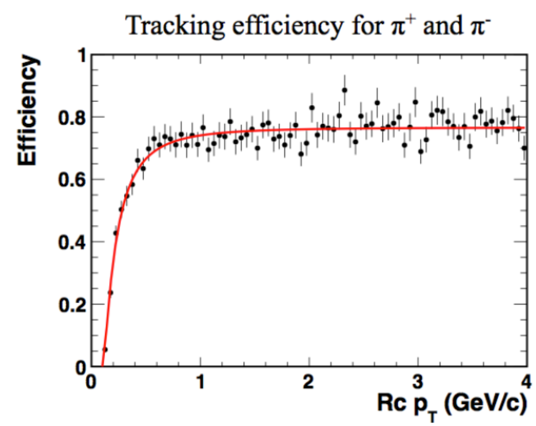
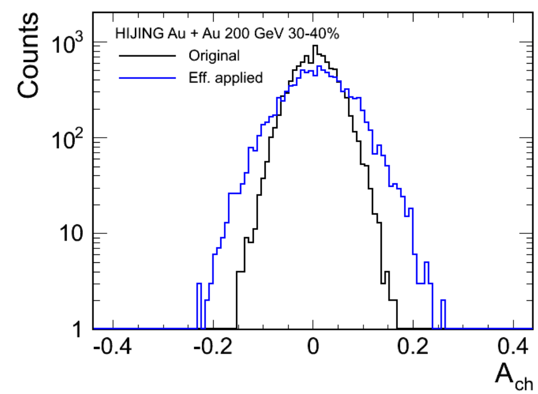


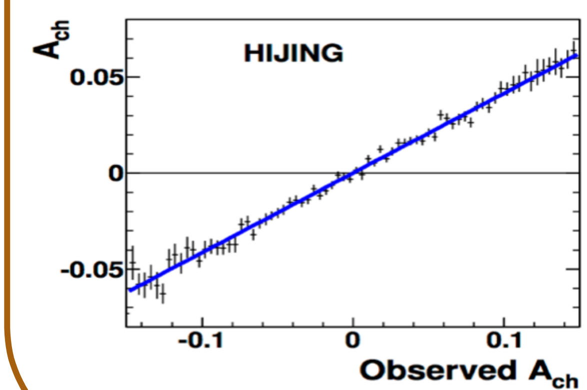
observed A_{ch}

$$A_{ch} = \frac{N_+ - N_-}{N_+ + N_-}$$

Each bin has the same number of events







Apply the same cuts in Monte-Carlo and real data calculation

Data Analysis
Slope Parameter

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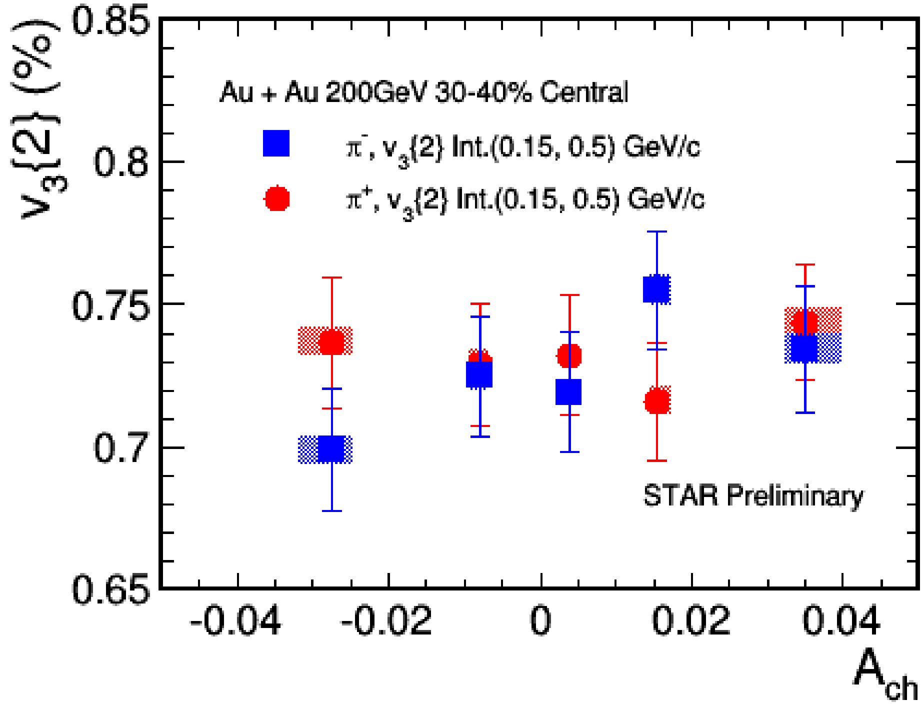

