Charge Asymmetry Dependency of $\pi^{\pm}$ and $K^{\pm}$ Anisotropic Flow in Heavy Ion Collisions at STAR

Hongwei Ke

(for the STAR Collaboration)

Brookhaven National Laboratory

Outline

- Motivation
- STAR Experiment
- Observations
  - Charge asymmetry dependency of $\pi^{\pm}/K^{\pm}$ v_2
  - Charge asymmetry dependency of $\pi^{\pm}$ v_3
- Summary

CME, CSE and CMW

- Chiral Magnetic Effect (CME): nonzero axial charge density induces a vector (electric) current along external magnetic field.

$$\boldsymbol{j}_V = \frac{N_c e}{2\pi^2}\mu_A \boldsymbol{B} \quad \Rightarrow \quad \text{electric charge separation along } B \text{ field}$$

- Chiral Separation Effect (CSE): nonzero vector charge density induces an axial (chiral) current along external magnetic field.

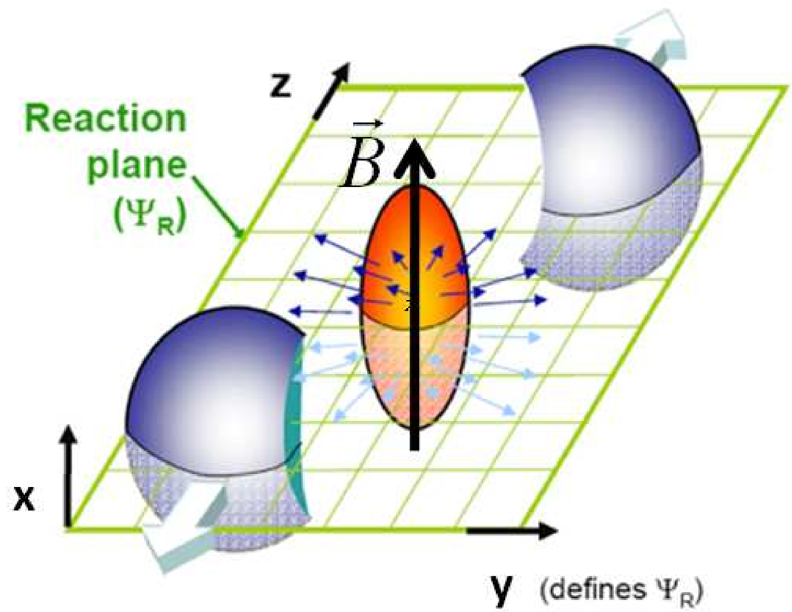
$$\boldsymbol{j}_A = \frac{N_c e}{2\pi^2}\mu_V \boldsymbol{B} \quad \Rightarrow \quad \text{chiral charge separation along } B \text{ field}$$

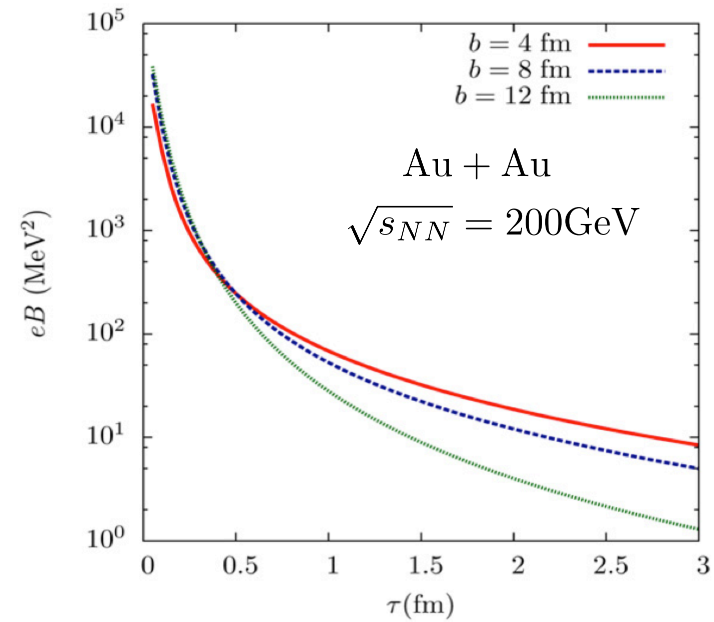
- Chiral Magnetic Wave (CMW): CME and CSE induce each other; form density waves of electric and chiral charge

$$\left(\partial_0 \mp \frac{N_c e B \alpha}{2\pi^2}\partial_1 - D_L \partial_1^2\right) j^0_{L,R} = 0$$

