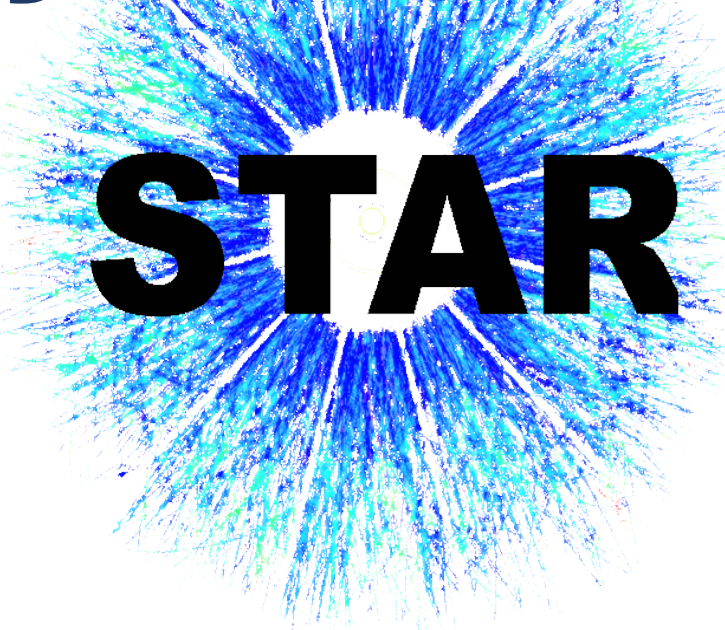


# Systematic Searches of CMW from Heavy-Ion Collisions at STAR



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## Abstract

The Chiral Magnetic Wave (CMW) was predicted to arise from the interplay of the chiral magnetic effect and the chiral separation effect, which can lead to the formation of electric quadrupole moment in heavy-ion collisions. This electric quadrupole moment can produce charge asymmetry dependence of the elliptic flow ( $v_2$ ) for charged particles:  $v_2(\pm) - v_2(\mp) = \mp r_2 \times A_{ch}$ , where  $r_2 = \frac{q_e}{\rho_e}$ .

In this poster, we will present the STAR measurements of the slope parameter ( $r_2$ ) from different colliding systems: Au+Au at 200 and 27 GeV, Cu+Cu and Cu+Au at 200 GeV. Two approaches, Q-Cumulant ( $v_2\{2\}$  and  $v_2\{4\}$ ) and event-plane ( $v_2\{EP\}$ ) methods, are used to measure  $v_2$  of  $\pi^\pm$  at low transverse momenta in order to evaluate the non-flow contributions in the  $v_2$  measurement. The  $v_2\{2\}$  and  $v_2\{EP\}$  with pseudorapidity gaps can reduce the short-range non-flow contributions. The  $v_2\{4\}$  can suppress non-flow contributions and is believed to be more sensitive to the reaction plane (and hence the magnetic field). Thus  $v_2\{4\}$  can be more sensitive to the CMW dynamics. The centrality dependence of  $r_2$  will be compared across different collision systems and beam energies. Physics implications on the search of the CMW and the background dynamics from our systematic studies will be discussed.

## Introduction

A non-zero chirality chemical potential can arise in Quark Gluon Plasma (QGP) due to vacuum transitions and chiral anomaly as predicted by theory. If coupled with strong magnetic field it can lead to charge separation along the magnetic field via effect called Chiral Magnetic Effect (CME). A complimentary effect to CME is called Chiral Separation Effect (CSE), where a chirality current is induced along magnetic field, coupled to the finite electric chemical potential. As two effects intertwine, it will lead to interplay of the two and form a collective excitation mode called the Chiral Magnetic Wave (CMW) which manifests itself by a finite quadrupole moment.

The collective motion of the heavy ions is quantified by the anisotropic flow Fourier coefficients:

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

The  $v_2$  is called the "elliptic" flow and characterizes the system evolution in transverse direction.

Theory suggests that this quadrupole will lead to the difference in  $v_2$  in positive and negative particles at the low transverse momentum [2]. The difference between the positive and negative  $v_2$  coefficients is linearly proportional to the event-by-event charge asymmetry defined as:

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

## Motivation and Approach

Why is it interesting?