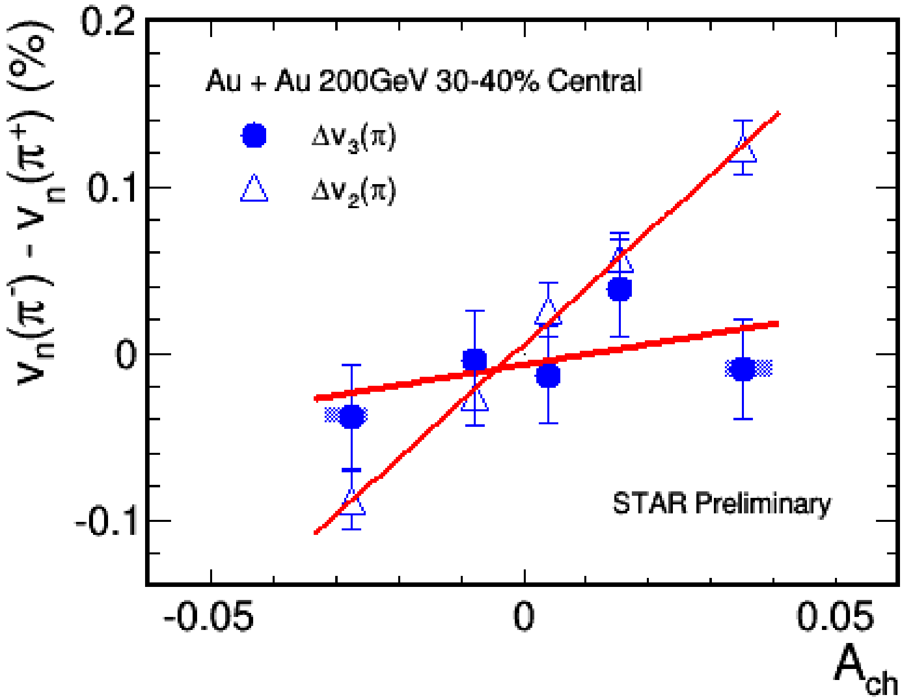

v_3 vs A_{ch}

Slope(Δv_3) < slope(Δv_2) in mid-centrality

Result

$\Delta v_2(\pi)$ Slope vs. Centrality (Au vs. U)