D. Kharzeev, L. McLerran, and H. Warringa, Nuclear Physics A **803**, 227 (2008)
D. T. Son and A. R. Zhitnitsky, Phys. Rev. D **70**, 074018 (2004)
D. Kharzeev and H.-U. Yee, Physical Review D **83**, 085007 (2011)

Heavy Ion Collisions

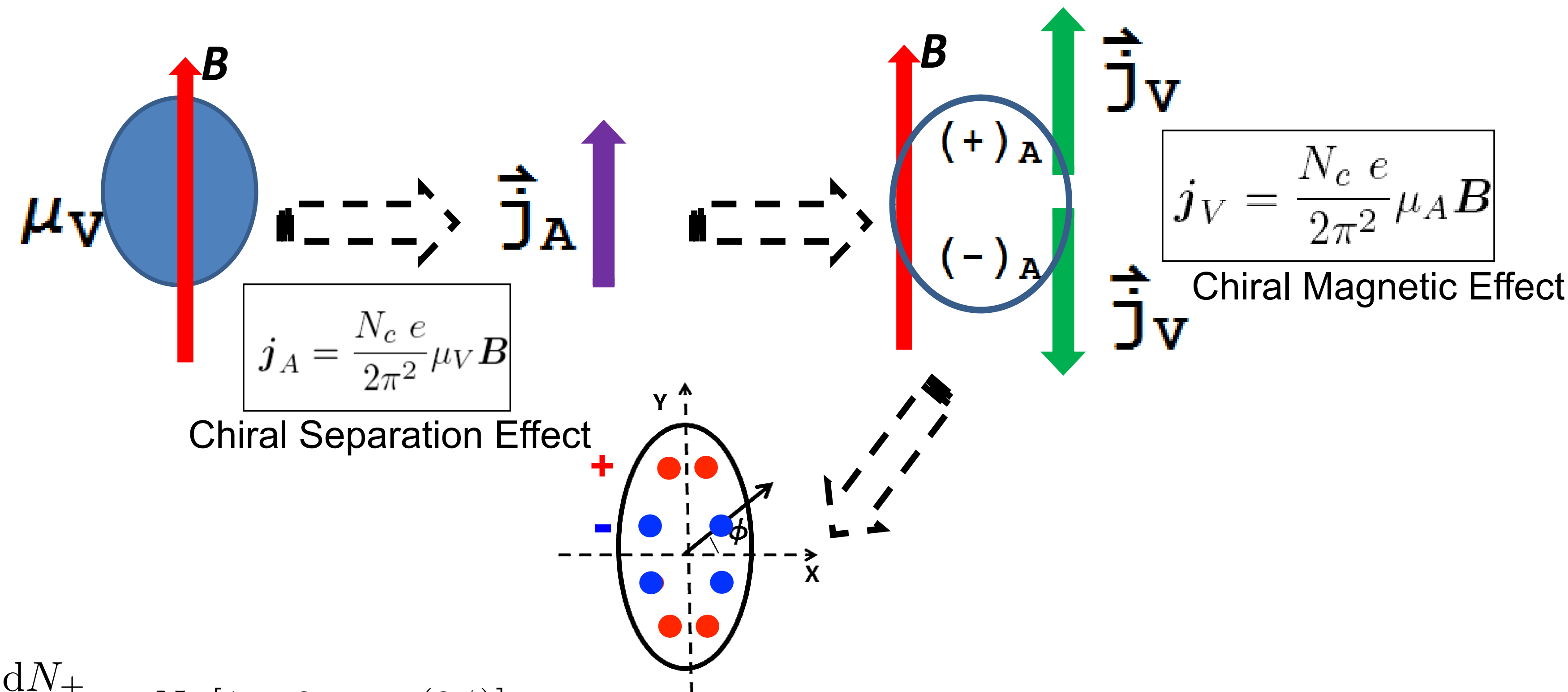




Nuclear Physics A **803**, 227 (2008).