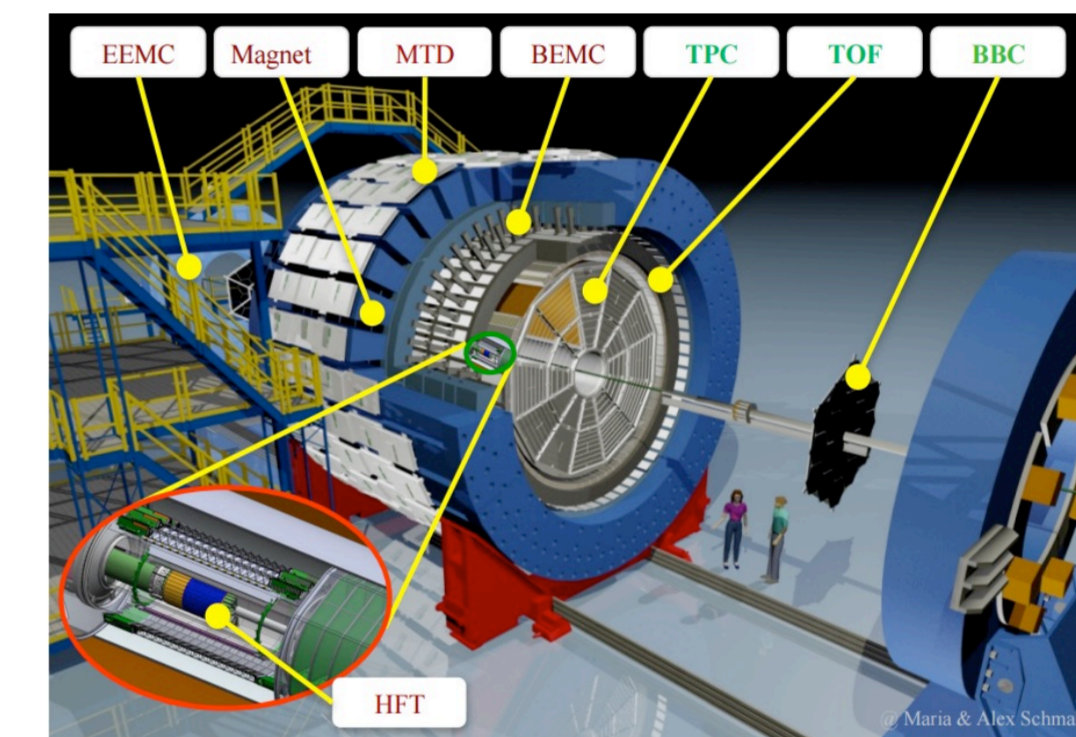
- Is it due to physics or background?
- If the effect is there, will confirm QGP and CME in heavy-ion collisions

Measurements have been performed at RHIC and LHC and seem to agree with theoretical predictions. However, non-CMW mechanisms could fake those signals. Are the same mechanisms at work at LHC and RHIC?

We obtained  $v_2$  coefficients by 2-particle correlations using sub-event method to reduce the non-flow contribution. In addition, we extracted  $v_2$  coefficients from 4-particle correlations [1].

