Beam Energy Dependence of Azimuthal Correlations in Au-Au Collisions at Mid and Forward Rapidity

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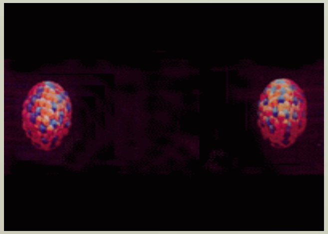
Initial Stages 2016



Outline

I. Introduction

i. QCD Phase Diagram

ii. STAR Detector

iii. Correlation function technique

II. Results

i. v_n p_T dependence

ii. v_n η dependence

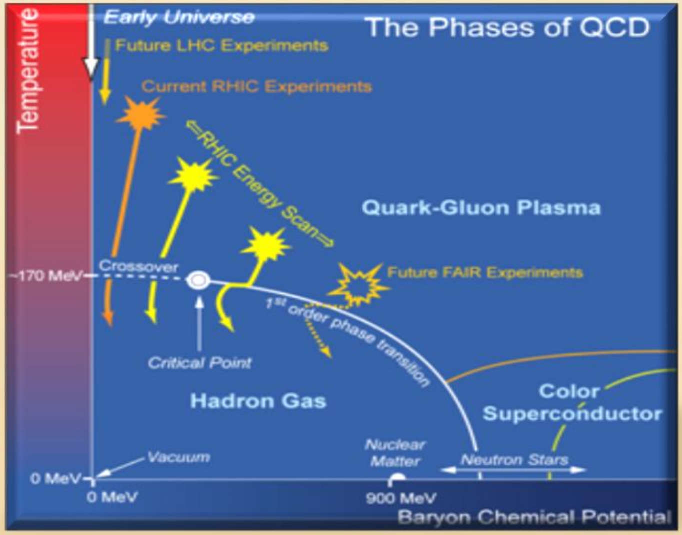
iii. v_n beam energy dependence

iv. Viscous coefficient

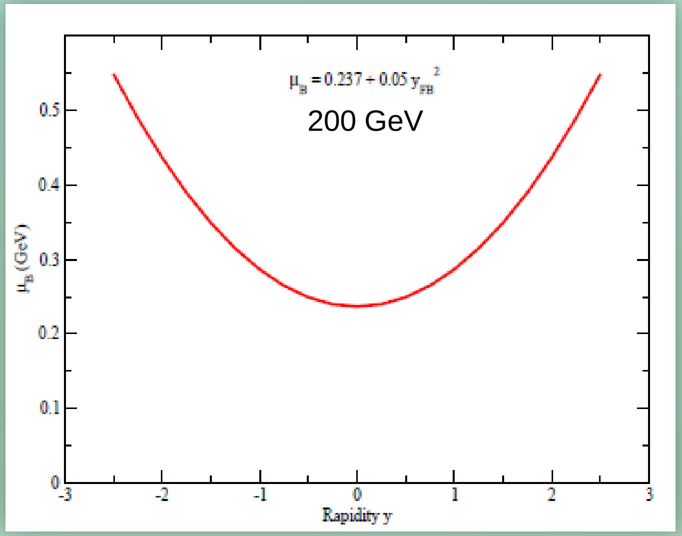
III. Conclusion

QCD Phase Diagram

- The BES at RHIC allows the study of a broad domain of $(\mu_B, T) -$ plane.



Rapidity dependence of (μ_B)



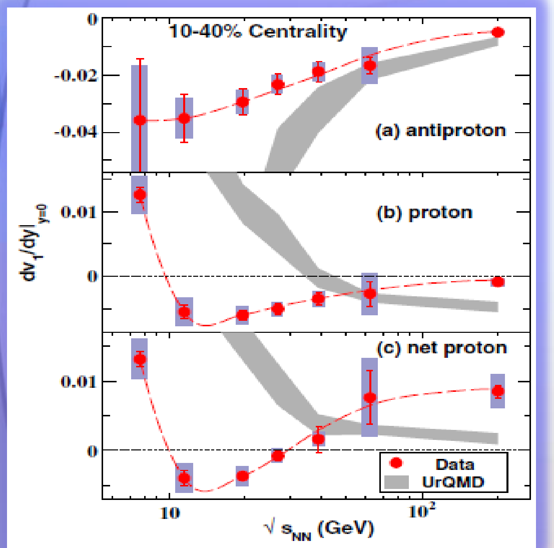
F. Becattini, PoSCPOD07:012,2007

- μ_B & T variations via beam energy or rapidity selections.

QCD Phase Diagram

➢ Strong interest in measurements which span a broad (μ_B, T) domain.

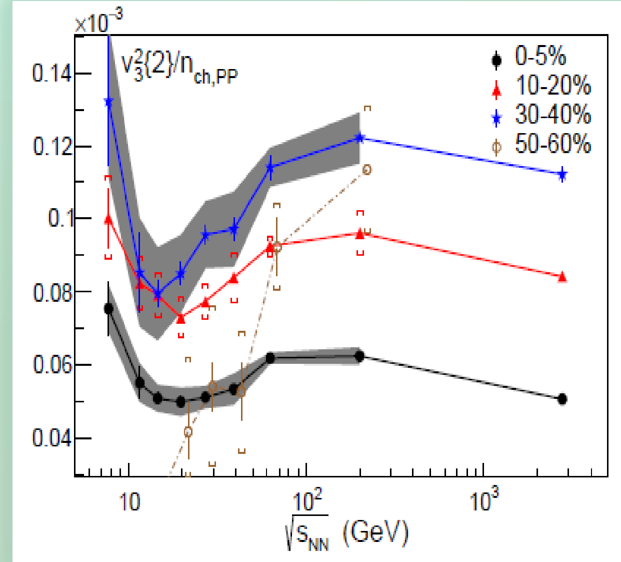
❖ Investigate signatures for the first-order phase transition



PRL 112,162301(2014)

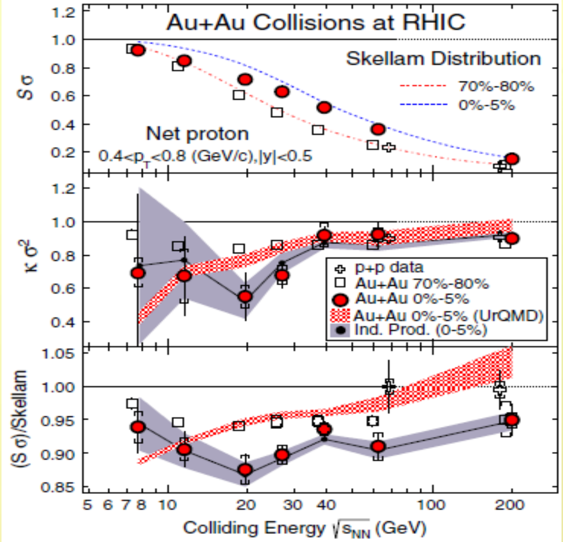
❖ Investigate transport coefficients as a function of (μ_B,T)

