System Size and Shape Dependence of Anisotropic Flow

Niseem Magdy
STAR Collaboration
Stony Brook University
niseem.abdelrahman@stonybrook.edu

The 33rd Winter Workshop 2017

Outline

I. Introduction

i. Motivation

ii. STAR Detector

iii. Correlation function technique

II. Results

i. System size effect

ii. System shape effect

III. Conclusion

Motivation

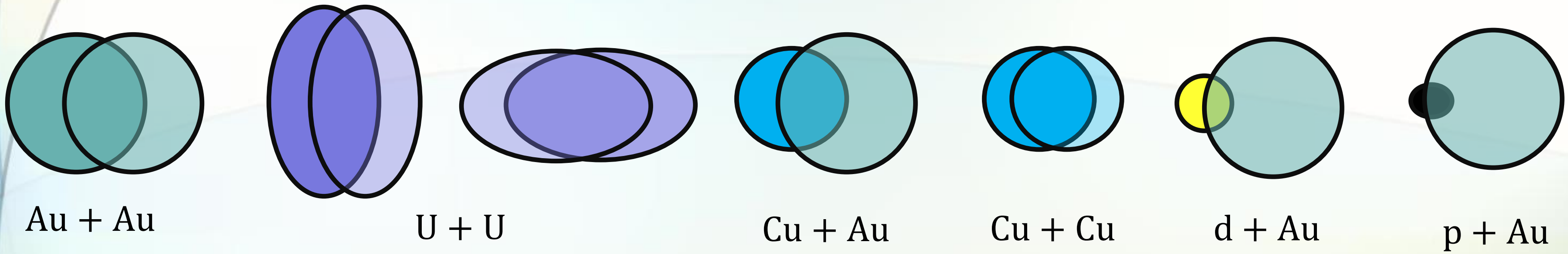
- Is the observed anisotropy in ion-ion collision a final- or initial state effect?

- What are the essential differences between the medium created in small (p+A) and large (A+A) collision systems?

- Is there a limiting size to lose final-state effects ?

Motivation

- STAR collectd data for different systems;



- v_n measurements for different systems are sensitive to system shape (ε_n), dimensionless size (RT) and transport coefficients $\left(\frac{\eta}{s}, \frac{\zeta}{s}, \ldots\right)$.

- Scaling out the system shape and size $\xrightarrow{\text{yields}}$ $\left(\frac{\eta}{s}, \frac{\zeta}{s}, \ldots\right)$ effect on v_n for each system.

Transport coefficients

- The v_n measurements are sensitive to ε_n, RT and $\left(\frac{\eta}{s}, \frac{\zeta}{s}, \ldots\right)$.

- Acoustic ansatz
  - ✓ Sound attenuation in the viscous matter reduces the magnitude of v_n.

- Anisotropic flow attenuation;

PRC84 034908 (2011)
P.Staig and E.Shuryak

$$\frac{v_n}{\varepsilon_n} \propto e^{-\beta n^2}, \ \beta \propto \frac{\eta}{s} \frac{1}{RT} + \cdots$$

arXiv:1305.3341
Roy A. Lacey, A. Taranenko, J. Jia, et al.

1

- From macroscopic entropy considerations $(RT)^3 \propto \frac{dN}{d\eta}$

2

$$ln\left(\frac{v_n}{\varepsilon_n}\right) = a\frac{\eta}{s}\left(\frac{dN}{d\eta}\right)^{\frac{-1}{3}} + ln(b)$$

arXiv:1601.06001
Roy A. Lacey, Peifeng Liu, Niseem Magdy, et al.