- Chiral symmetry restoration
- Extremely strong magnetic field created in heavy ion collision, ~10^{15} Tesla!
- Chiral Magnetic Effect ➔ out-of-plane electric charge separation
- Chiral Separation Effect ➔ out-of-plane chiral charge separation
- Chiral Magnetic Wave ➔ electric quadrupole moment

Chiral Magnetic Wave



$$\frac{dN_\pm}{d\phi} = N_\pm[1 + 2v_2\cos(2\phi)]$$

$$\approx N_\pm[1 + 2v_2\cos(2\phi) \mp A_{ch} r\cos(2\phi)]$$

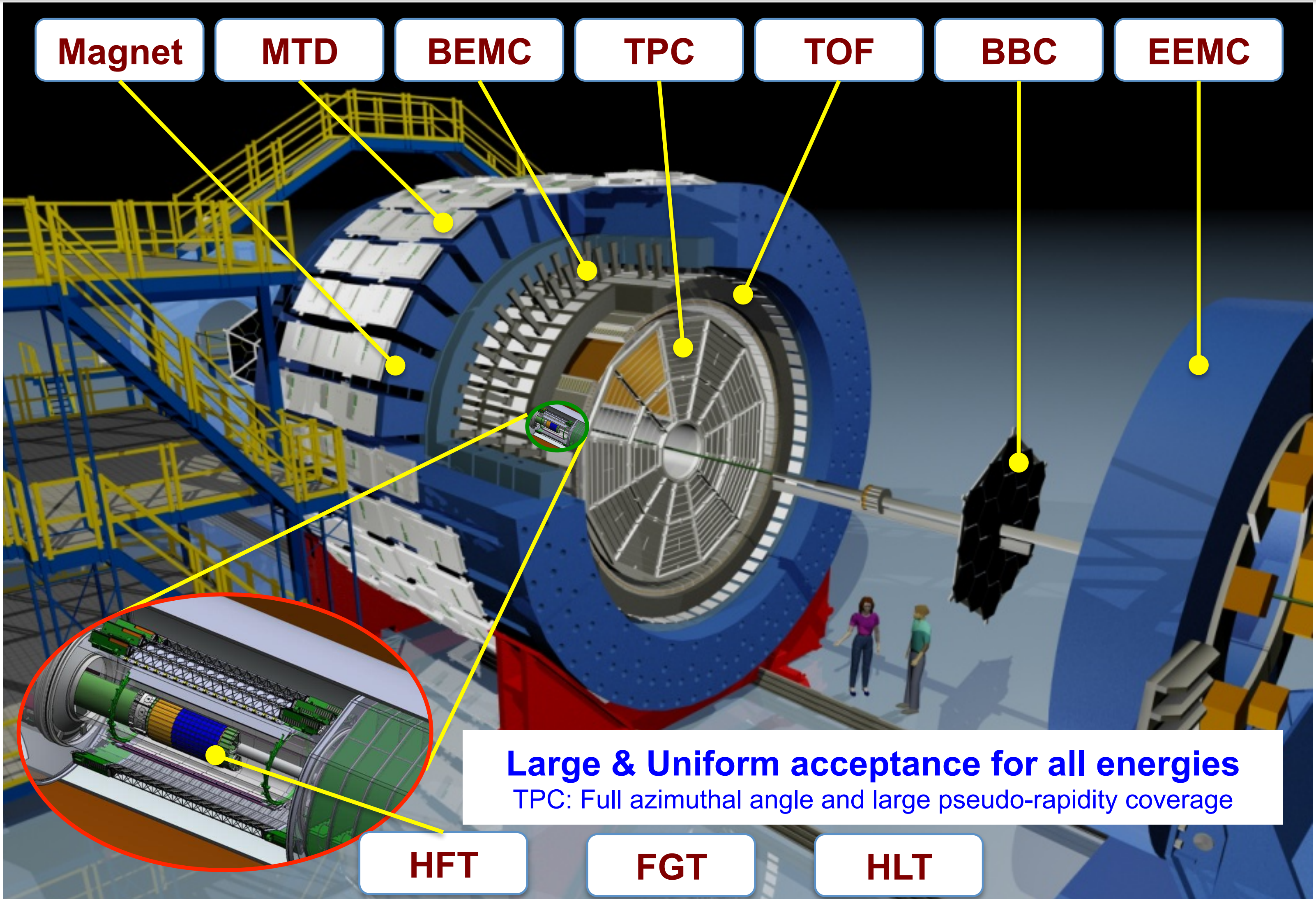
$$A_{ch} = \frac{N_+ - N_-}{N_+ + N_-} \qquad r = 2\left(\frac{q_e}{\bar{\rho}_e}\right)$$