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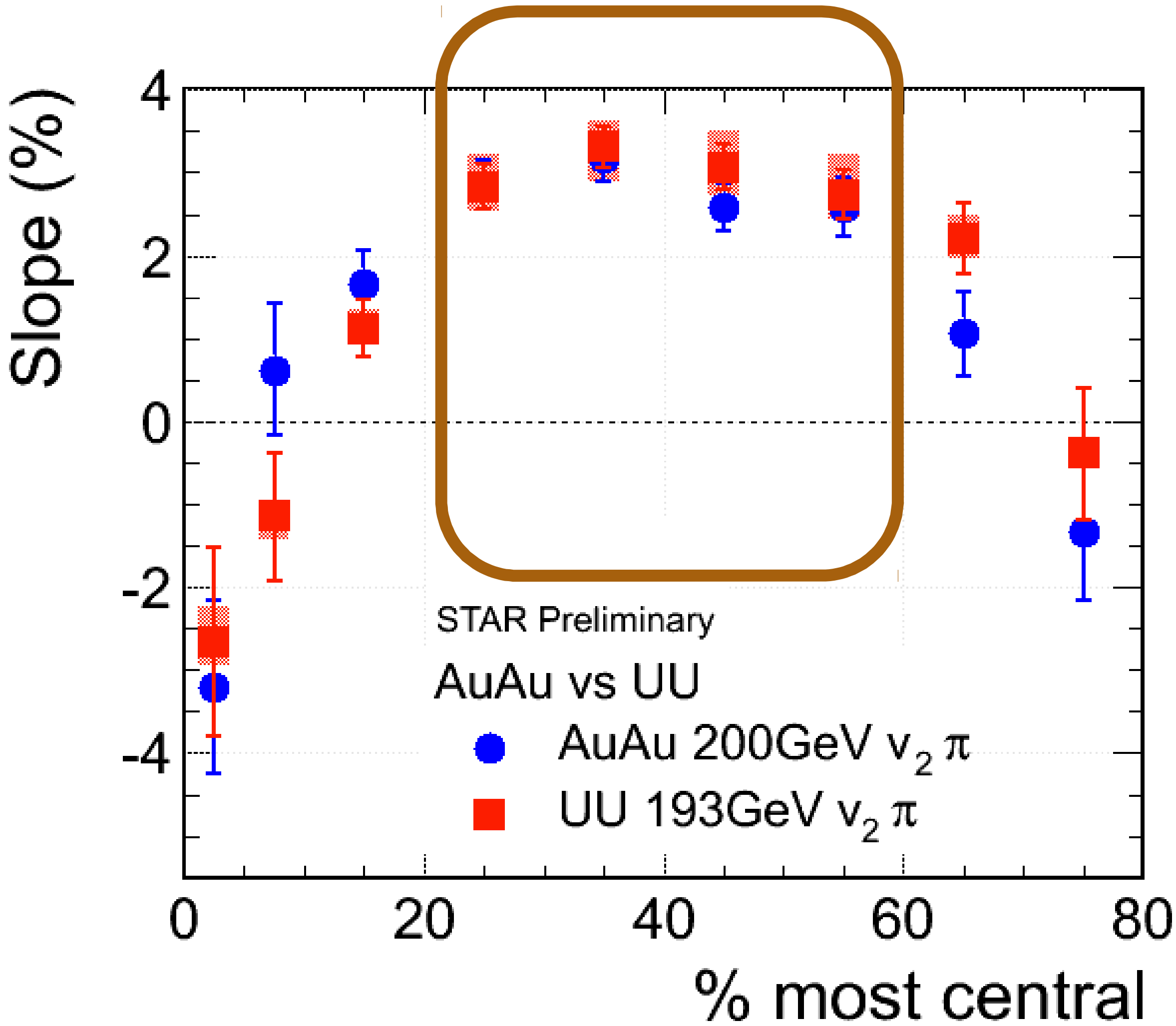