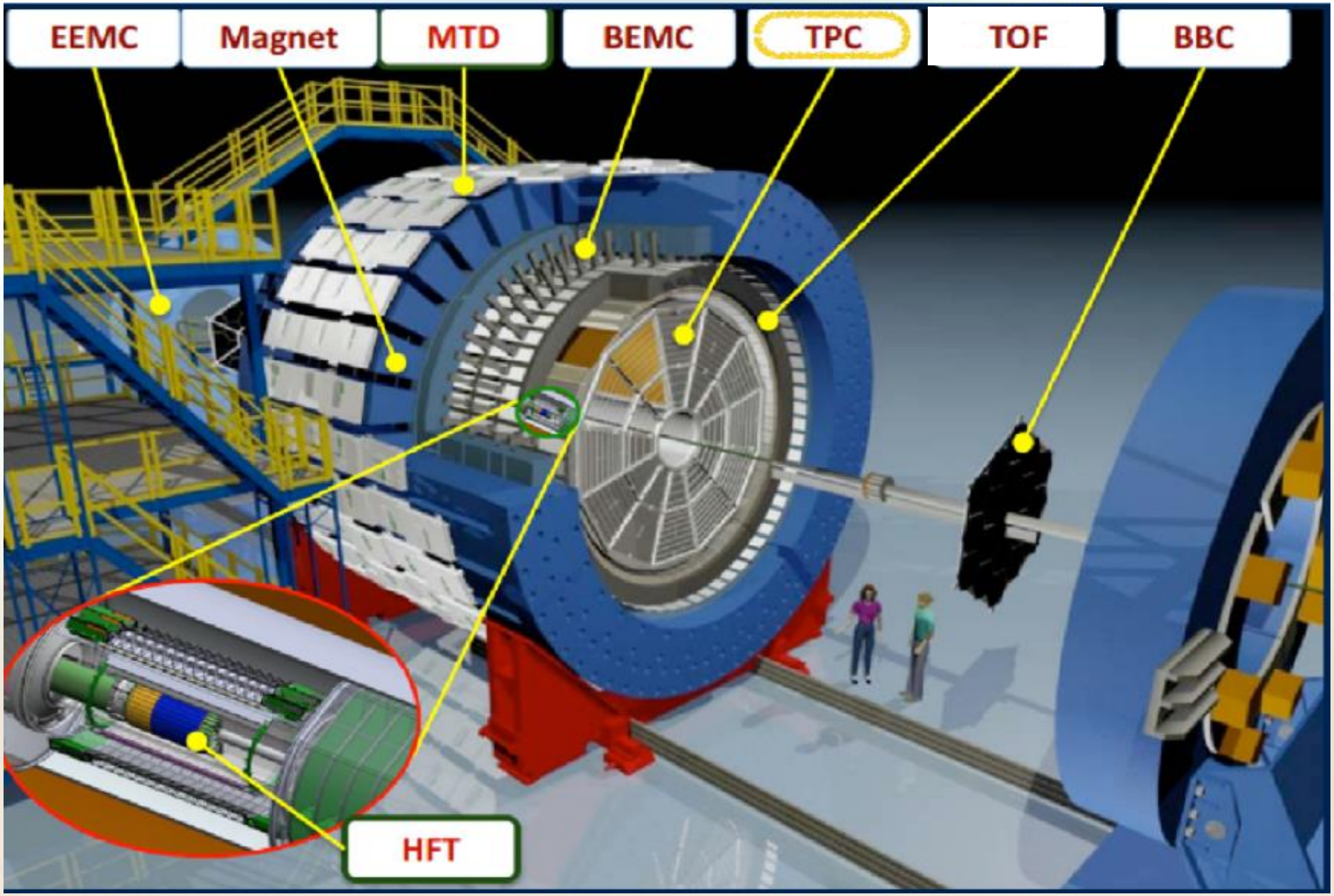
3

$$ln(v_n) = a\left(\frac{\eta}{s}\right)\left(\frac{dN}{d\eta}\right)^{\frac{-1}{3}} + ln(\varepsilon_n) + ln(b)$$

4

- ✓ Scaling out the system size $\left(\frac{dN}{d\eta}\right)$ and shape (ε_n) should give similar transport coefficient $\left(\frac{\eta}{s}\right)$ (i.e. similar v_n) for different systems (final state-effect).

STAR Detector at RHIC



- Uniform acceptance in $|\eta| < 1$

Correlation function technique

- All current techniques used to study v_n are related to the correlation function.

- Two particle correlation function $Cr(\Delta\varphi)$ *used in this analysis*,

$$Cr(\Delta\varphi) = \frac{dN/d\Delta\varphi(same)}{dN/d\Delta\varphi(mix)} \quad \text{and} \quad v_{nn} = \frac{\sum_{\Delta\varphi} Cr(\Delta\varphi)\cos(n\,\Delta\varphi)}{\sum_{\Delta\varphi} Cr(\Delta\varphi)}$$ 5

- Non-flow signals, as well as some residual detector effects (track merging/splitting) suppressed with $|\Delta\eta = \eta_1 - \eta_2| > 0.7$ cut.

$$\boxed{v_{nn}(p_T^a, p_T^t) = v_n(p_T^a)\, v_n(p_T^t) \qquad n > 1}$$ 6

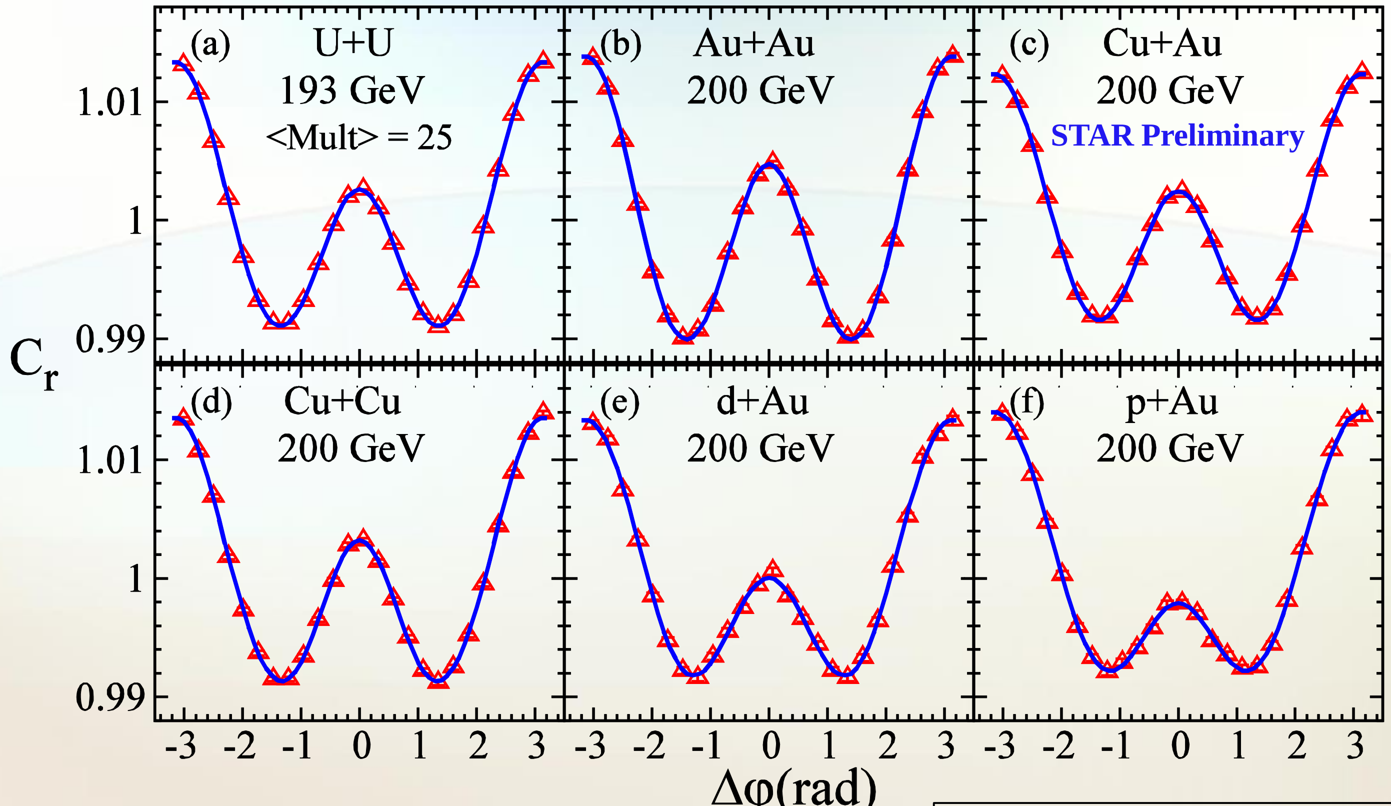
✓ Factorization ansatz for v_n $(n > 1)$ verified.

$$\boxed{v_{11}(p_T^a, p_T^t) = v_1^{even}(p_T^a) v_1^{even}(p_T^t) - C\, p_T^a\, p_T^t}$$ PRC 86, 014907 (2012) ATLAS Collaboration 7

- C is the momentum conservation parameter $C \propto \dfrac{1}{<Mult><p_T^2>}$

Correlation function

Different system correlation function



Using the correlating function we can extract v_{nn}

$$v_{nn} = \frac{\sum_{\Delta\varphi} Cr(\Delta\varphi)\cos(n\,\Delta\varphi)}{\sum_{\Delta\varphi} Cr(\Delta\varphi)}$$

$v_n(p_T)$ for $n \neq 1$ as

$$v_n(p_T) = v_{\mathrm{nn}}(p_{T_{ref}}, p_T)/\sqrt{v_{\mathrm{nn}}(p_{T_{ref}})}$$

For $n = 1$?