❖ Possible non-monotonic patterns



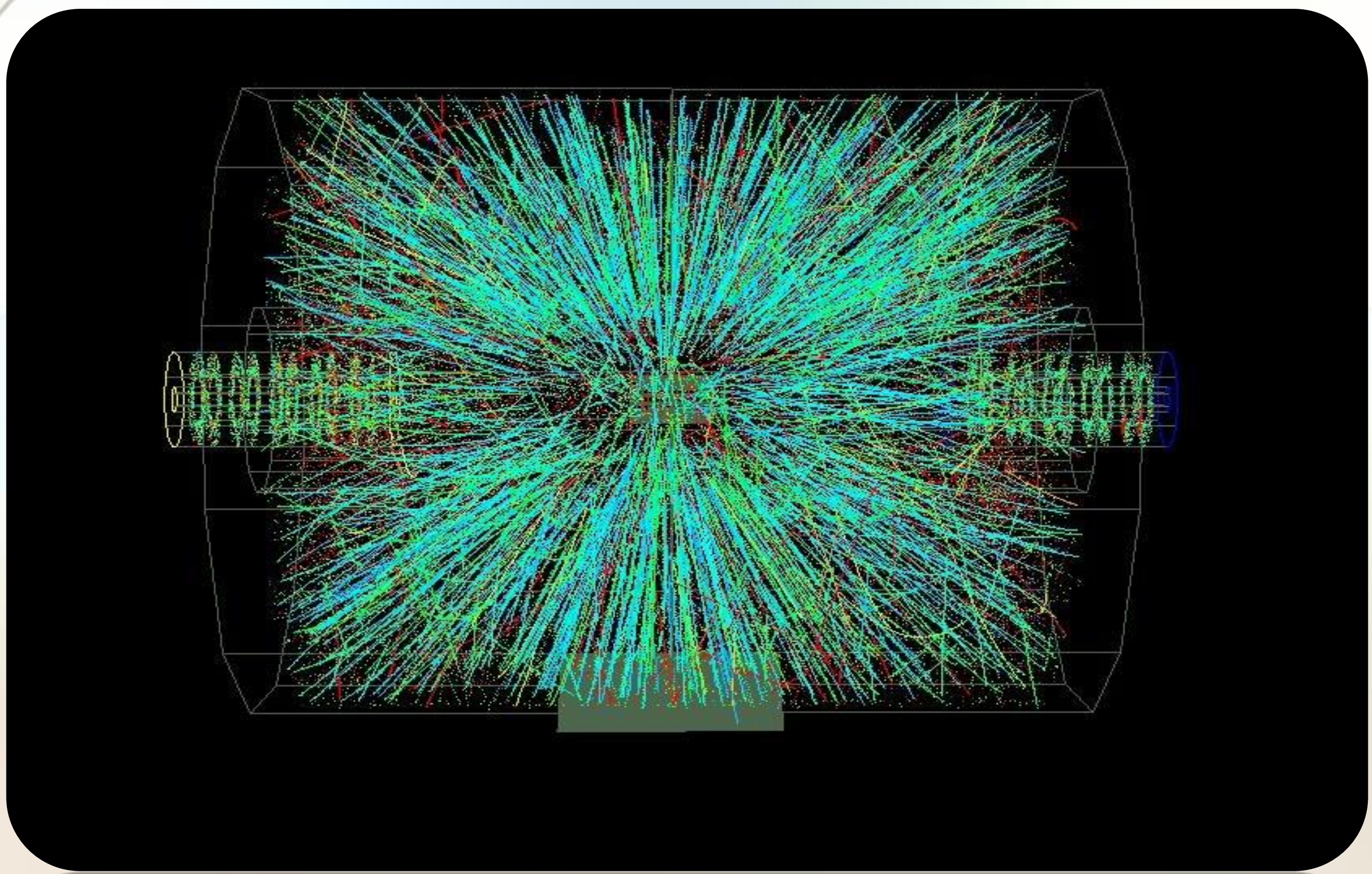
PRL 116, 112302 (2016)

❖ Search for critical fluctuations



PRL 112, 032302 (2014)

STAR Detector at RHIC



- TPC detector covers $|\eta| < 1$
- FTPC detector covers $2.5 < |\eta| < 4$

Correlation function technique

- All current techniques used to study v_n are related to the correlation function.
- Two particle correlation function $C(\Delta\varphi = \varphi_1 - \varphi_2)$ *used in this analysis*,

$$C(\Delta\varphi) = \frac{dN/d\Delta\varphi(same)}{dN/d\Delta\varphi(mix)} \quad \text{and} \quad v_n^2 = \frac{\sum_{\Delta\varphi} C(\Delta\varphi)\cos(n\,\Delta\varphi)}{\sum_{\Delta\varphi} C(\Delta\varphi)}$$

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PLB 708, 249 (2012)

$$v_n(p_T) = \frac{v_n^2(p_{T_{ref}}, p_T)}{\sqrt{v_n^2(p_{T_{ref}})}} \quad \text{and} \quad v_n(\eta) = \frac{v_n^2(\eta, \eta_{ref})}{\sqrt{v_n^2(\eta_{ref})}}$$