$$v_2^\pm = v_2 \mp \frac{r}{2}A_{ch}$$

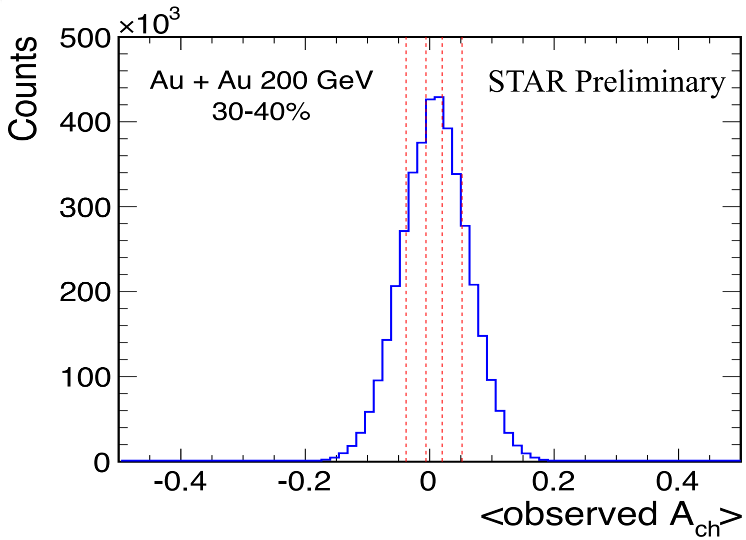
$$v_2^- - v_2^+ = rA_{ch}$$

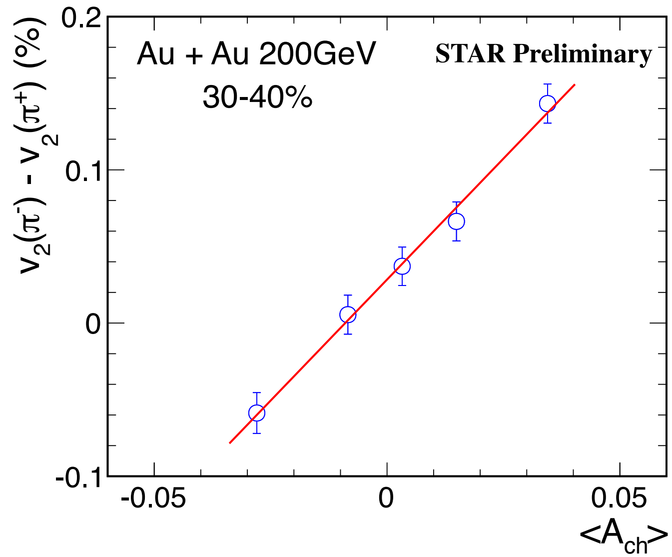
Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, Phys. Rev. Lett. **107**, 052303 (2011)