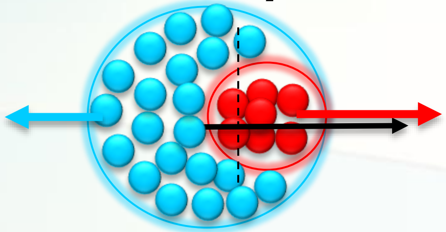
For n = 1

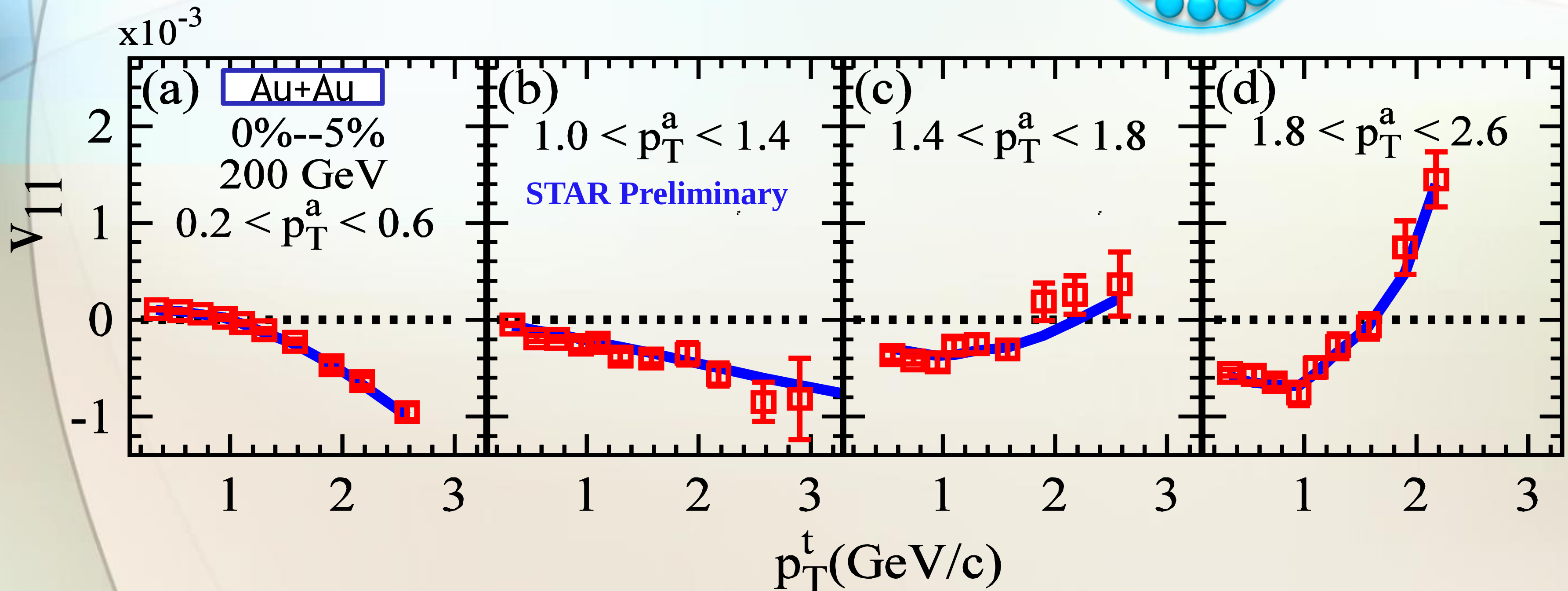
Dipolar Flow

Simultaneous fit

$$v_{11}(p_T^a, p_T^t) = v_1^{even}(p_T^a)\, v_1^{even}(p_T^t) - C\, p_T^a\, p_T^t \quad [7]$$

- v_{11} $Eq[7]$ *represents* $N{\times}N$ *matrix which we fit with* $N+1$ *parameters*
- Dipolar nature require that $\int_0^\infty \frac{dN}{dp_T}\, p_T\, v_1^{even} = 0$





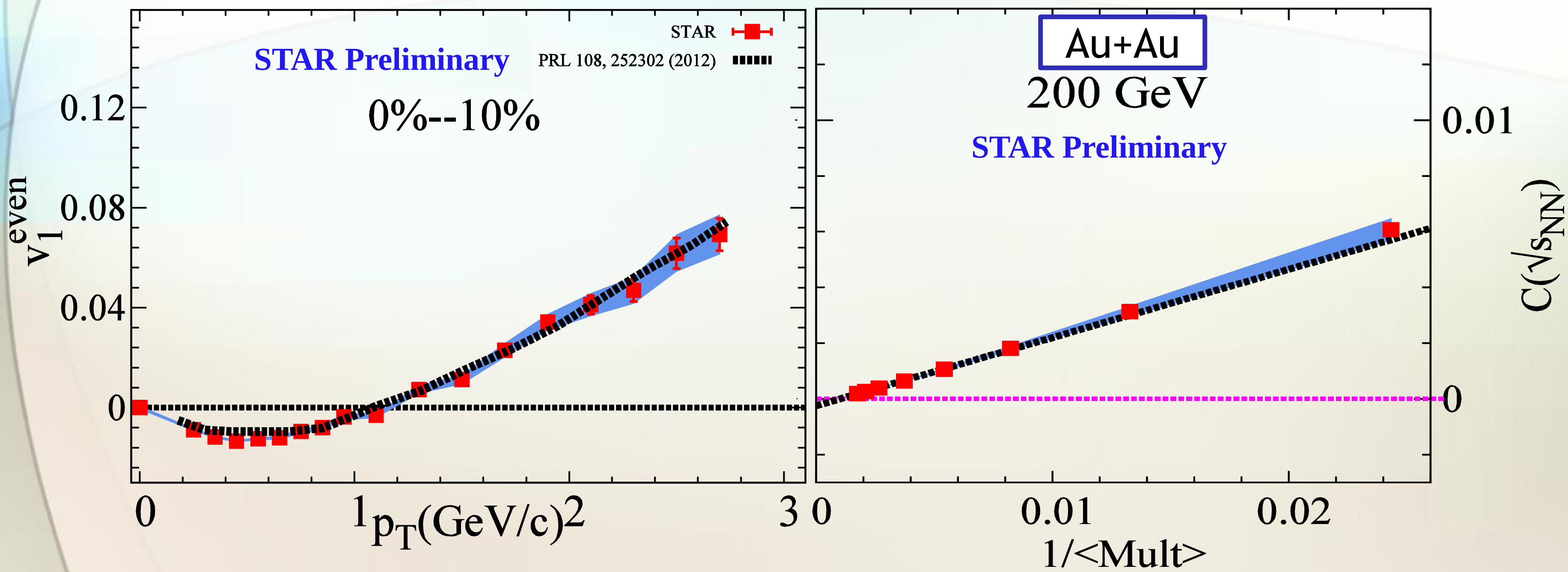
- Good simultaneous fit obtained with fit function Eq[7].
- v_{11} characteristic behavior gives a good constraint for $v_1^{even}(p_T)$ extraction.