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

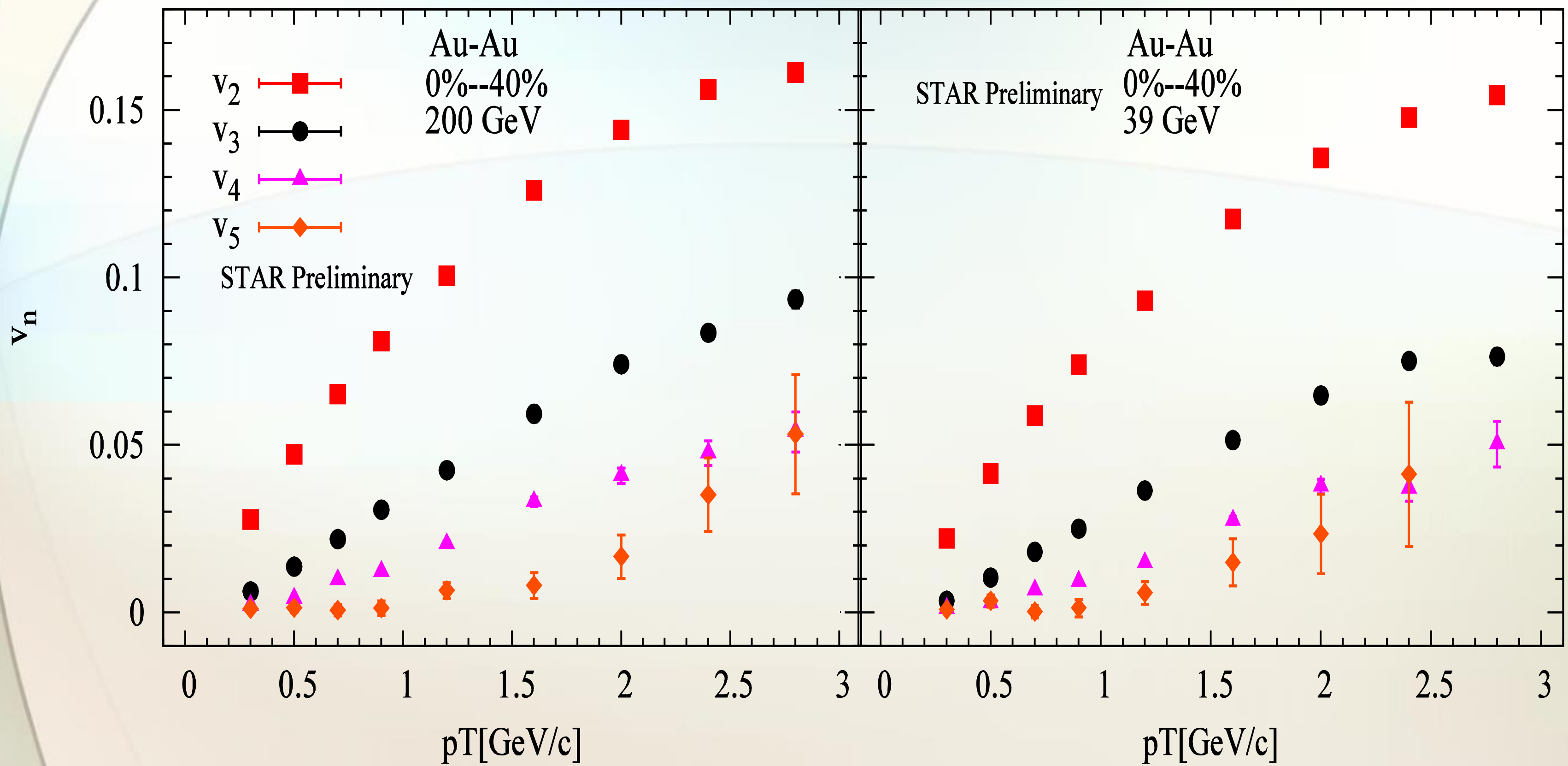
Results

- $v_n(pT) = \frac{v_n^2\left(p_{T_{ref}}, p_T\right)}{\sqrt{v_n^2\left(p_{T_{ref}}\right)}}$
  - ✓ $|\eta| < 1$
- $v_n(\eta) = \frac{v_n^2(\eta, \eta_{ref})}{\sqrt{v_n^2(\eta_{ref})}}$
  - ✓ $|\eta_{ref}| < 1 \; and \; |\eta| < 4$
  - ✓ $0.2 < p_T < 4\mathrm{GeV/c}$
- $v_n\left(\sqrt{s_{NN}}\right)$
- Viscous coefficient

Data presented with only statistical uncertainties

$v_n(p_T)$

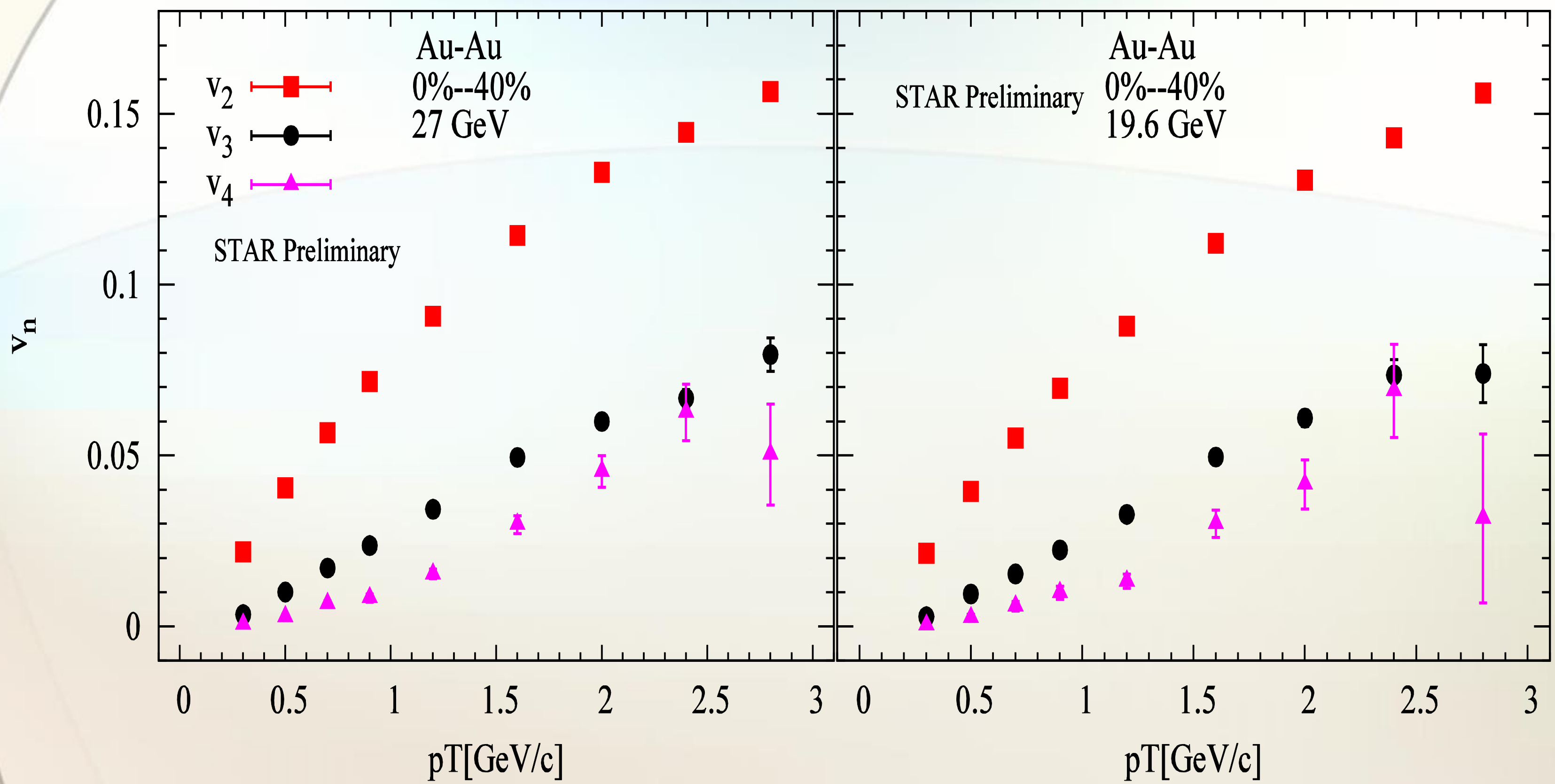
$|\eta| < 1$ and $|\Delta\eta| > 0.7$



- $v_n(p_T)$ indicate a similar trend for different beam energies.
- $v_n(p_T)$ decreases with harmonic order n.