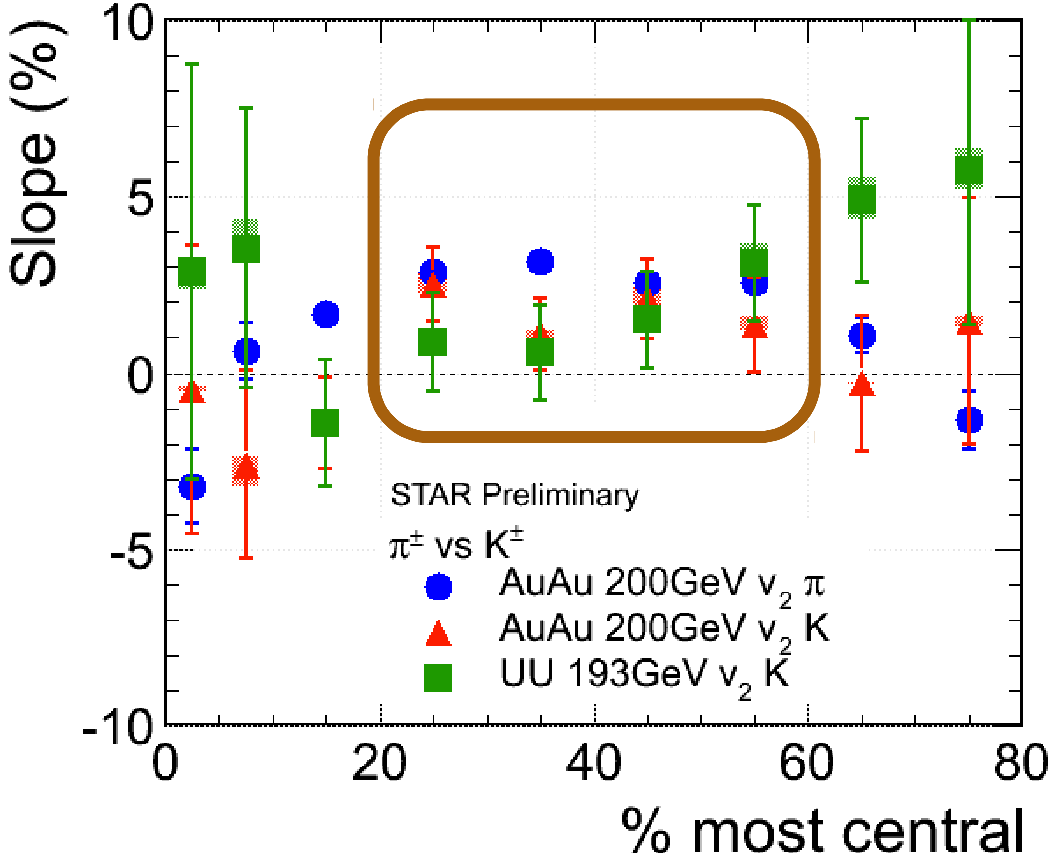
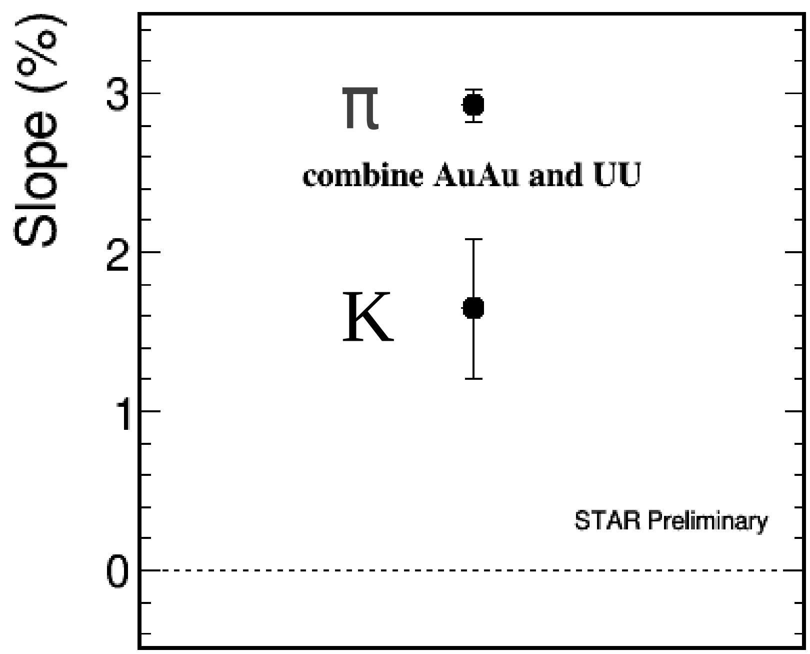