Dipolar Flow

7

$$v_{11}(p_T^a, p_T^t) = v_1^{even}(p_T^a)v_1^{even}(p_T^t) - C\, p_T^a\, p_T^t$$

- *The extracted* $v_1^{even}(p_T)$ and the momentum conservation parameter C at 200 GeV



- The characteristic behavior of $v_1^{even}(p_T)$ in good agreement with the hydrodynamics calculations
- The momentum conservation parameter C scales as 1/<Mult>

Results

$|\eta| < 1$ and $|\Delta\eta| > 0.7$

System size effect

$$\boldsymbol{ln(v_n) = a\left(\frac{\eta}{s}\right)\cancel{\left(\frac{dN}{d\eta}\right)^{\frac{1}{3}}} + ln(\varepsilon_n) + ln(b)}$$

System size and shape effect

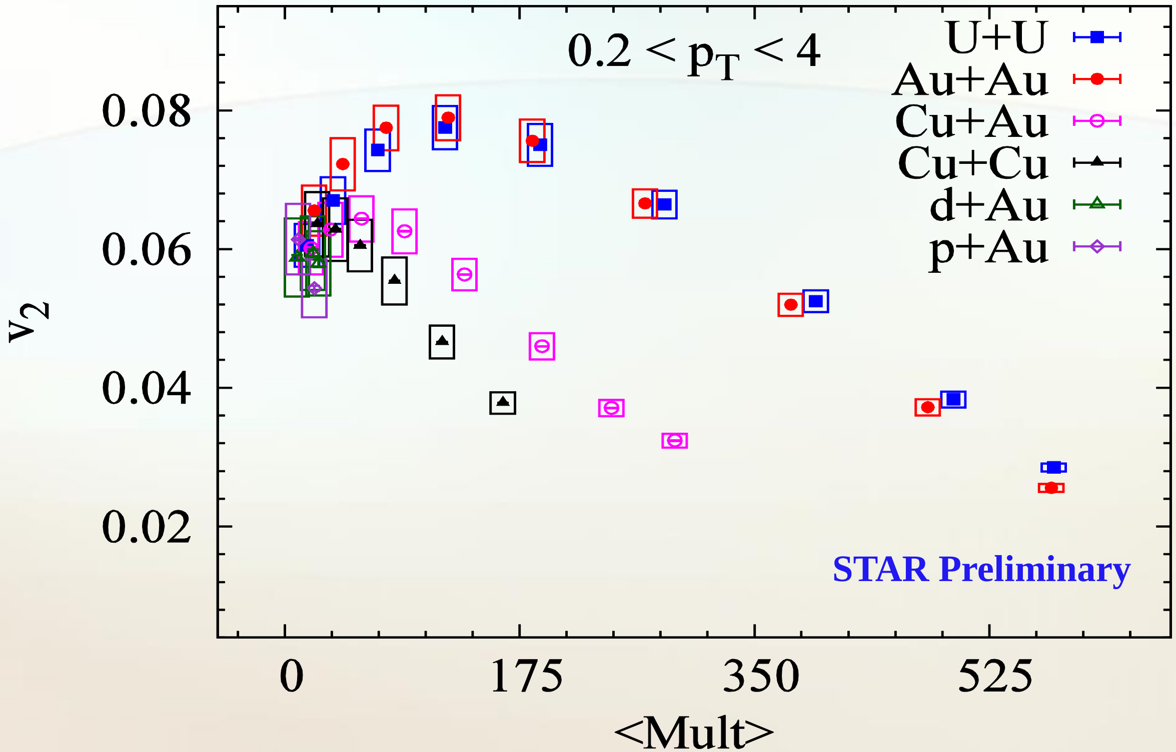
$$\boldsymbol{ln(v_n) = a\left(\frac{\eta}{s}\right)\cancel{\left(\frac{dN}{d\eta}\right)^{\frac{1}{3}}} + \cancel{ln(\varepsilon_n)} + ln(b)}$$