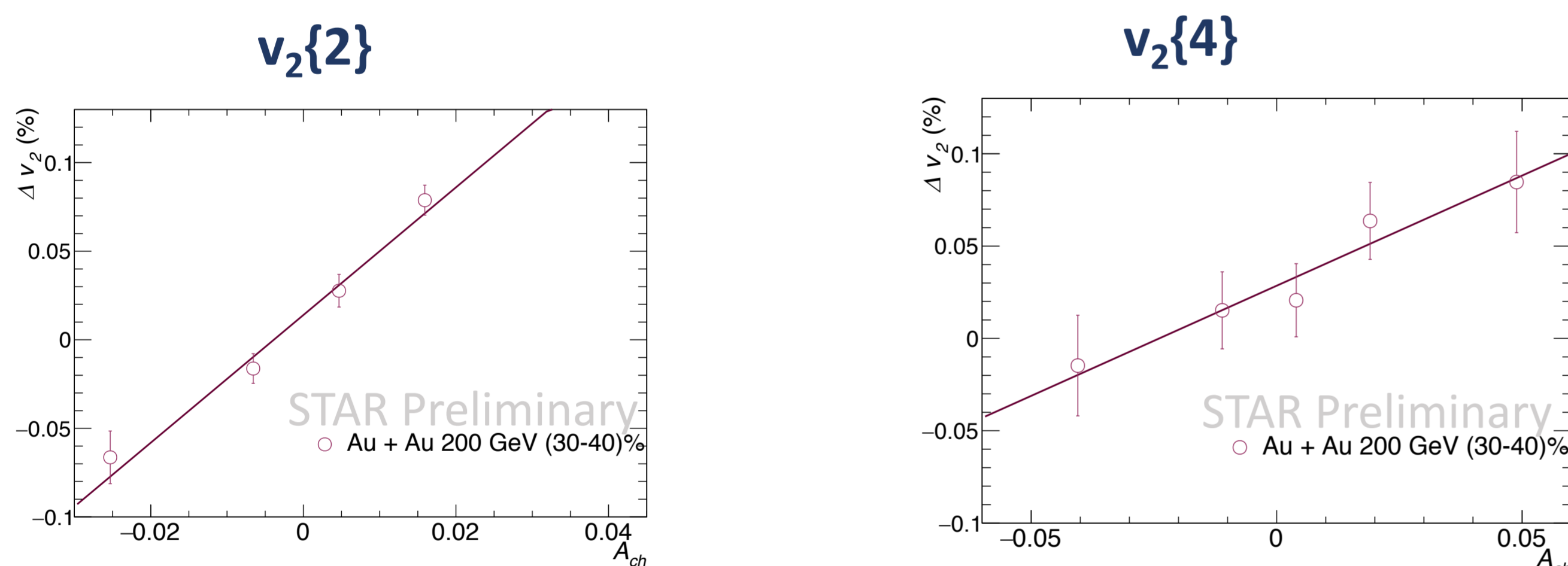
## The STAR Experiment @RHIC

Au+Au 27 and 200 GeV  
Cu+Au 200 GeV  
Cu+Cu 200 GeV  
REP:  $0.2 < p_t < 2$  GeV/c  
Distance of Closest Approach  $< 1$  cm  
 $|\eta| < 1$   
 $|z_{\text{Vertex}}| < 30$  cm



POI:  $0.15 < p_t < 0.5$  GeV/c  
REP:  $0.15 < p_t < 2$  GeV  
TPC:  $|\eta| < 1$

