# Charge Asymmetry Dependency of $\pi^+/\pi^-$ Azimuthal Anisotropy in Au + Au Collisions at STAR

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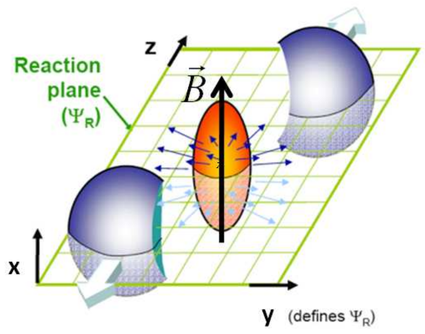
**Abstract**: A recent theoretical study indicates that a chiral magnetic wave at finite baryon density could induce an electric quadrupole moment in the quark-gluon plasma produced in ultra-relativistic heavy ion collisions. The quadrupole deformation will lead to a difference in azimuthal anisotropy, $v_2$, between positive and negative pions. The magnitude of the difference is expected to be proportional to the system charge asymmetry $A_\pm = (N^+ - N^-)/(N^+ + N^-)$.

In this poster, we present a STAR measurement of $v_2$ difference between charged pions in Au + Au collisions at $\sqrt{s_{NN}}$ = 200, 62.4, 39, 27 and 19.6 GeV. The $p_T$ integrated $v_2$ of $\pi^+$ ($\pi^-$) decreases (increases) linearly with increasing $A_\pm$. The $v_2$ difference between $\pi^+$ and $\pi^-$ is found proportional to $A_\pm$. The centrality dependence of the slope parameters has the similar trend as predicted.

## Motivation

- Relativistic heavy-ion collisions create hot and dense matter, i.e. Quark-Gluon Plasma (QGP), in the reaction region.
- Extremely strong magnetic fields are induced by the spectators.
- With the present of QCP and external magnetic field ***B***, the axial anomaly induces two phenomena

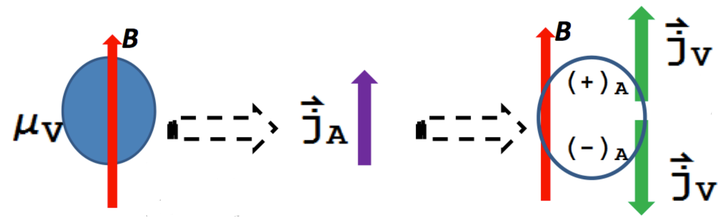



Chiral Magnetic Effect (CME):

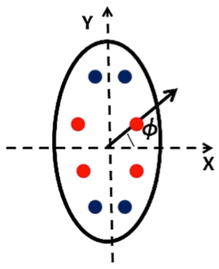
$$j_V = \frac{N_c e}{2\pi^2}\mu_A B$$

Chiral Separation Effect (CSE):

$$j_A = \frac{N_c e}{2\pi^2}\mu_V B$$




- CME and CSE make a Chiral Magnetic Wave (CMW).
- CMW can form an electrical quadrupole moment and lead to more positive charge near the poles and more negative charge near the equator.
- Different azimuthal anisotropy, $v_2$, of pions should be observed.

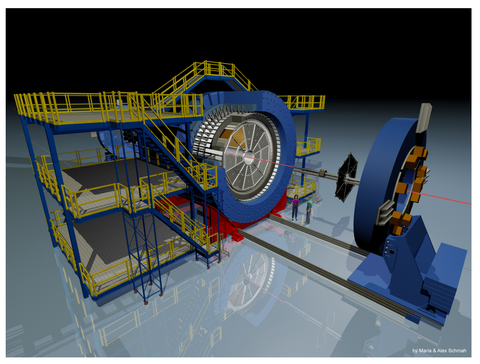



$$\Delta v_2^{\mathrm{CMW}} \equiv v_2(\pi^-) - v_2(\pi^+) \approx r A_\pm$$

while $A_\pm \equiv (\bar{N}_+ - \bar{N}_-)/(\bar{N}_+ + \bar{N}_-)$ is Net Charge Asymmetry and the slope $r \equiv 2q_e/\bar{\rho}_e$ reflects the effect of the quadrupole moment, which will be our observable [1, 2].