$v_n(Mult)$

System size and shape

$|\eta| < 1$ and $|\Delta\eta| > 0.7$

v_2 vs mean multiplicity for all systems



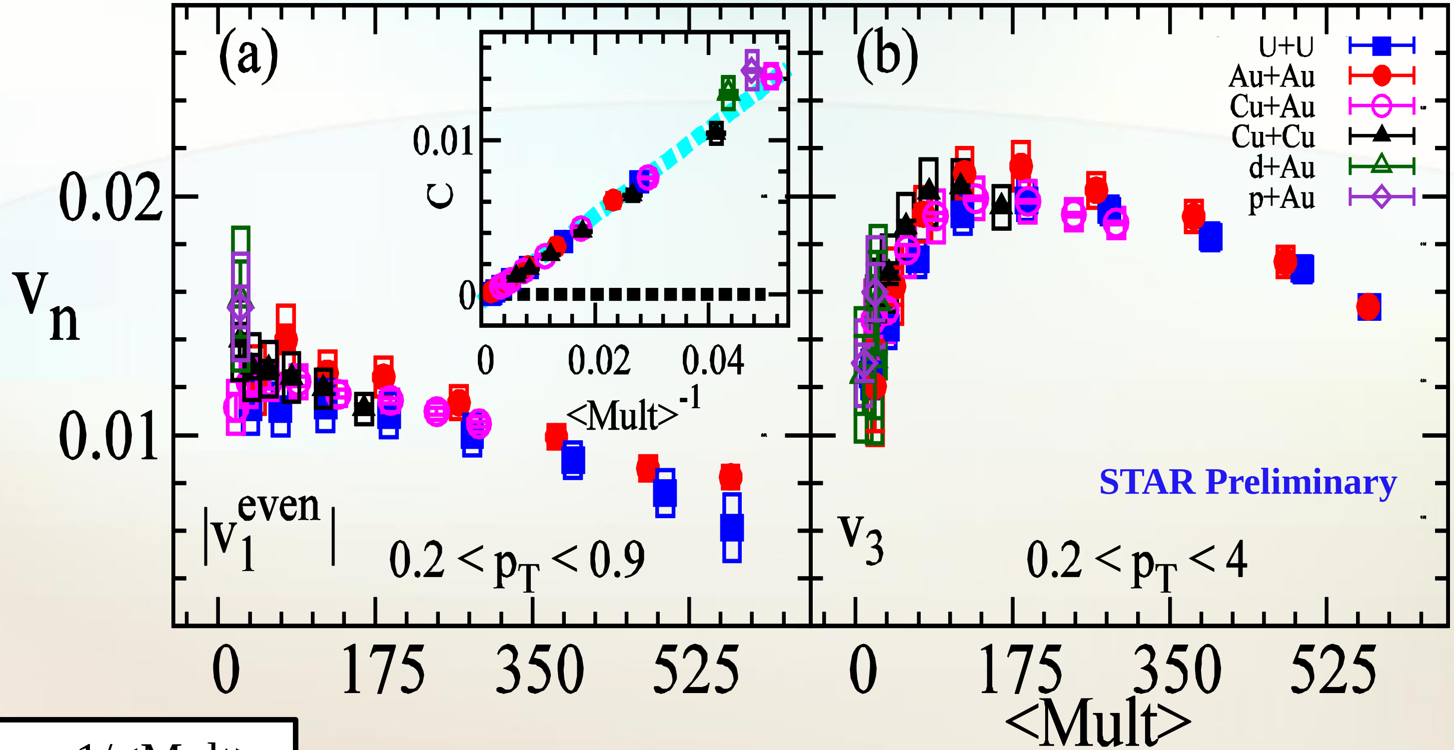
- $v_2(Mult)$ show similar trends for all systems.
- v_2 is system dependent (shape).

$v_n(Mult)$

System size

$|\eta| < 1$ and $|\Delta\eta| > 0.7$

v_1^{even} and v_3 vs mean multiplicity for all systems



C scales as 1/<Mult>

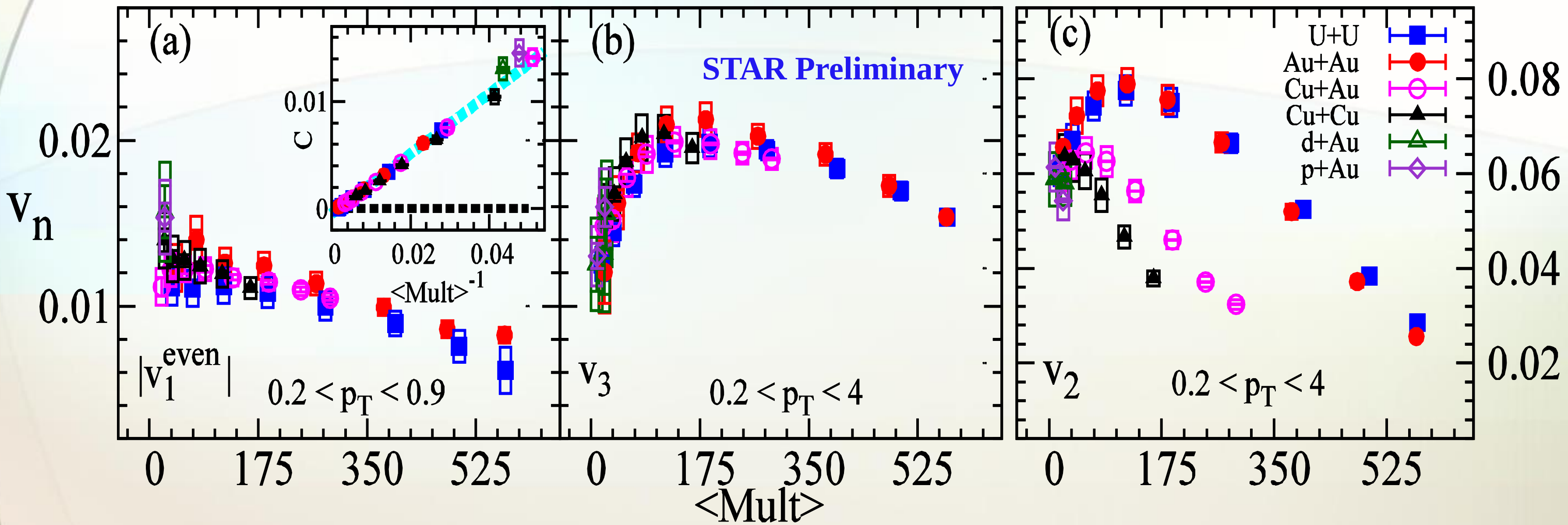
- v_1^{even} and v_3 show similar trends and magnitudes for all systems.
- v_1^{even} and v_3 are system independent (similar $\frac{\eta}{s}$).