$v_n(p_T)$

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

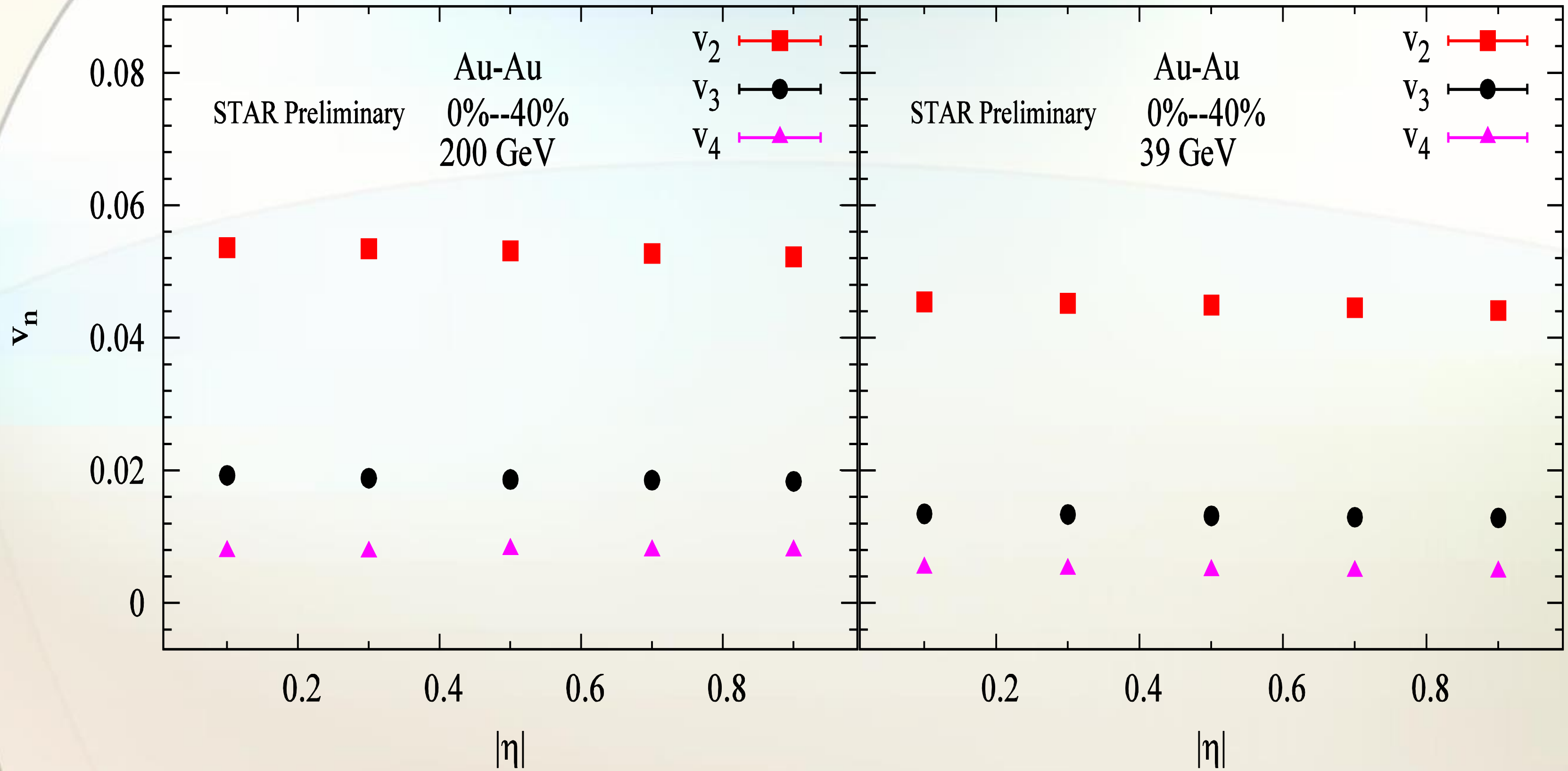


- $v_n(p_T)$ indicate similar trends for different beam energies.
- $v_n(p_T)$ decreases with harmonic order n.