## Dataset

**T**ime **P**rojection **C**hamber
- Full azimuthal angle coverage
- Identifies particle by ionization energy loss



STAR Detector

Net Charge Asymmetry
- charged particles
- $|\eta| < 1.0$
- $0.15 < p_T < 12$ GeV/$c$
- exclude $p(\bar{p})$, $p_T < 0.4$ GeV/c

Select $\pi^+/\pi^-$
- TPC particle identification
- DCA < 1.0 cm
- $0.15 < p_T < 0.5$ GeV/$c$

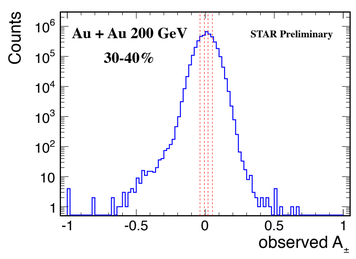
Methods of $v_2$ estimation
- Q-cumulants [2], two-particle correlation
- $\eta$-sub event method

Used Statistics

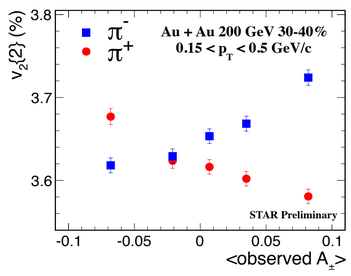
| $\sqrt{s_{NN}}$ (GeV) | Events |
|---|---|
| 200 | 238M |
| 62.4 | 63M |
| 39 | 104M |
| 27 | 46M |
| 19.6 | 23M |

## Analysis Strategy

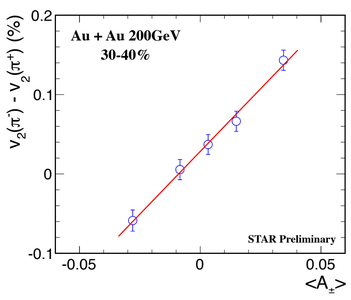
Observed $A_\pm$
- Measure net charge asymmetry event-by-event
- Divide each centrality into five bins



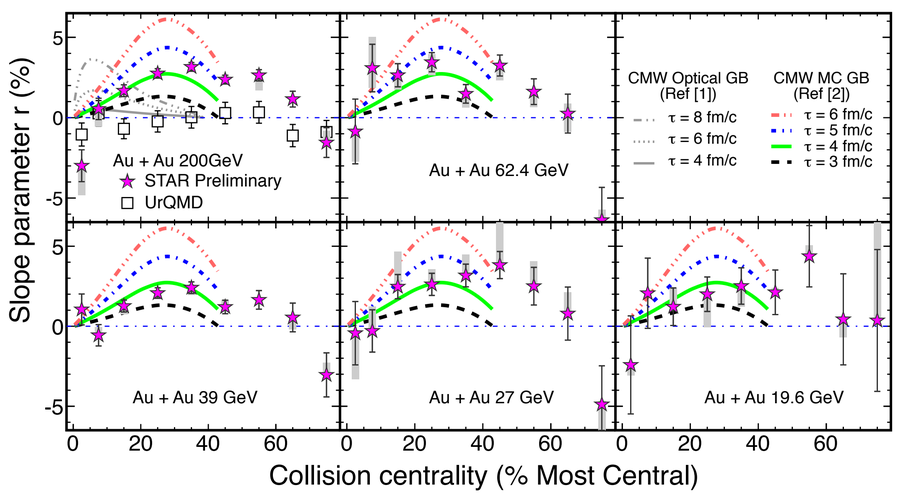

$v_2$ vs. observed $A_\pm$
- Reconstruct $v_2$ of $\pi^+$ and $\pi^-$ as a function of observed $A_\pm$




Extract slope
- Take the $v_2$ difference between $\pi^+$ and $\pi^-$
- Correct observed $A_\pm$ by applying tracking efficiency
- Fit $\Delta v_2$ vs. $A_\pm$ with a straight line to get the slope $r$




## Results




- Slope parameters *r* is measured for different centralities at $\sqrt{s_{NN}}$ = 200, 62.4, 39, 27 and 19.6 GeV.
- Slope parameter *r* shows a similar trend as the recent CMW calculations using MC Glauber Model as input [2].
- The negative slopes beyond statistical fluctuations in the most central and most peripheral centrality bins are under investigation.

## Summary

- The difference between $v_2(\pi^-)$ and $v_2(\pi^+)$ shows a linear dependency on net charge asymmetry in Au + Au collisions at $\sqrt{s_{NN}}$ = 200, 62.4, 39, 27 and 19.6 GeV.
- As a function of collision centrality, the slope parameter *r* shows a raise and fall from central to peripheral collisions.
- The above observations are consistent with the recent CMW calculations using MC Glauber Model as input [2].
- At $\sqrt{s_{NN}}$ = 200 GeV, the UrQMD model calculations, without CMW effect, can not reproduce the centrality dependency of the slope parameter.

References
[1] Y. Burnier, D. E. Kharzeev, J. Liao, and H.-U. Yee, Phys. Rev. Lett. **107**, 052303 (2011)
[2] Y. Burnier, talk in The RBRC Workshop on P- and CP-Odd Effects in Hot and Dense Matter, BNL, 2012.
[3] A. Bilandzic, R. Snellings, and S. Voloshin, Phys. Rev. C **83**, 044913 (2011)