$v_n(Mult)$

Summary

$|\eta| < 1$ and $|\Delta\eta| > 0.7$

v_n mean multiplicity dependence for all systems



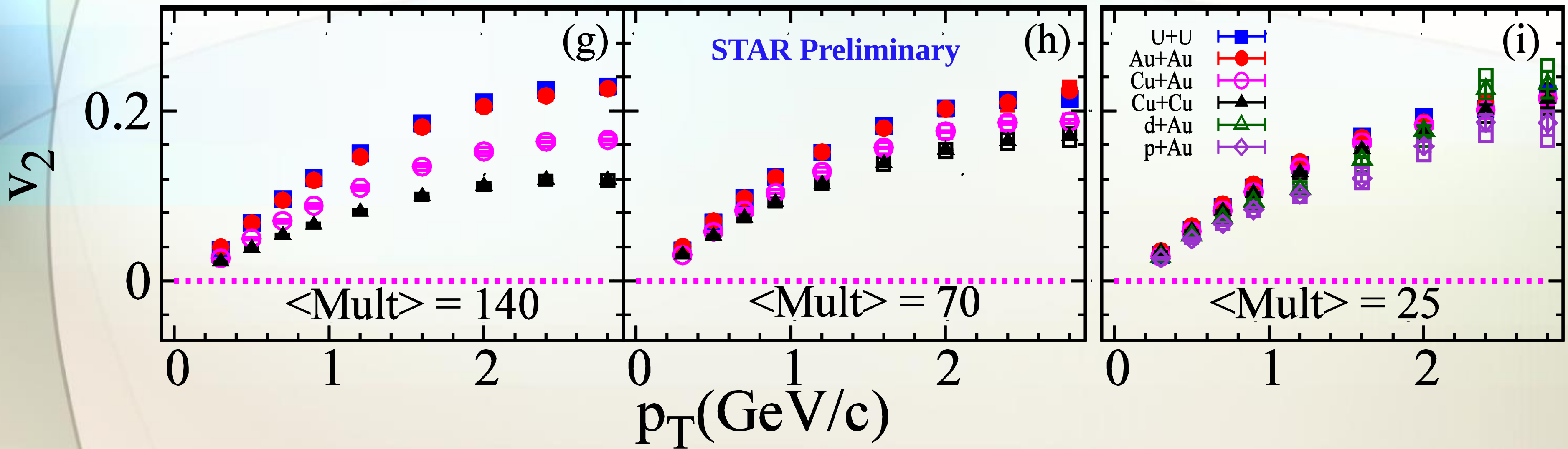
- For a given n, $v_n(p_T)$ show similar trends for all systems.
- v_1^{even} and v_3 are system independent (similar $\frac{\eta}{s}$).
- v_2 is system dependent.

$v_n(p_T)$

System size

$|\eta| < 1$ and $|\Delta\eta| > 0.7$

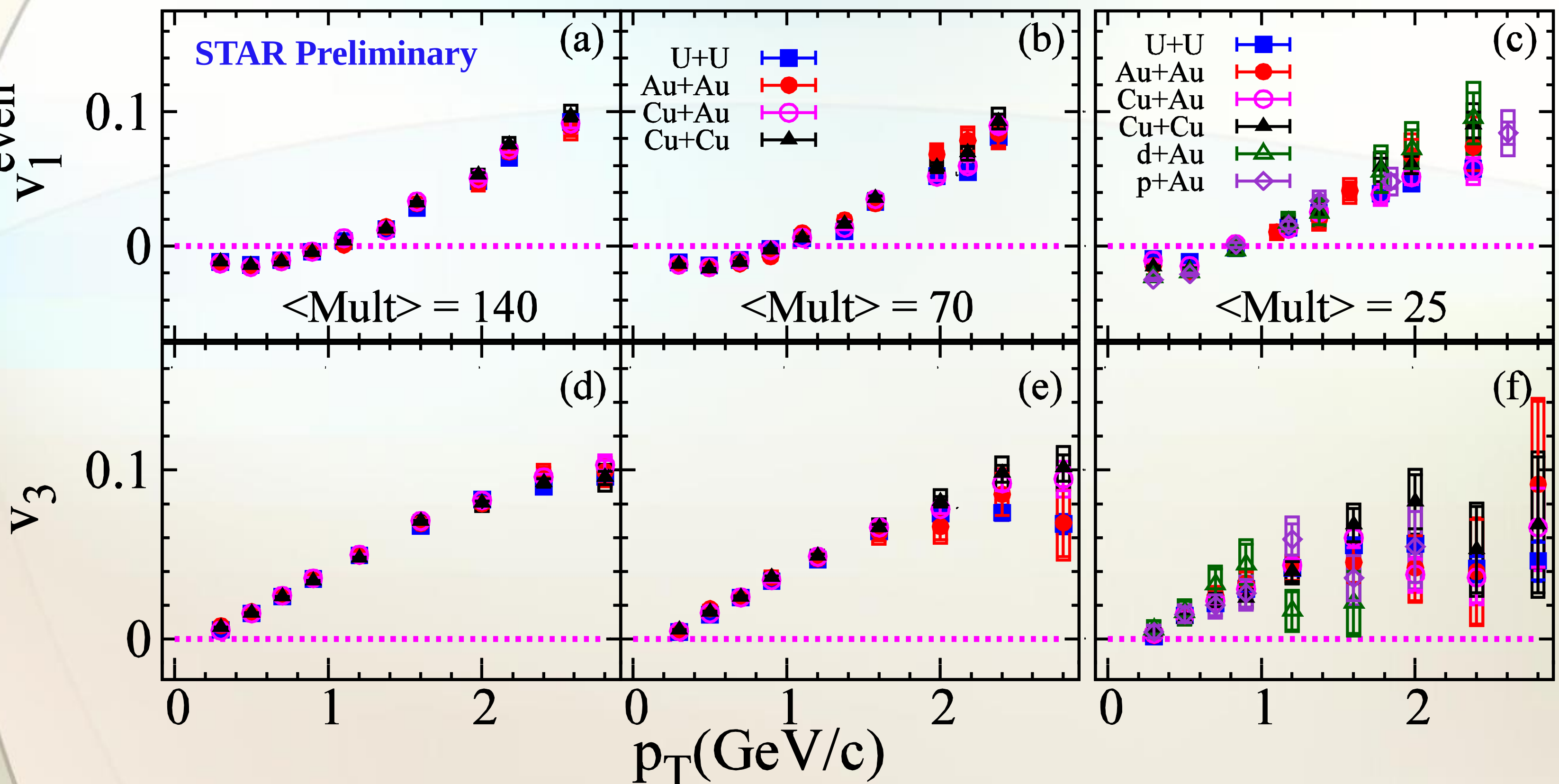
v_2 vs p_T at fixed mean multiplicity for all systems



- ➢ v_2 show similar trends for all systems.
- ➢ v_2 is system dependent (shape).