## Comparison between $v_2\{2\}$ and $v_2\{4\}$ in Au+Au 200 GeV



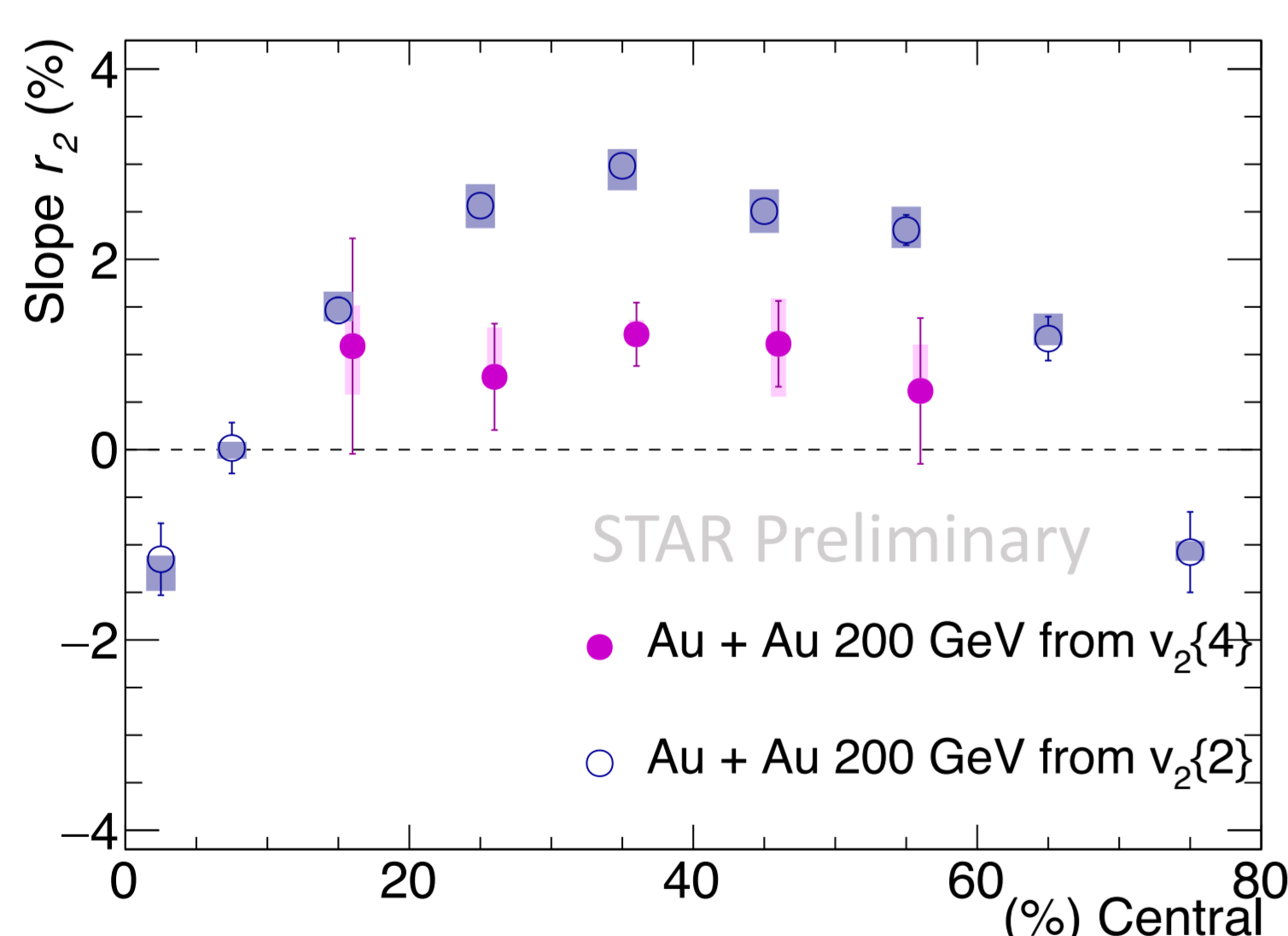
All systems have the same linear dependence for each centrality as in Au+Au 200 GeV. Slope obtained from  $v_2\{2\}$  still contains the proposed so-called "trivial" term [\*].

Similar linear relationship in  $\Delta v_2\{4\}$  as in  $\Delta v_2\{2\}$  in all collision systems and energies.