Slope in UU collisions is consistent with that in AuAu collisions

Result

Δv_2(K) Slope vs. Centrality



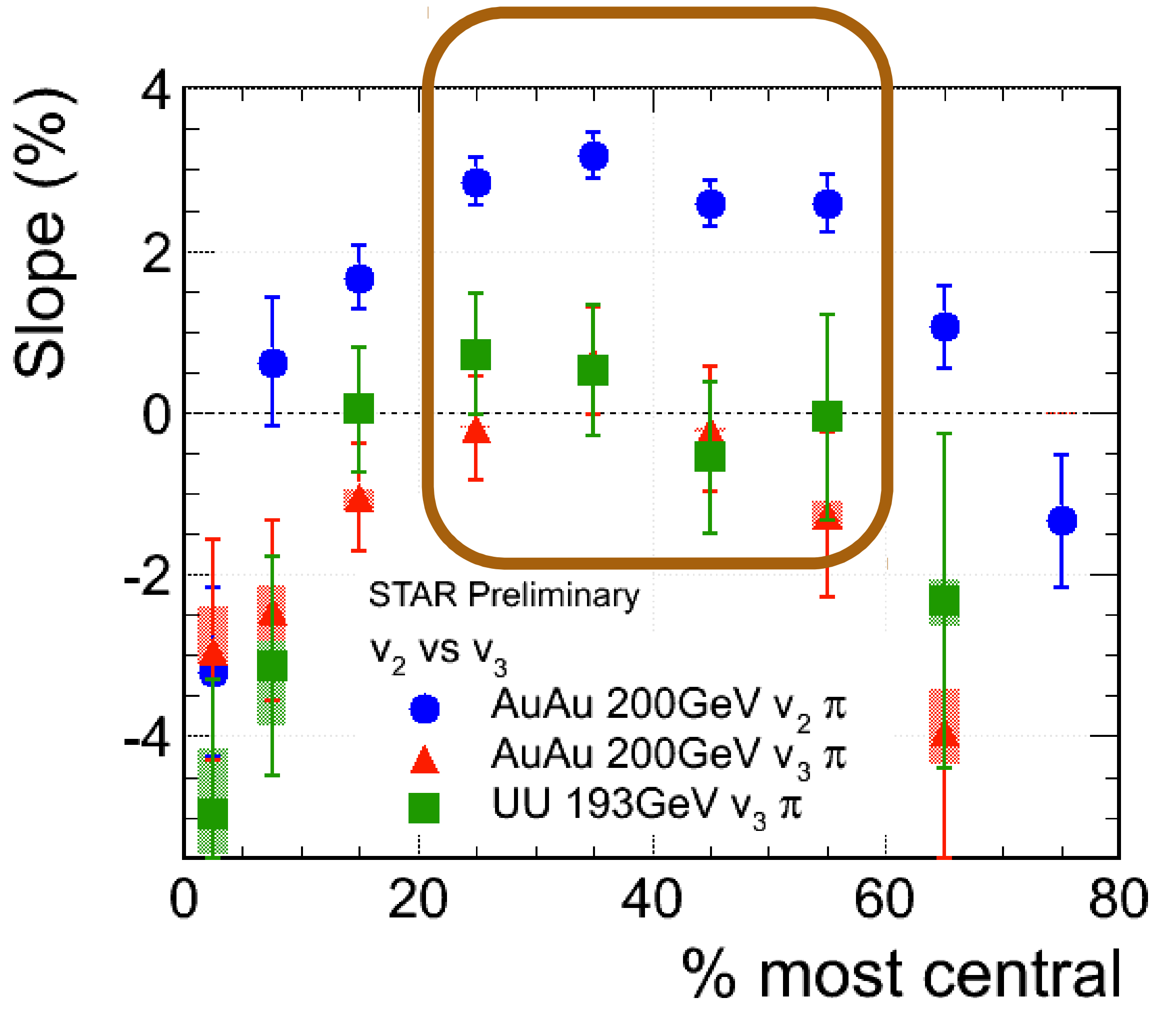


Slope of Δv_2 vs A_{ch} for kaons could be different from slope for pions (flow difference are likely to be masked or reversed)

Slope (π)	2.92±0.10 %
Slope (K)	1.65±0.44 %

Result

$\Delta v_2(\pi)$, $\Delta v_3(\pi)$ Slope vs. Centrality



In mid-centrality bins, the slope of $\Delta v_3(\pi)$ is much smaller than that of $\Delta v_2(\pi)$