$v_n(p_T)$
System size
$|\eta| < 1$ and $|\Delta\eta| > 0.7$

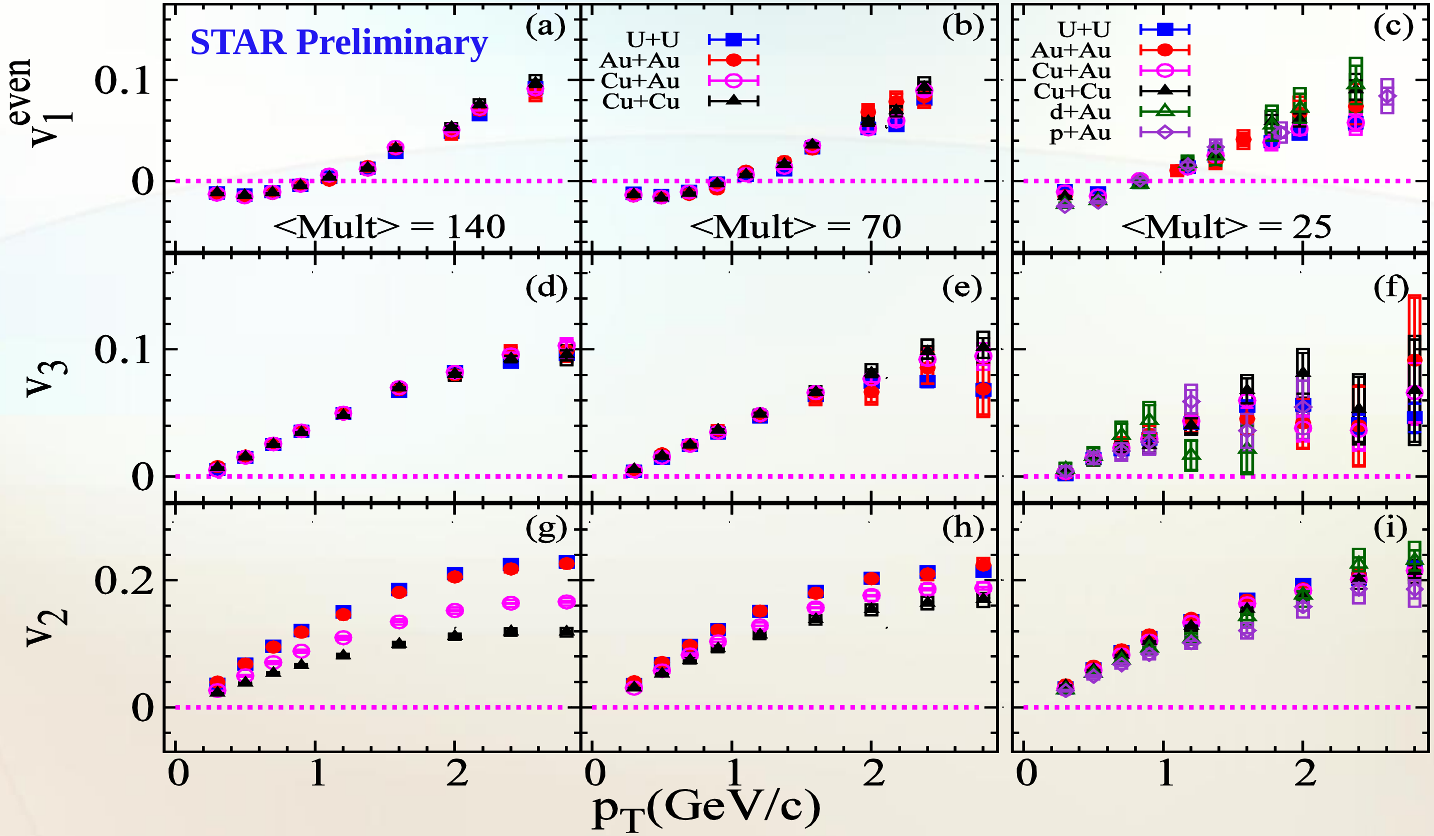
v_1^{even} vs p_T at fixed mean multiplicity for all systems



- v_1^{even} and v_3 show similar trends and magnitudes for all systems.
- v_1^{even} and v_3 *is* system independent (similar $\frac{\eta}{s}$).

$v_n(p_T)$
Summary
$|\eta| < 1$ and $|\Delta\eta| > 0.7$

v_{n} vs p_T at fixed mean multiplicity for all systems



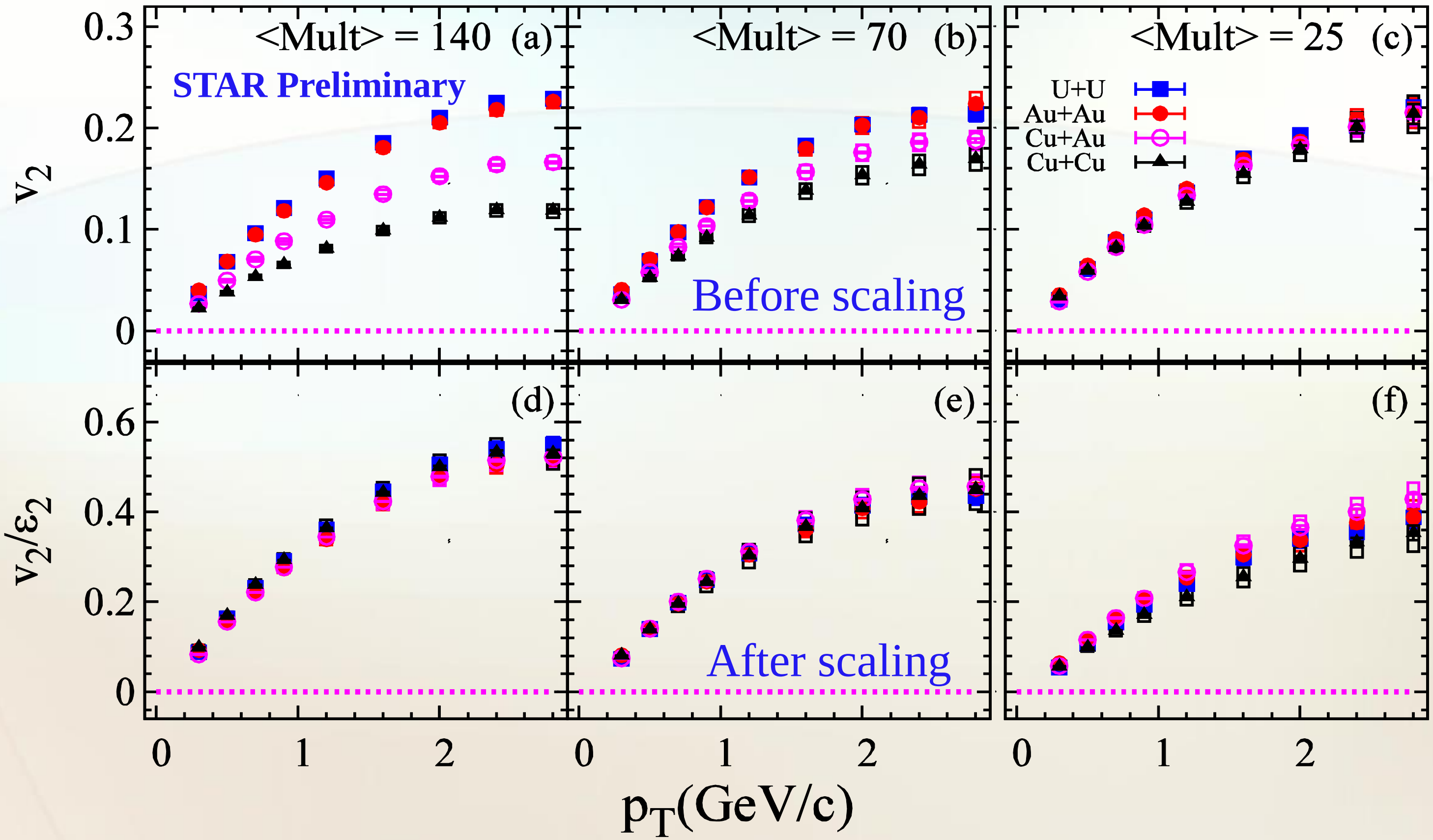
- For a given n, $v_{\mathrm{n}}(p_T)$ show similar trends for all systems.
  - v_1^{even} and v_3 are system independent (similar $\frac{\eta}{s}$).
  - v_2 is system dependent (shape).