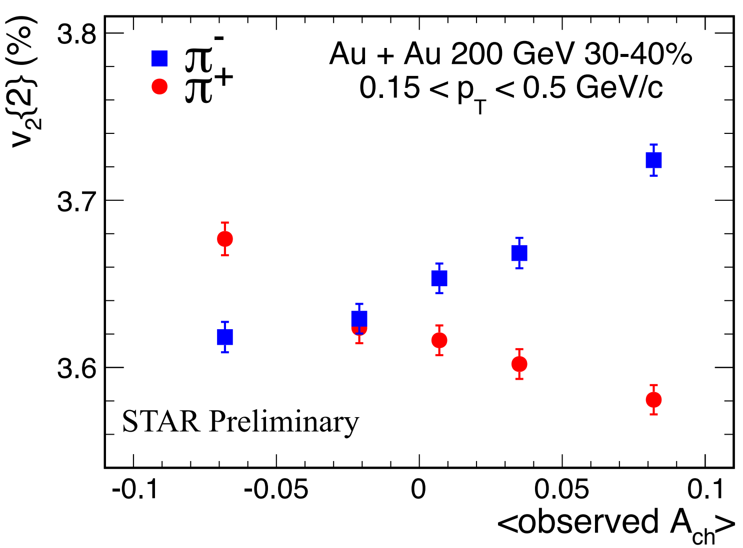
STAR Experiment



Integrated v_2

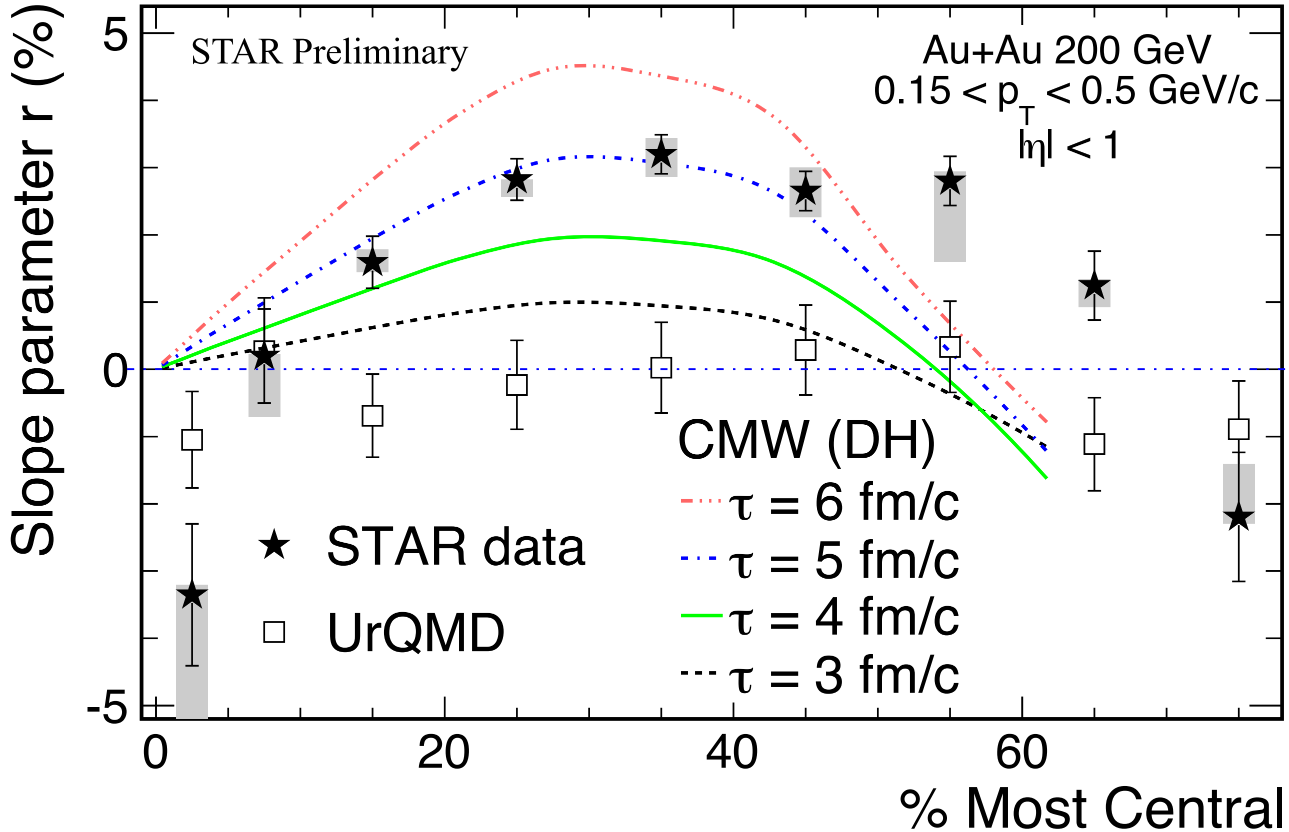






- $v_2(\pi^+)$ and $v_2(\pi^-)$ integrated over $0.15 < p_T < 0.5$ GeV/c
- $v_2(\pi^+)$ and $v_2(\pi^-)$ have linear dependency to A_{ch}
- $v_2(A_{ch})$ slopes of π^+ and π^- have
  - opposite sign
  - similar magnitude
- v_2 difference vs. A_{ch} may have a non-zero intercept

