System Size and Shape Dependence of Anisotropic Flow

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Outline

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Motivation

- Is the observed anisotropy in ion-ion collision a
  - ✓ Final state effect? E.g. viscous hydrodynamic-like expansion.

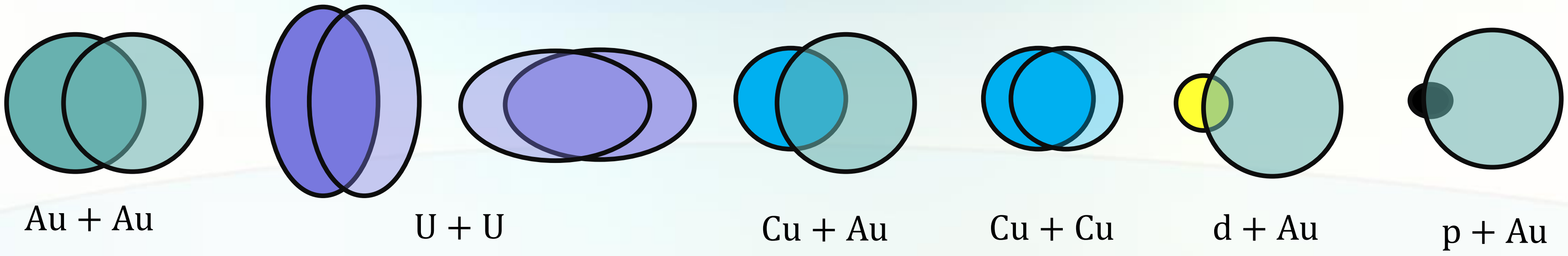
  or
  - ✓ Initial state effect? E.g. correlations of gluons present in the nucleon and nuclear wave functions.

- 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

- Collected data for different systems;



- Viscous hydrodynamic-like expansion (Final state ansatz)
  - ✓ v_n measurements for different systems are sensitive to system shape (ε_n), 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.

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

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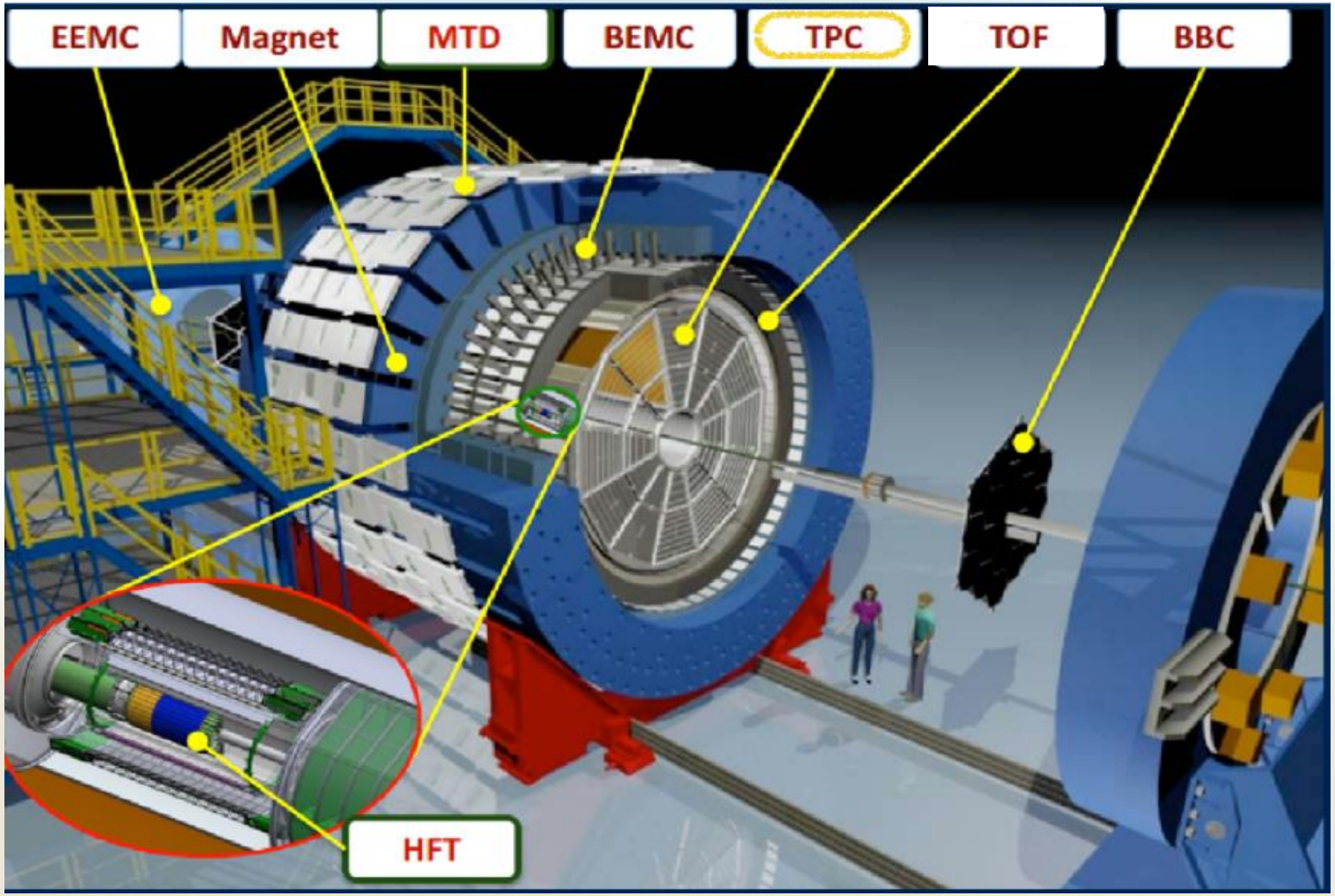
arXiv:1305.3341
Roy A. Lacey, A. Taranenko, J. Jia, et al.