Result
Comparison between slope(Δv_2) and slope(Δv_3)

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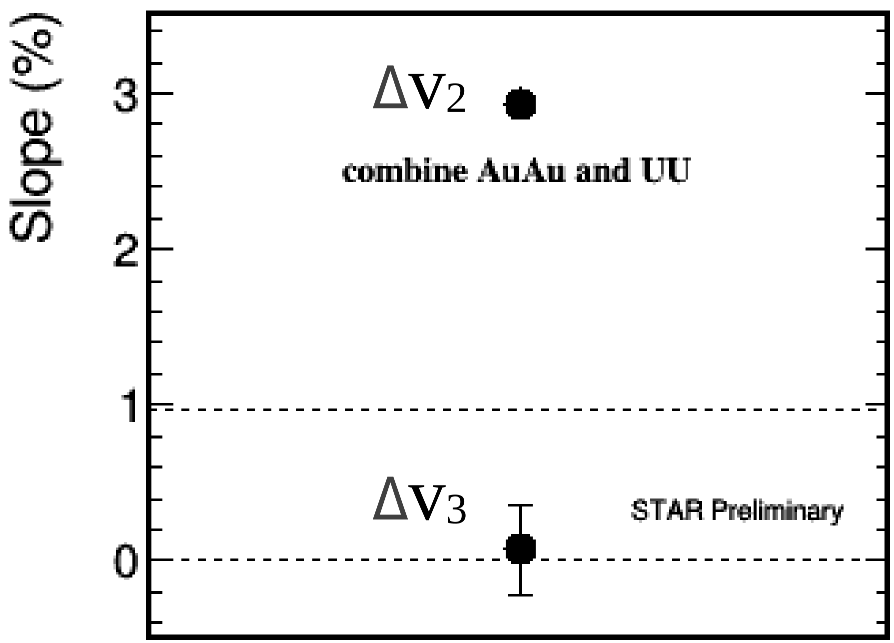
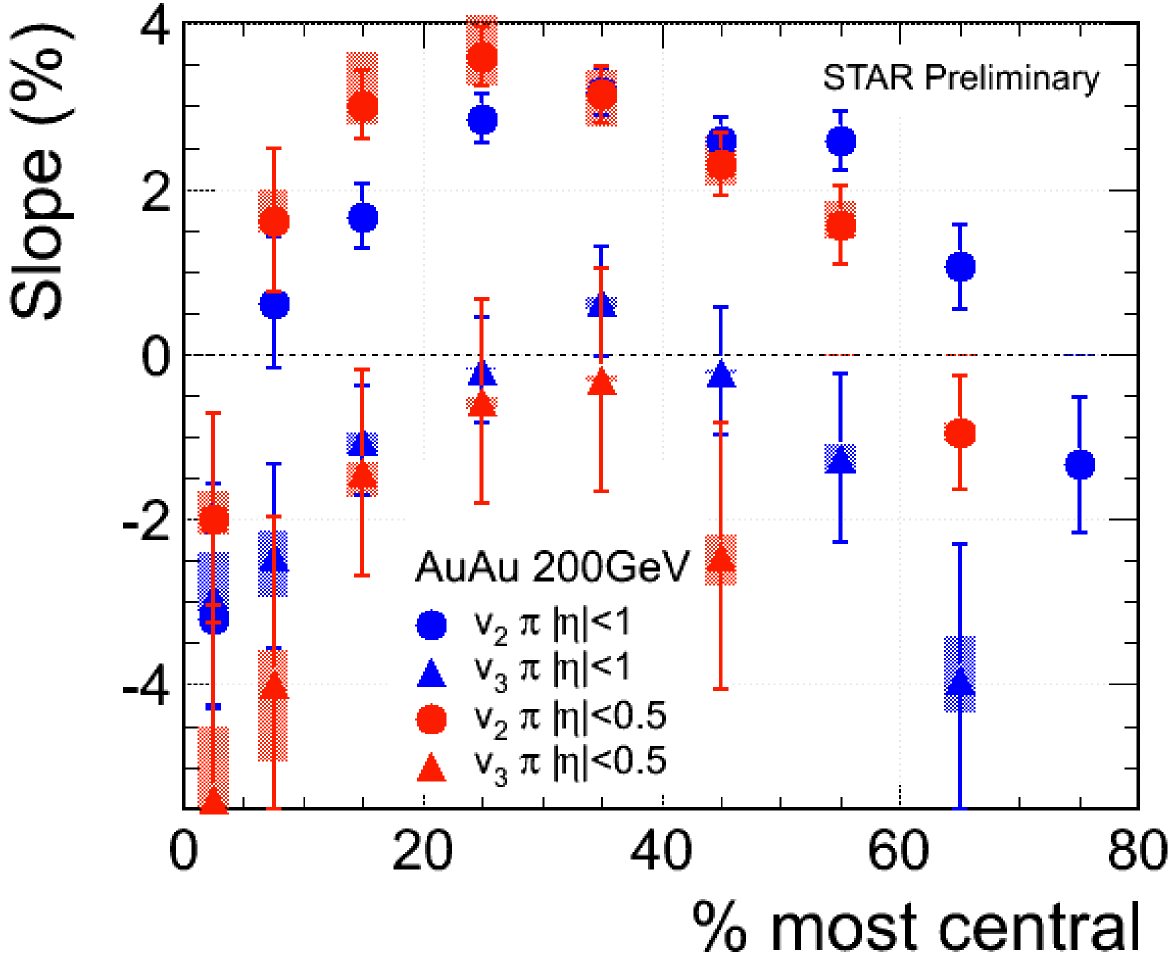