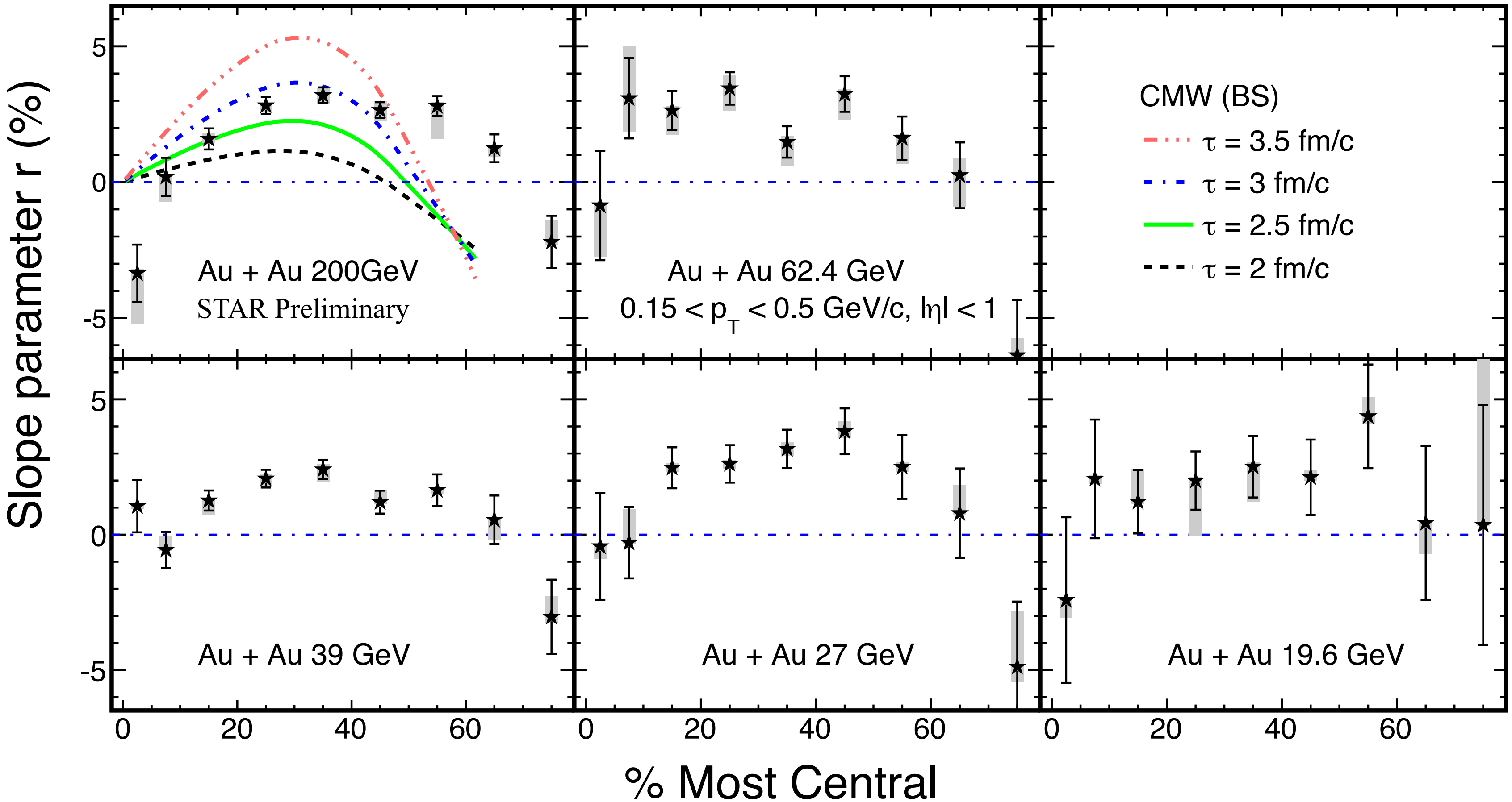
Slope vs. Centrality



- Similar trends between data and theoretical calculations with CMW.
- UrQMD cannot reproduce the slopes at $\sqrt{s_{NN}}$ = 200 GeV.

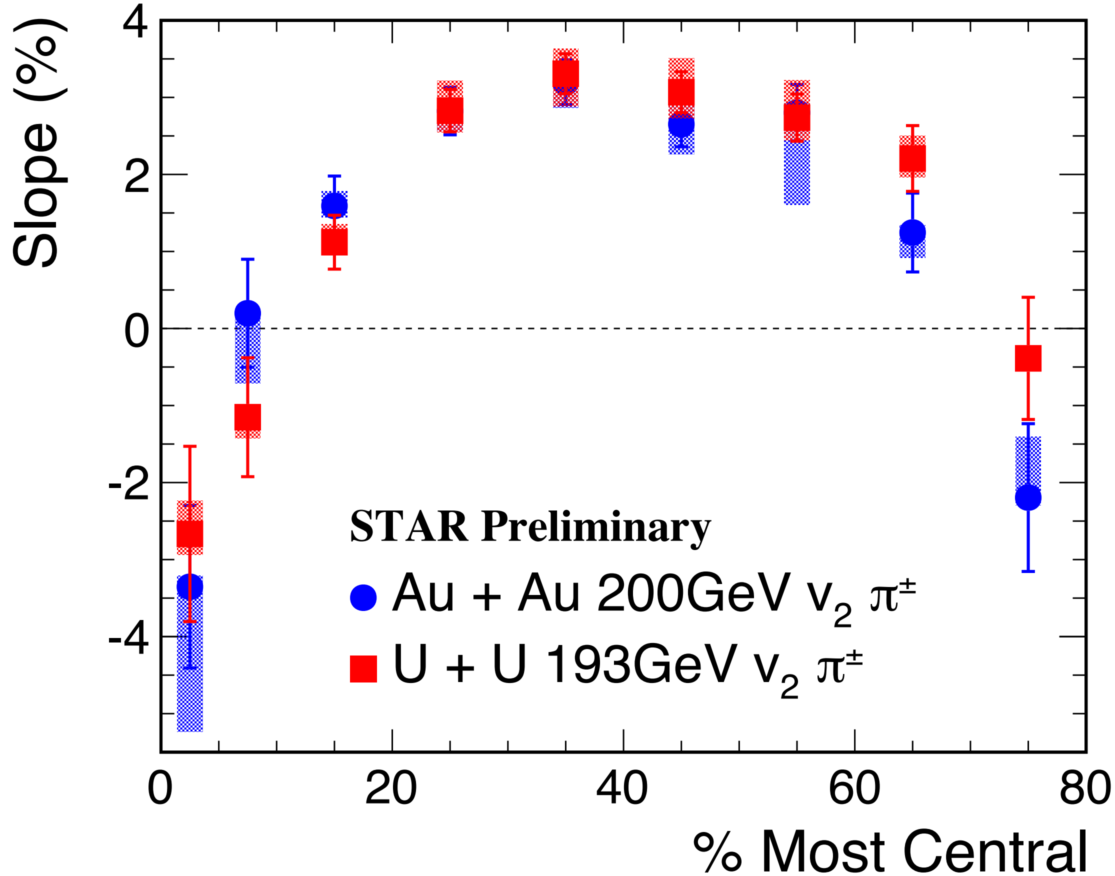
Y. Burnier, D. E. Kharzeev, J. Liao, and H.-U. Yee, arXiv:1208.2537