$v_n(\eta)$

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

$0.2 < p_T < 4\text{GeV/c}$

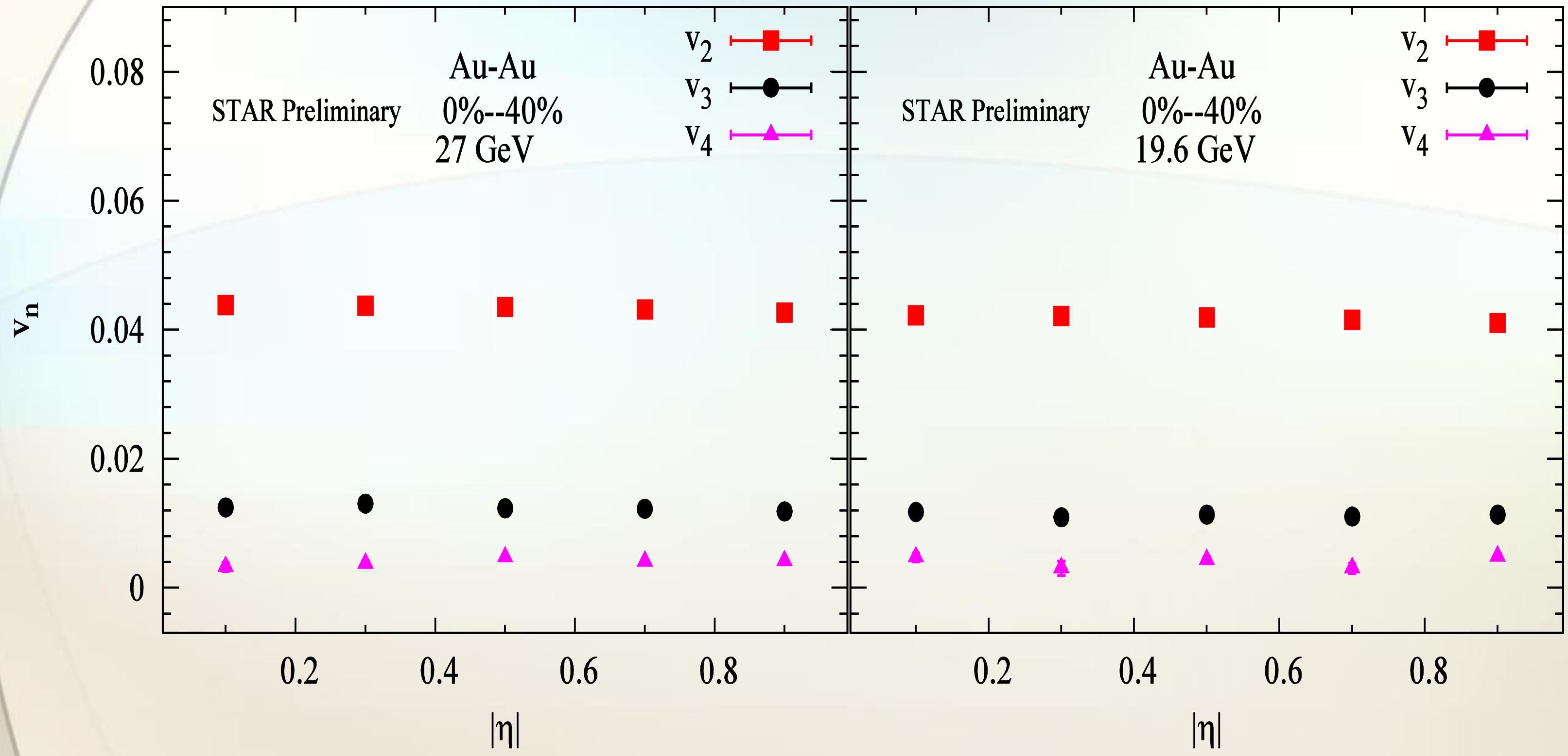


- Mid rapidity $v_n(\eta)$ shows a weak dependence at different energies.
- $v_n(\eta)$ decreases with harmonic order n.

$v_n(\eta)$

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

$0.2 < p_T < 4\text{GeV/c}$

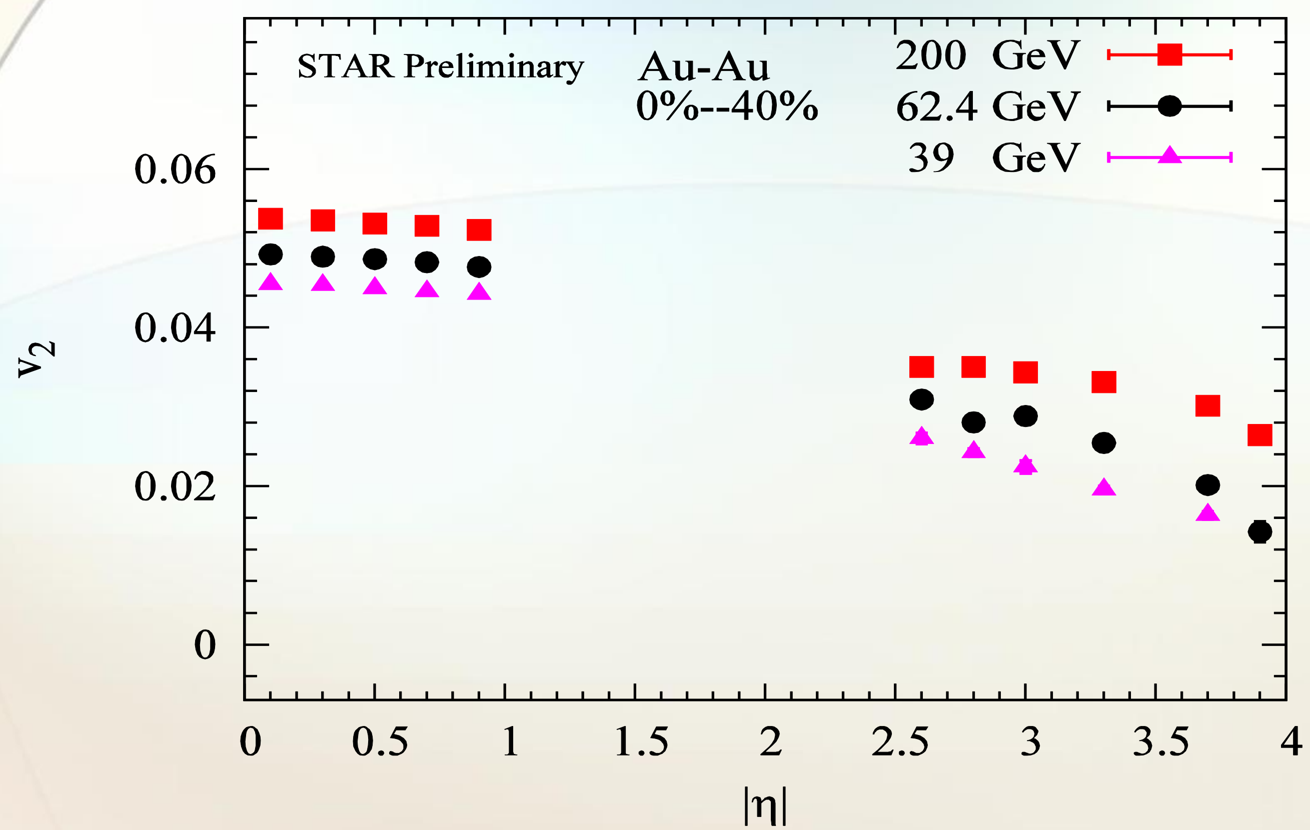


- Mid rapidity v_n(η) shows a weak dependence for different energies.
- v_n(η) decreases with harmonic order n.