slope(Δv_2)	2.92±0.10 %
slope(Δv_3)	0.07±0.28 %

Combining 20-60% centrality bins, slope(Δv_3) value is 3.2σ away from 1/3 of slope(Δv_2)

Result

$\Delta v_2(\pi)$, $\Delta v_3(\pi)$ Slope vs. Centrality (Narrow η)



Results do not show η dependence

Summary

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- **The same linear relationship between $\Delta v_2(\pi^\pm)$ and A_{ch} has been observed in both minimum bias AuAu and UU collisions**

- **The first attempt to study the slope for $\Delta v_2(K)$**
  $\Delta v_2(K^\pm)$ results show consistency with CMW expectations

- **$\Delta v_3(\pi)$ as a function of A_{ch} studied in AuAu and UU collisions**
  In mid-central collisions, the ratio of slope of $\Delta v_3(A_{ch})$ to that of $\Delta v_2(A_{ch})$, is 3.2σ below the predicted value (1/3) from hydro + local charge conservation at freeze-out. This indicates that it is unlikely that such effect can have a significant contribution to the splitting of $v_2(\pi)$ as a function of A_{ch}

- **Both $\Delta v_3(A_{ch})$ and $\Delta v_2(A_{ch})$ measurements do not show η dependence**

Thank you for your attention!

Backup

Data Analysis

Event, Track Selection

Event

Run10 AuAu 200GeV
~328M MinBias
Run11 AuAu 200GeV
~555M MinBias
Run12 UU 193GeV
~643M MinBias

- $|V_z| < 30$ cm
- $|V_r| < 2$ cm

Charge Asymmetry

- All charged particles excluding (anti)proton with $p_T < 0.4$ GeV/c
- $0.15 < p_T < 12$ GeV/c
- $|\eta| < 1$

Flow

- Primary Tracks
  DCA < 1 cm
- Pion PID
  $|n\sigma_\pi| < 2$
  $0 < m^2 < 0.1$
- Kaon PID
  $|n\sigma_k| < 2$
  $0.15 < m^2 < 0.35$
- $0.15 < p_T < 0.5$ GeV/c
- $|\eta| < 1$