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

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

STAR Detector at RHIC



- ➢ TPC detector covers $|\eta| < 1$

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*,

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

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PLB 708, 249 (2012)
ALICE Collaboration

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

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

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

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

PRC 86, 014907 (2012)
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- C is the momentum conservation parameter $C \propto \frac{1}{<Mult><p_T^2>}$

Dipolar Flow

Simultaneous fit

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

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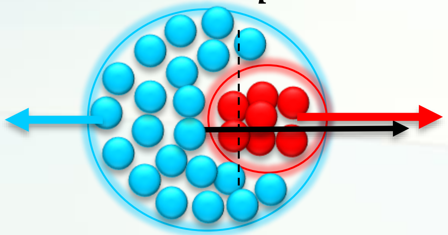
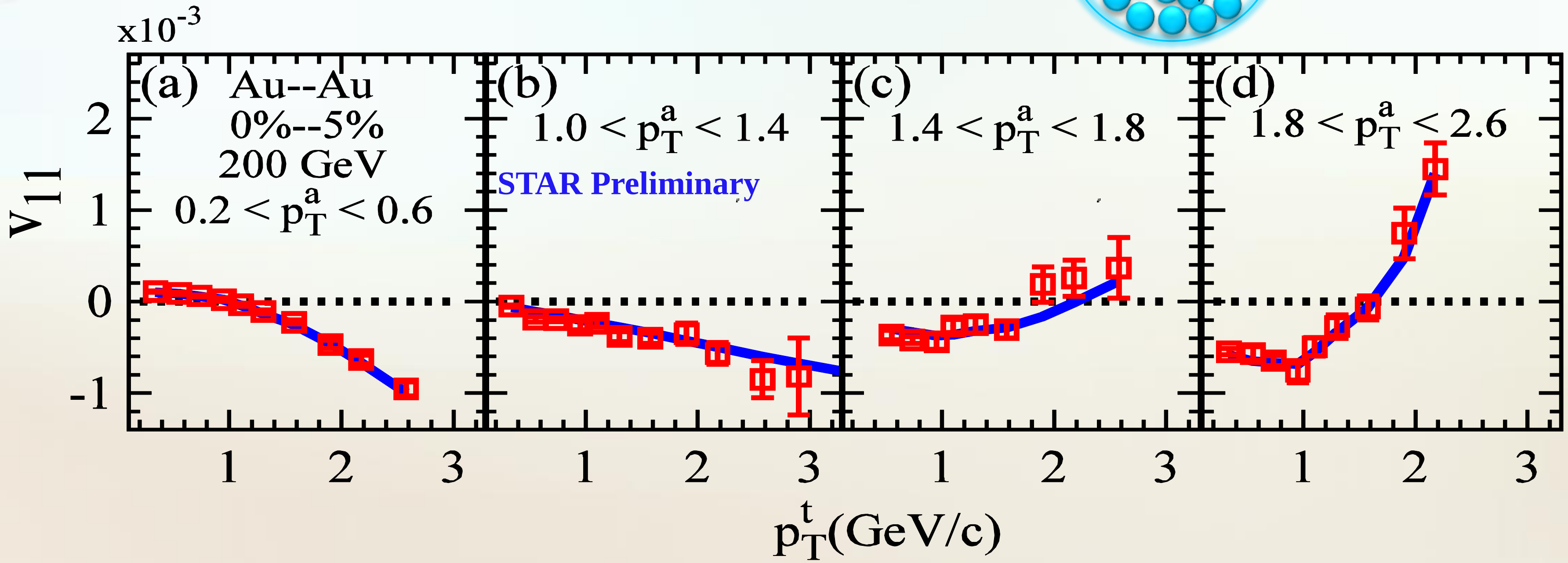
- v_{11} *Eq[4] represents N×N matrix which we fit with N + 1 parameters*
- Dipolar nature require that $\int_0^\infty \frac{dN}{dp_T}\, p_T\ v_1^{even} = 0$





- Good simultaneous fit obtained with fit function Eq[4].
- v_{11} characteristic behavior gives a good constraint for $v_1^{even}(p_T)$ extraction.