$v_n(\eta)$

$|\eta_{ref}| < 1$ *and* $|\eta| < 4$

$0.2 < p_T < 4\mathrm{GeV/c}$

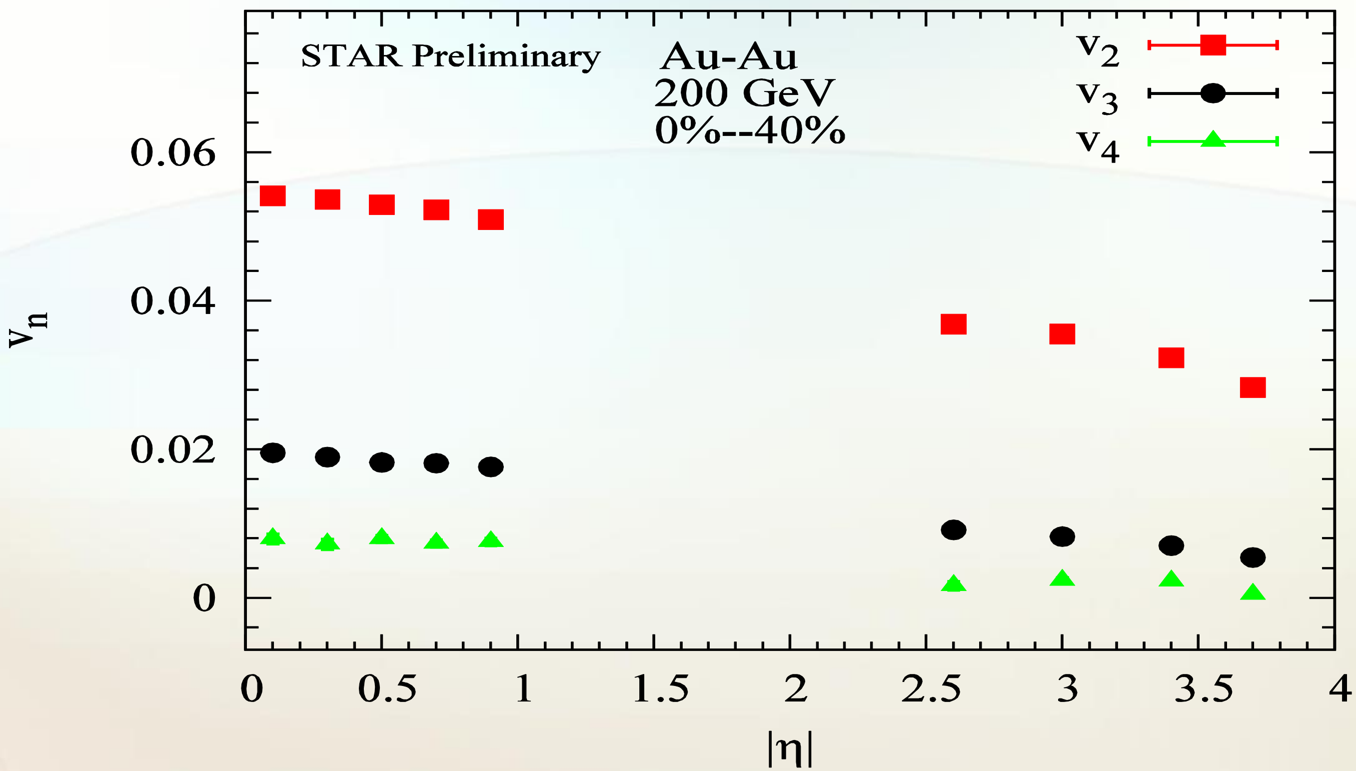


- $v_2(\eta)$ show similar trends for the respective beam energies.
- $v_2(\eta)$ increases with beam energy over the measured η range.

$v_n(\eta)$

$|\eta_{ref}| < 1$ *and* $|\eta| < 4$

$0.2 < p_T < 4\text{GeV/c}$

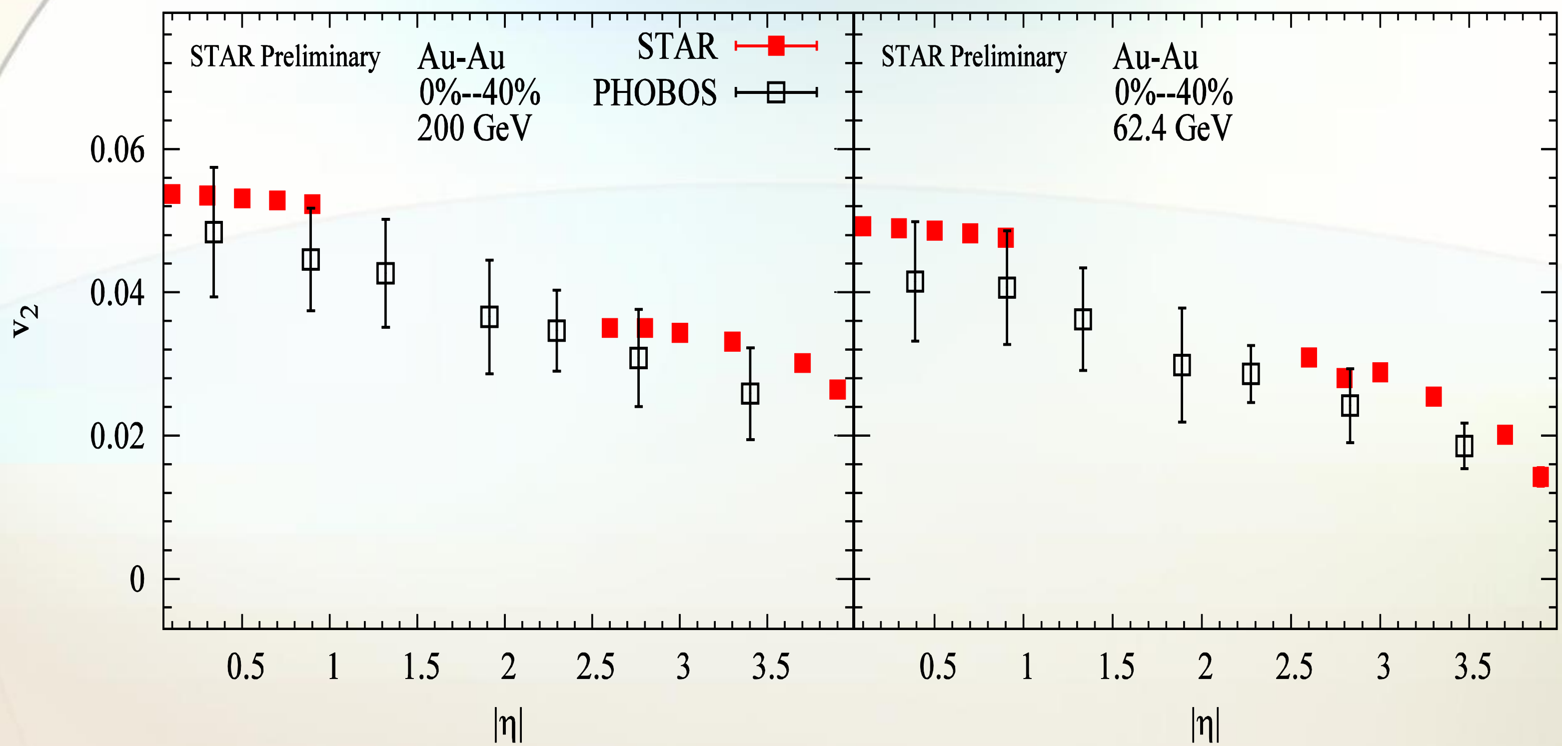


- Mid and forward rapidity $v_n(\eta)$ decreases with harmonic order n.