$$\Delta v_2 = v_2^- - v_2^+$$

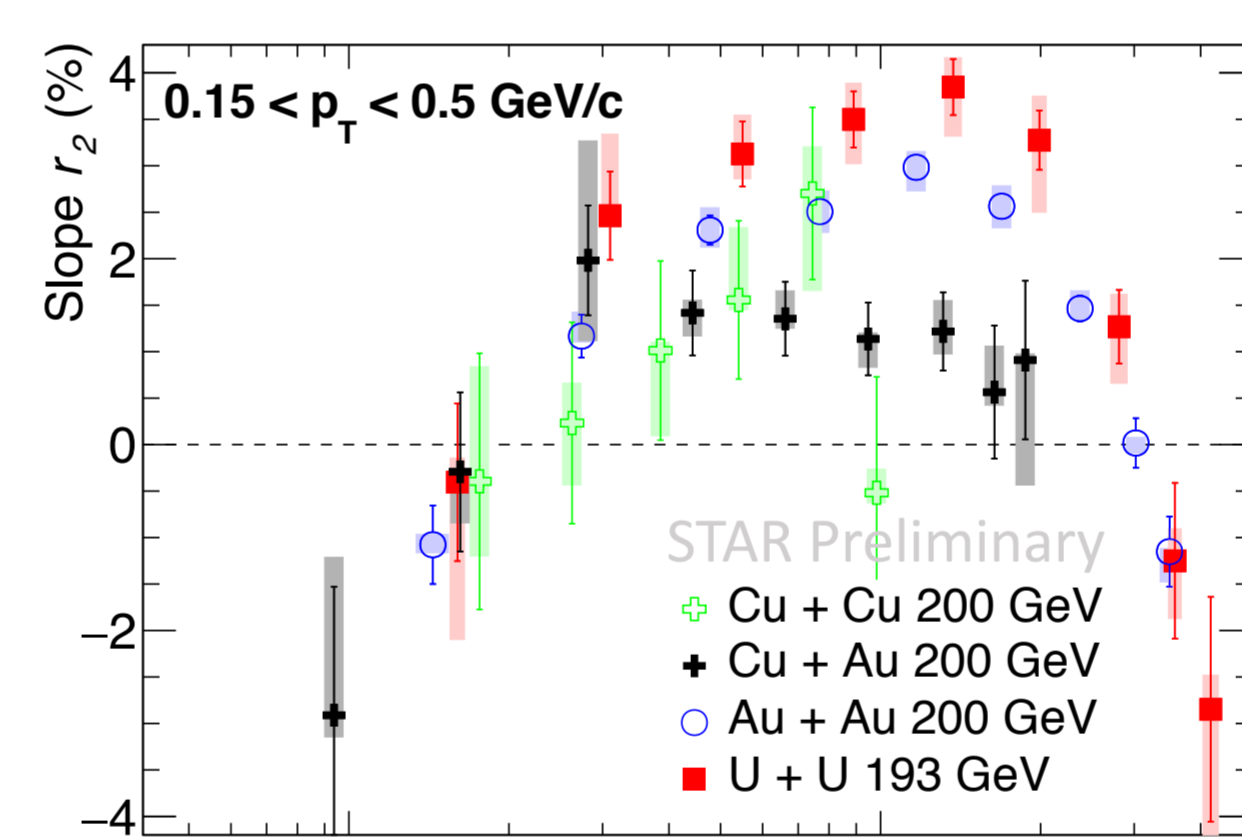
The data obtained from  $v_2\{4\}$  has been shifted horizontally for clarity. Similar dependence as in  $v_2\{2\}$ . Statistical uncertainties are significantly reduced by combining 4 different datasets (Au+Au 200 GeV). The  $r_2$  is clearly non-zero for most of the centralities. It is clear that  $r_2$  obtained from  $v_2\{2\}$  has significantly more background contribution than slope obtained from  $v_2\{4\}$ .

\*Measurement of non-flow influence on  $r_2$  obtained from  $\Delta v_2\{2\}$  was done. For details check poster CH26 by Haojie Xu