$v_n(p_T)$

System size and shape

$|\eta| < 1$ and $|\Delta\eta| > 0.7$

$\frac{v_2}{\epsilon_2}\ p_T$ dependence at fixed mean multiplicity for all systems



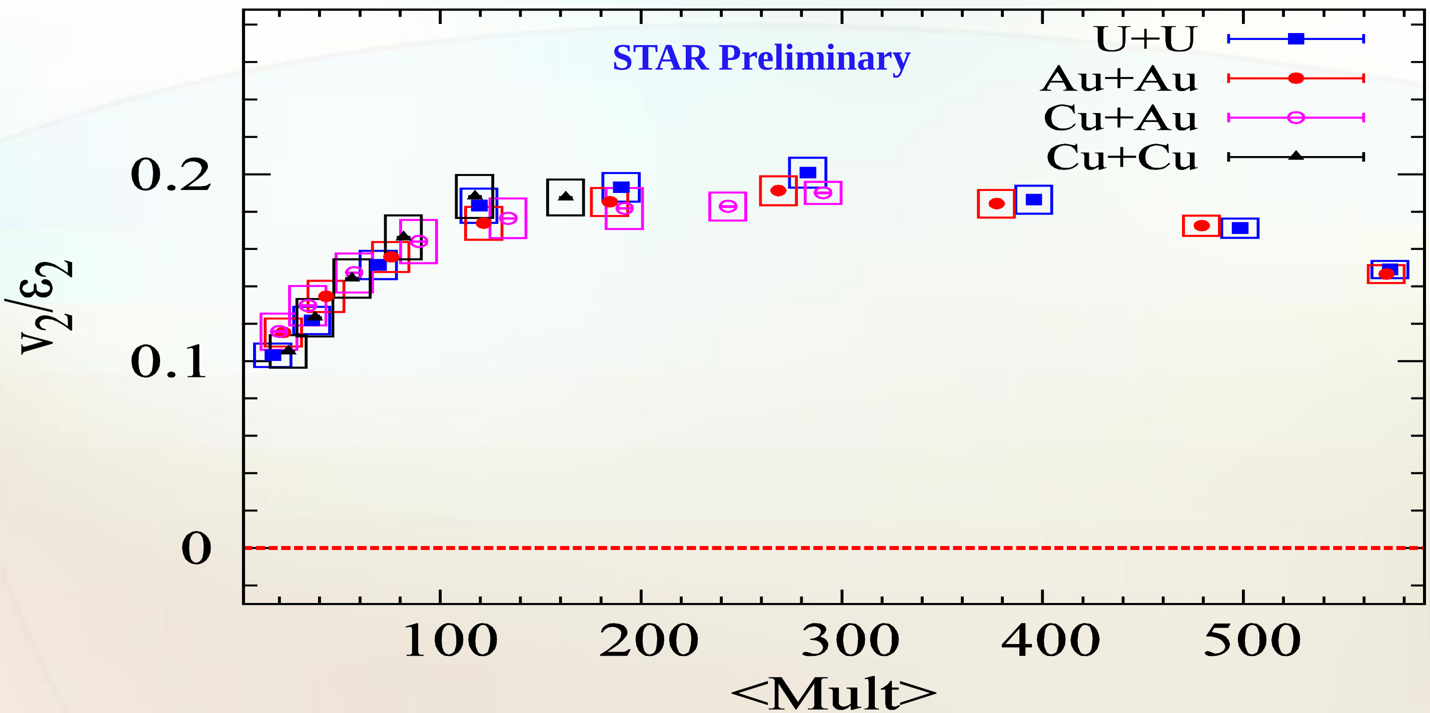
- $\frac{v_2}{\epsilon_2}(p_T)$ for all systems scales to a single curve.
- Similar $\frac{\eta}{s}$ for all systems.

$v_n(Mult)$

System size and shape

$|\eta| < 1$ and $|\Delta\eta| > 0.7$

$\frac{v_2}{\epsilon_2}$ mean multiplicity dependence for all systems



- $\frac{v_2}{\epsilon_2}(Mult)$ for all systems scales to a single curve.
- Similar $\frac{\eta}{s}$ for all systems.

III. Conclusion

Comprehensive set of STAR measurements presented for $v_n(p_T, Mult)$ for several collision systems.

- For all systems;
  - ✓ For n =1, v_1^{even} (p_T) shows the same characteristic behavior.
  - ✓ For n >1, v_n decreases with the harmonic order.

- Scaling the system size;
  - ✓ The odd harmonics v_1^{even} and v_3 are shape independent
  - ✓ $\frac{v_2}{\epsilon_2}$ for all systems scaled onto one curve
  - ✓ Final state ansatz hold for presented systems

Scaling features suggest that all presented systems have similar transport coefficient $(\frac{\eta}{s})$ at $\sqrt{s_{NN}} \sim 200\ GeV$

(final-state effect)

III. Conclusion

Answers to initial questions?

- Is the observed anisotropy in ion-ion collision final- or initial state effect?
  - ✓ Final state ansatz hold for presented systems (p+Au, d+Au, Cu+Cu, Cu+Au, Au+Au and U+U).

- What are the essential differences between the medium created in small (p+A) and large (A+A) collision systems?
  - ✓ Size and shape are system dependent.
  - ✓ Scaled results suggest similar ($\frac{\eta}{s}$) for p+Au, d+Au, Cu+Cu, Cu+Au, Au+Au and U+U.

- Is there a limiting size to lose final state effects ?
  - ✓ All presented systems show evidence for strong final state effects.

THANK YOU