Data Analysis
Flow Calculation - 1

1. Flow vectors:

Reference Particle (RP): $Q_n \equiv \sum_{i=1}^{M} e^{in\phi_i}$

Particle of Interest (POI): $p_n \equiv \sum_{i=1}^{m_p} e^{in\psi_i}$

RF & POI: $q_n \equiv \sum_{i=1}^{m_q} e^{in\psi_i}$

2. Two-particle Correlations:

$$\langle 2 \rangle = \frac{|Q_n|^2 - M}{M(M-1)}$$

$$\langle 2' \rangle = \frac{p_n Q_n^* - m_q}{m_p M - m_q}$$

3. Cumulants:

$$c_n\{2\} = \langle\langle 2 \rangle\rangle$$

$$d_n\{2\} = \langle\langle 2' \rangle\rangle$$

4. Flow estimation:

Reference flow: $v_n\{2\} = \sqrt{c_n\{2\}}$

Differential flow: $v'_n\{2\} = \frac{d_n\{2\}}{\sqrt{c_n\{2\}}}$

A. Bilandzic, R. Snellings and S. Voloshin, Phys. Rev. C 83, 044913 (2011)

Data Analysis

Flow Calculation - 2

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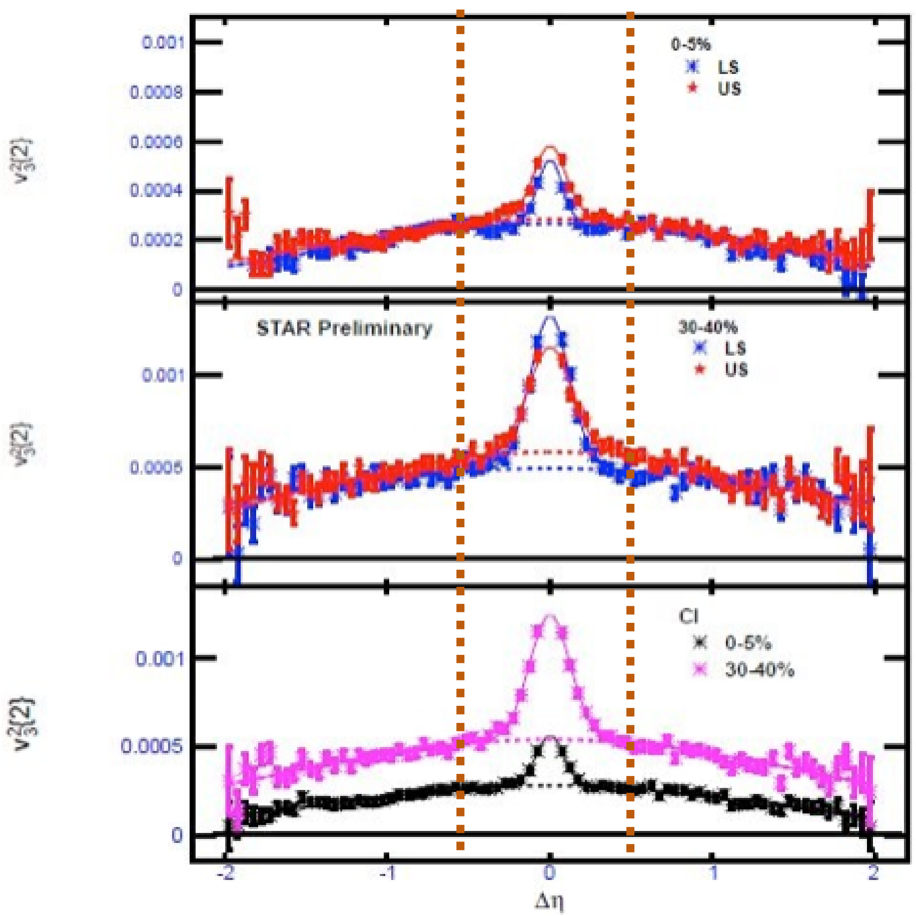

- Δη between two correlated particles should be larger than 0.3 to subtract non-flow effect
- Divide a given event into two sub-groups according to η to guarantee the η gap

Yadav Pandit (for the Star Collaboration) 2013 J. Phys.: Conf. Ser. 420 012038