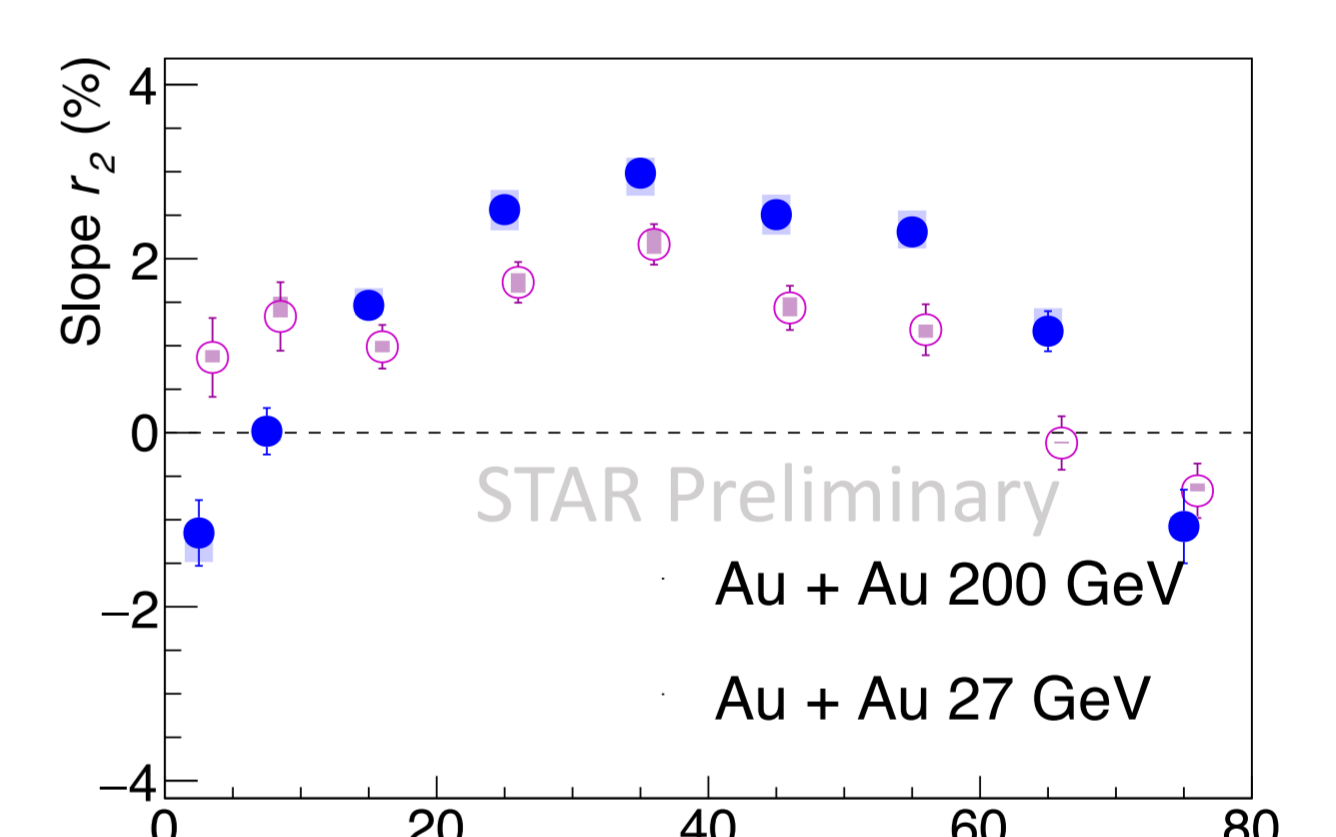
## Slope Parameter ( $r_2$ ) obtained from $v_2\{2\}$ and/or $v_2\{EP\}$

### System Size Dependence



The slope increases with increasing system size.