Dipolar Flow

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

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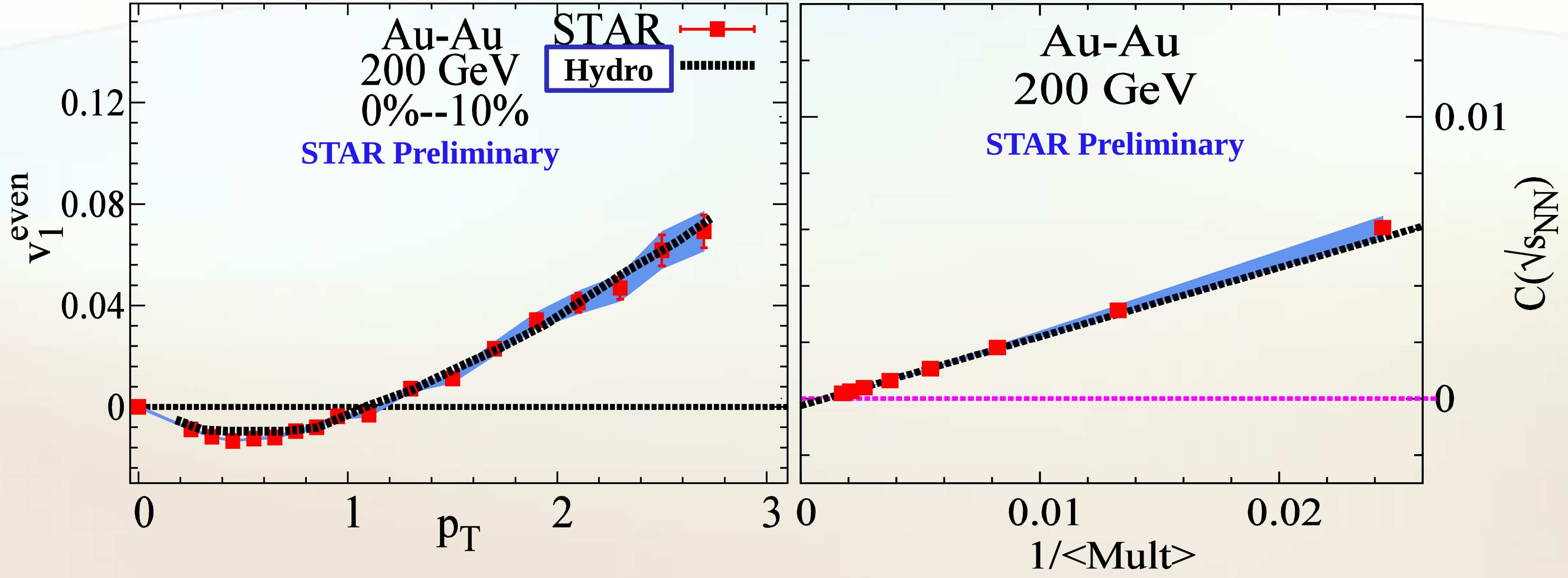
- *The extracted* $v_1^{even}(p_T)$ and the momentum conservation parameter C at 200 GeV