Energy Dependence in Au+Au Collisions



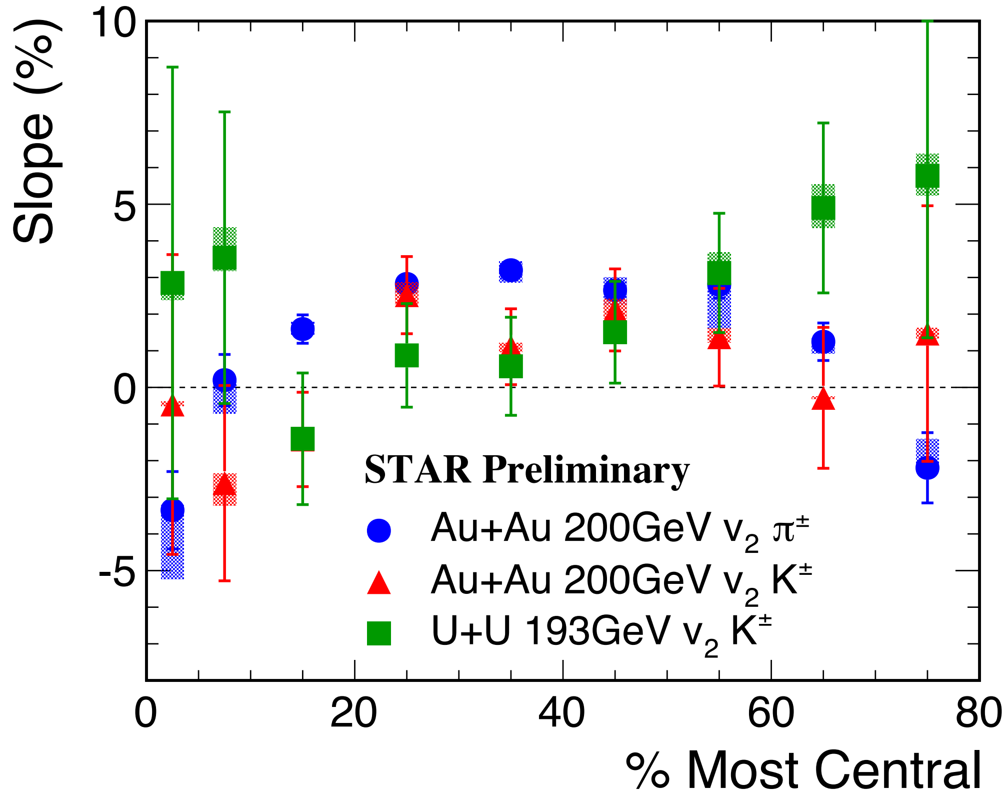
- The slope parameter *r* shows a rise and fall feature from central to peripheral collisions
- Slope as a function of centrality shows weak energy dependency
- Similar trend to the theoretical calculation based on CMW