$v_2(\eta)$

$|\eta_{ref}| < 1$ and $|\eta| < 4$

$0.2 < p_T < 4\text{GeV/c}$

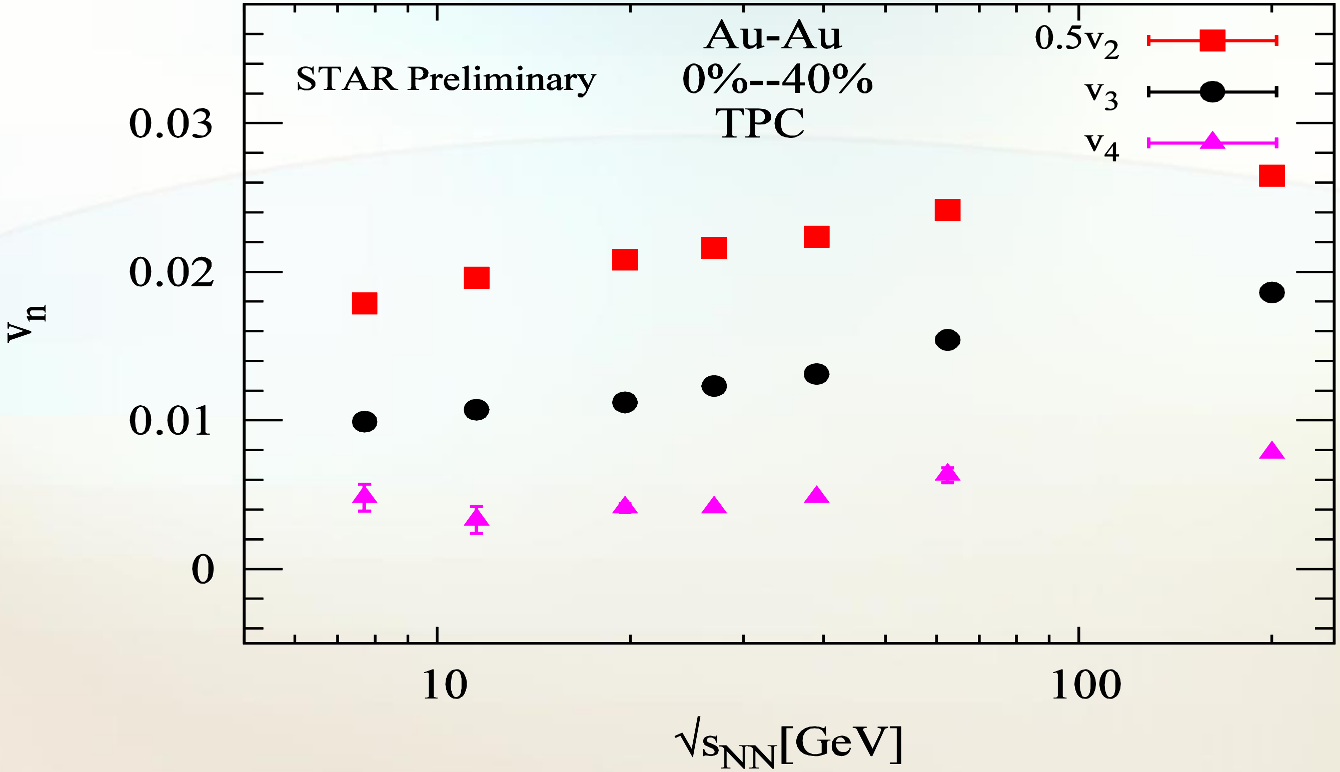


- Reasonable agreement between the STAR and PHOBOS measurements.

$v_n(\sqrt{s_{NN}})$

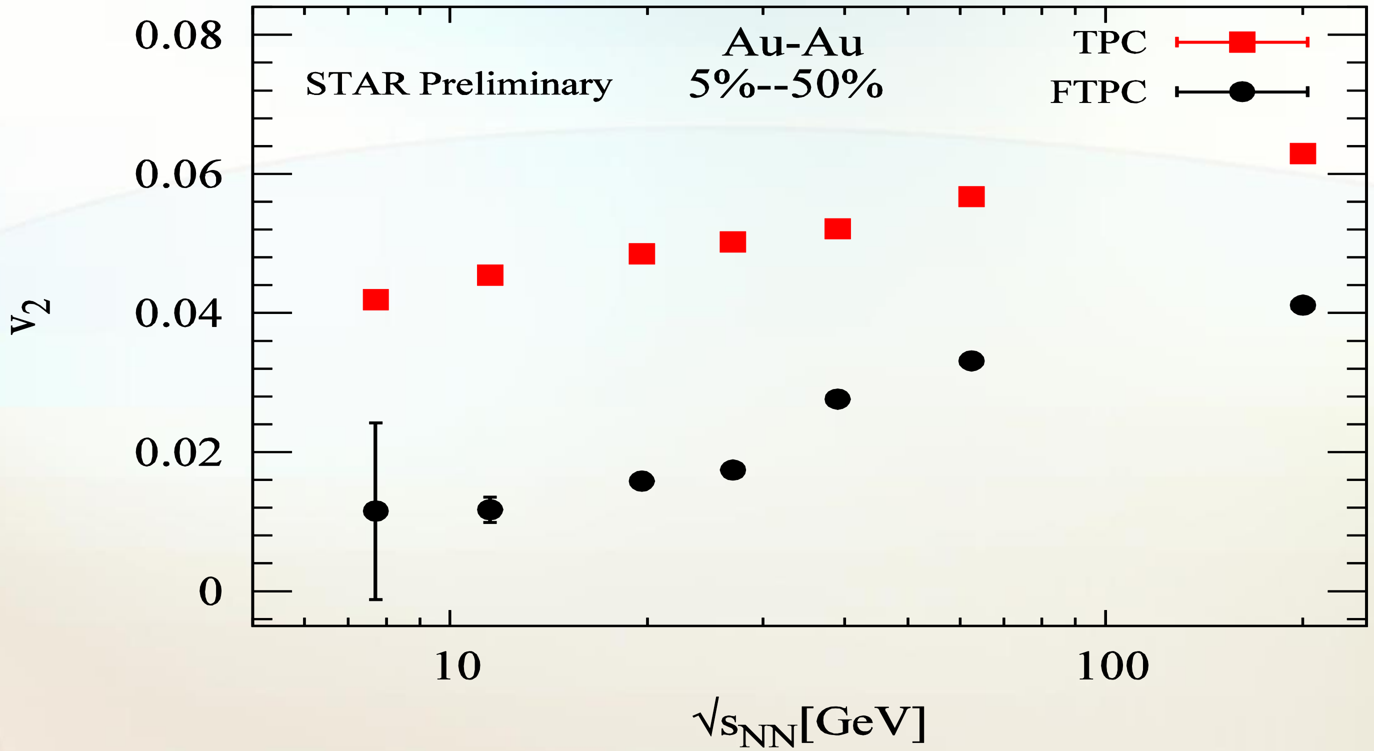
$|\eta| < 1$ and $|\Delta\eta| > 0.7$

$0.2 < p_T < 4\mathrm{GeV/c}$



- Mid rapidity $v_n(\sqrt{s_{NN}})$ shows a monotonic increase with beam energy.
- $v_n(\sqrt{s_{NN}})$ decreases with harmonic order n.