- 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>

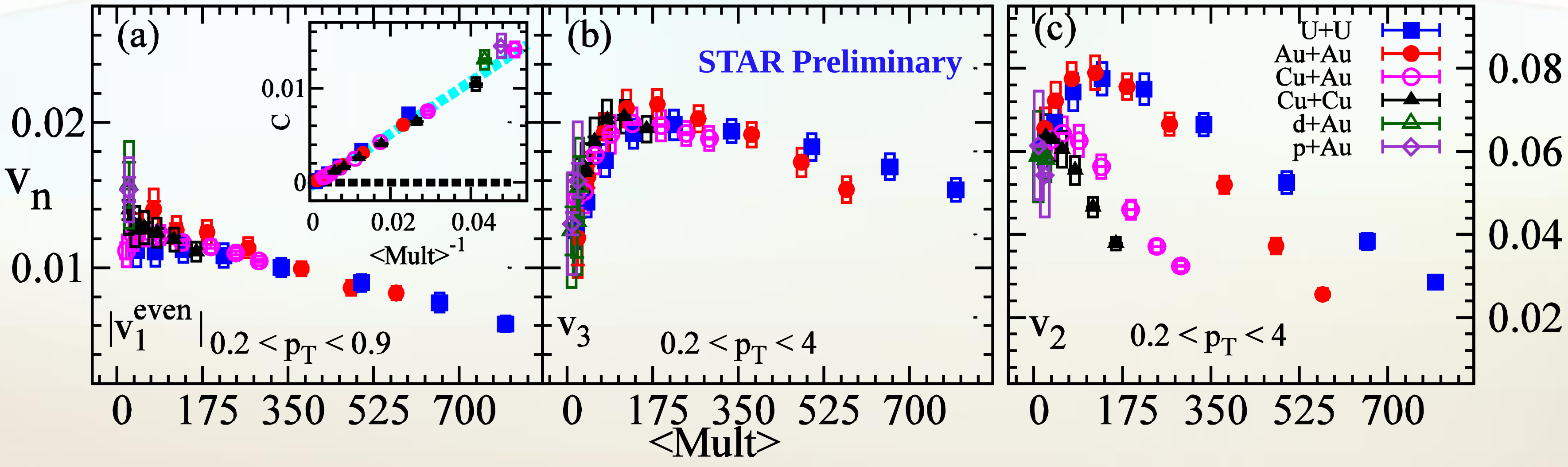
$v_n(Mult)$

System size

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

The multiplicity dependence of v_n for different systems

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



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

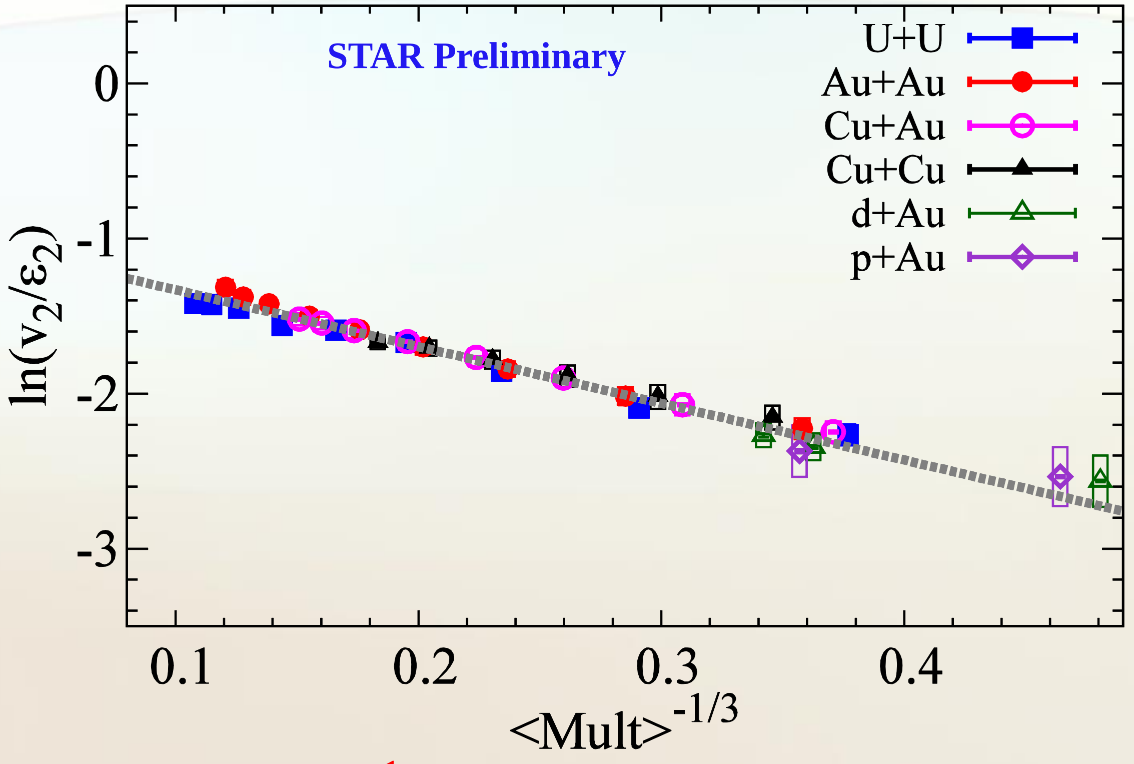
$v_n(Mult)$

System size and shape

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

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

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



- $v_n(< Mult >^{-\frac{1}{3}})$ for all systems scales to a single curve.
- Same $\frac{\eta}{s}$ for all systems.

III. Conclusion

Comprehensive set of STAR measurements for $v_n(Mult)$ of different systems are presented.

- 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
  - ✓ Viscous hydrodynamic-like expansion ansatz holds for presented systems

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

III. Conclusion

The initial questions answer?

- Is the observed anisotropy in heavy ion collision final- or initial state effect?
  - ✓ Final state ansatz holds for presented systems
- 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 remain within the final state effect.

THANK YOU