Slope vs. Centrality in U+U Collisions



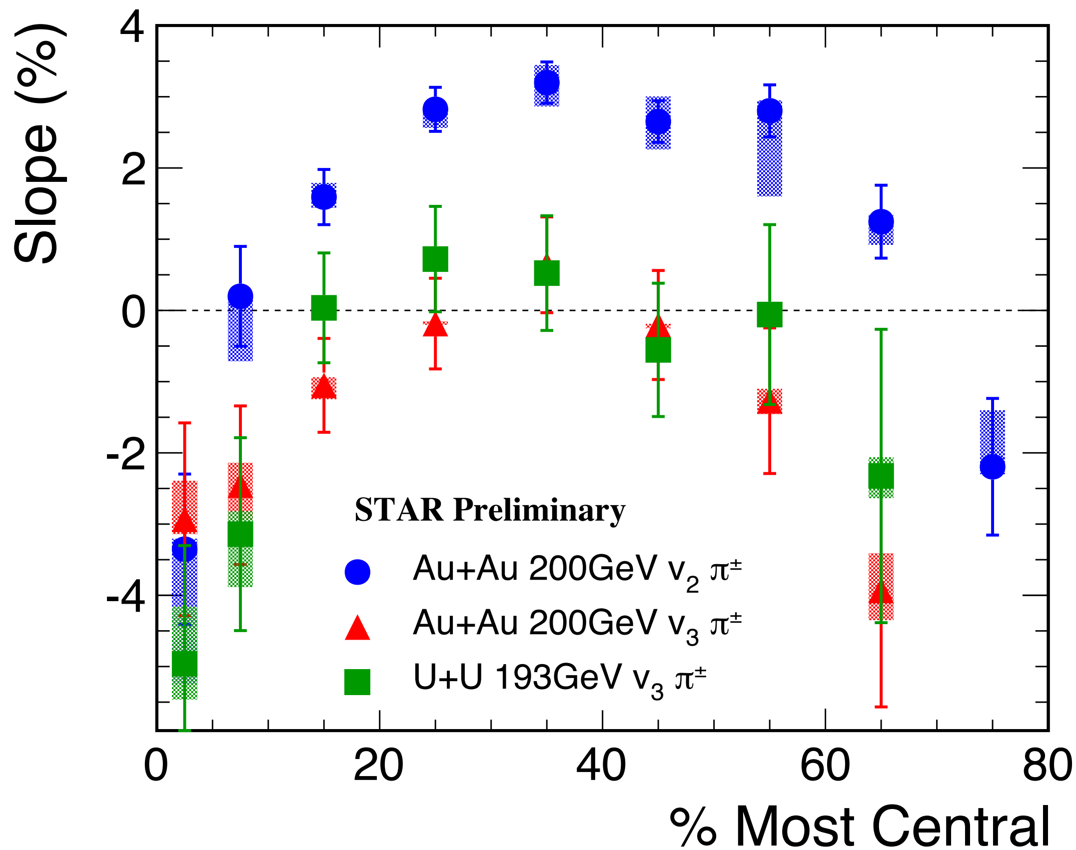
- A similar centrality dependence of the slope parameter has been seen in U + U collisions at $\sqrt{s_{NN}}$ = 193 GeV

Slope vs. Centrality for $K^{\pm}$



- Theoretical calculations suggest the slope of $v_2(A_{ch})$ for K can be different form that of π
- More experimental data are needed to make the measurements of K conclusive

Slope vs. Centrality from v_3 of $\pi^{\pm}$



- The trend of $\Delta v_3(\pi)$ slope is similar to that of $\Delta v_2(\pi)$
- The $\Delta v_3(\pi)$ slope is consistent with zero in mid-central collisions in contrast to finite values

A. Bzdak and P. Bozek, Physics Letters B **726** (2013) 239

Summary

- The difference between $v_2(\pi^-)$ and $v_2(\pi^+)$ shows a linear dependency on charge asymmetry in Au + Au collisions at $\sqrt{s_{NN}}$ = 200, 62.4, 39 and 27 GeV and in U + U collisions at $\sqrt{s_{NN}}$ = 193 GeV. The UrQMD model calculations cannot reproduce this feature in Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

- As a function of collision centrality, the slope parameter *r* for $\pi^{\pm}$ shows a rise and fall feature from central to peripheral collisions and the energy dependence seems weak.

- The $v_3(\pi^{\pm})$ as a function of A_{ch} has been studied in Au + Au and U + U collisions. The centrality dependency of $\Delta v_3(\pi)$ slope is similar to that of $\Delta v_2(\pi)$ slope. However, the $\Delta v_3(\pi)$ slope is consistent with zero in mid-centrality collisions.

- The centrality dependency of the $\Delta v_2(\pi)$ slope shows a similar trend of the calculations based on Chiral Magnetic Wave .