$v_2(\sqrt{s_{NN}})$
TPC and FTPC
$0.2 < p_T < 4\text{GeV/c}$



- Mid and forward rapidity $v_2(\sqrt{s_{NN}})$ shows a monotonic increase with beam energy.
- Forward rapidity $v_2(\sqrt{s_{NN}})$ shows a stronger dependence.

Viscous coefficient

- **Use $v_n(p_T, \text{cent})$ to extract the viscous coefficient as a function of $\sqrt{s_{NN}}$, based on the acoustic ansatz**
  - ✓ **the viscous coefficient encodes the transport coefficient $\frac{\eta}{s}$**

Viscous coefficient

- The v_n measurements are sensitive to ε_n, transport coefficient η/s and the expanding parameter RT.

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

- Anisotropic flow attenuation,

$$\frac{v_n}{\varepsilon_n} \propto e^{-\beta n^2}$$

arXiv:1305.3341 3

- For two different harmonics n *and* $n'(n' = 2)$,

$$\frac{(v_n)^{\frac{1}{n}}}{(v_{n'})^{\frac{1}{n'}}} \propto c \;\; e^{-\beta (n - n')} \quad \text{and} \quad \beta \propto \frac{\eta}{s} \frac{1}{RT}, \; c = \frac{(\epsilon_n)^{\frac{1}{n}}}{(\epsilon_{n'})^{\frac{1}{n'}}}$$

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

arXiv:1601.06001 5

- The viscous coefficient ξ encodes the transport coefficient $\frac{\eta}{s}$,

$$\xi = \left(\frac{dN}{d\eta}\right)^{1/3} \ln\left(\frac{(v_n)^{\frac{1}{n}}}{(v_2)^{\frac{1}{2}}}\right) \propto -(n-2)\frac{\eta}{s} + \left(\frac{dN}{d\eta}\right)^{1/3} \ln(c)$$

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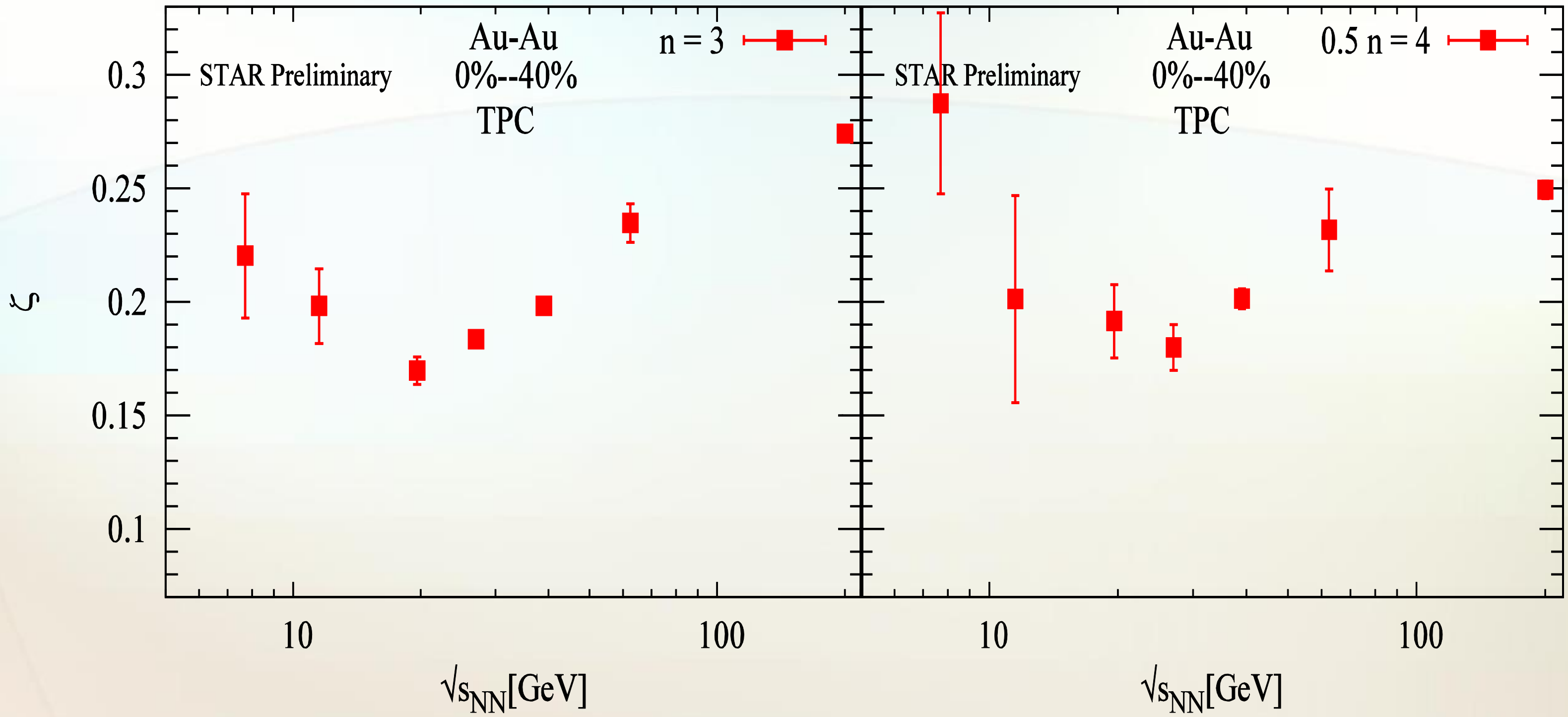
Viscous coefficient

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

$0.2 < p_T < 4$ GeV/c



- ➢ The viscous coefficient ξ shows a non-monotonic behavior with beam energy in both cases, n = 3 and n = 4.

III. Conclusion

Comprehensive set of STAR measurements for $v_n(p_T, \eta, \text{cent}, \sqrt{s_{NN}})$ presented.

- Mid and forward rapidity v_2 shows a monotonic increase with beam energy,
  - ✓ Stronger $\sqrt{s_{NN}}$ dependence for forward v_2.

- $For\ \ a\, given \sqrt{s_{NN}}\ \ v_n$ decrease with the harmonic order.
  - ✓ Similar patterns but different magnitude for different $\sqrt{s_{NN}}$

- **The viscous coefficient ξ, which encodes the transport coefficient $\frac{\eta}{s}$, indicates a non-monotonic pattern for the beam energy range studied.**

THANK YOU