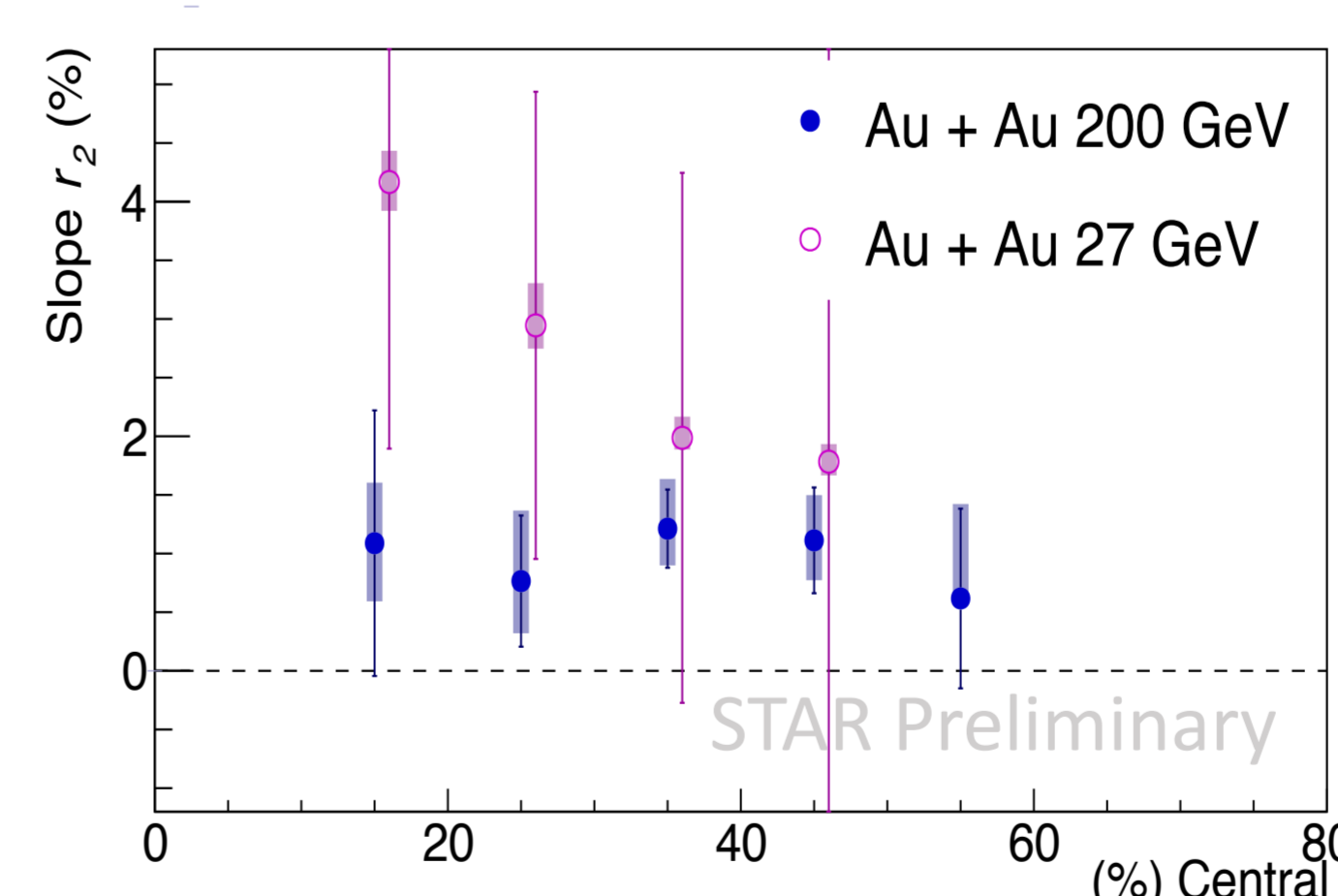
### Energy Dependence



The data from 27 GeV has been shifted horizontally for clarity. Slopes are similar for 27 GeV and 200 GeV

## Slope Parameter ( $r_2$ ) obtained from $v_2\{4\}$

### Energy Dependence



$$v_2(\pm) - v_2(\mp) = \mp r_2 * A_{ch}$$

The data from 27 GeV has been shifted horizontally for clarity. Larger slope for lower energy but statistics are too limited for 27 GeV to make a proper conclusion.

## Summary

The slope parameter ( $r_2$ ) was measured using different methods in different collision systems and at different energies.

The  $r_2$  results using the 2-particle correlation or the event-plane methods show that the larger the system, the larger the slope is, which meets the CMW expectation. The energy dependence of  $r_2$  is similar for 27 GeV and 200 GeV.

The 4-particle correlations suffer from limited statistics, which prevents a claim on the system dependence. Energy dependence of  $r_2$  is observed: the higher the energy, the lower the slope but 27 GeV dataset suffers from limited statistics. At 200 GeV,  $v_2\{4\}$  suppresses the non-flow contributions, and the corresponding  $v_2\{4\}$  slope does follow the same trend as  $v_2\{2\}$ , leaving the CMW as a potential explanation of the signal. Further investigation into background sources is needed indeed.

## References

- [1] A.M.Poskanzer and S.A. Voloshin, Phys. Rev. C **58**, 1671
- [2] Y. Burnier, D. E. Kharzeev, J. Liao and H.-U. Yee, Phys. 645 Rev. Lett. 107,052303 (2011).