Viscous Damping of Anisotropic Flow in 7.7 − 200 GeV Au+Au Collisions

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Strangeness in Quark Matter 2016

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ii. STAR Detector

iii. Correlation function technique

II. Results

i. v_n p_T dependence

ii. v_n $Centrality$ dependence

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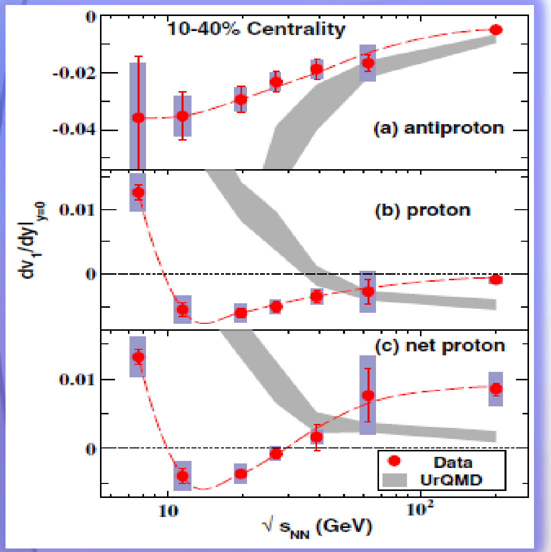
QCD Phase Diagram

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

❖ Investigate signatures for the first-order phase transition



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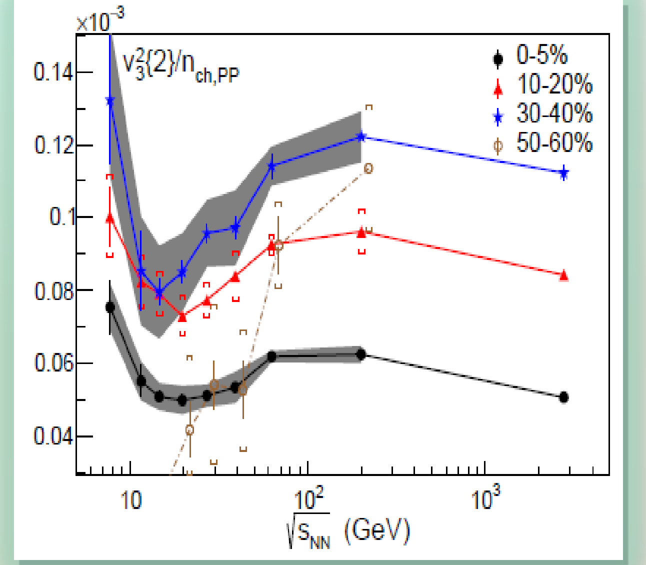
❖ Investigate transport coefficients as a function of (μ_B, T)

❖ Possible non-monotonic patterns



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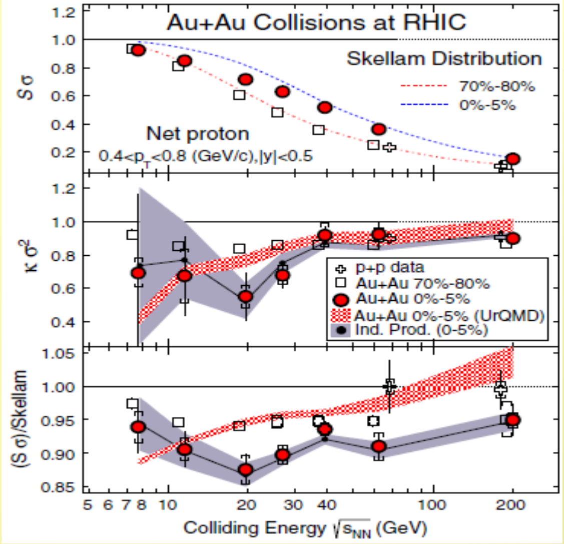
❖ Search for critical fluctuations



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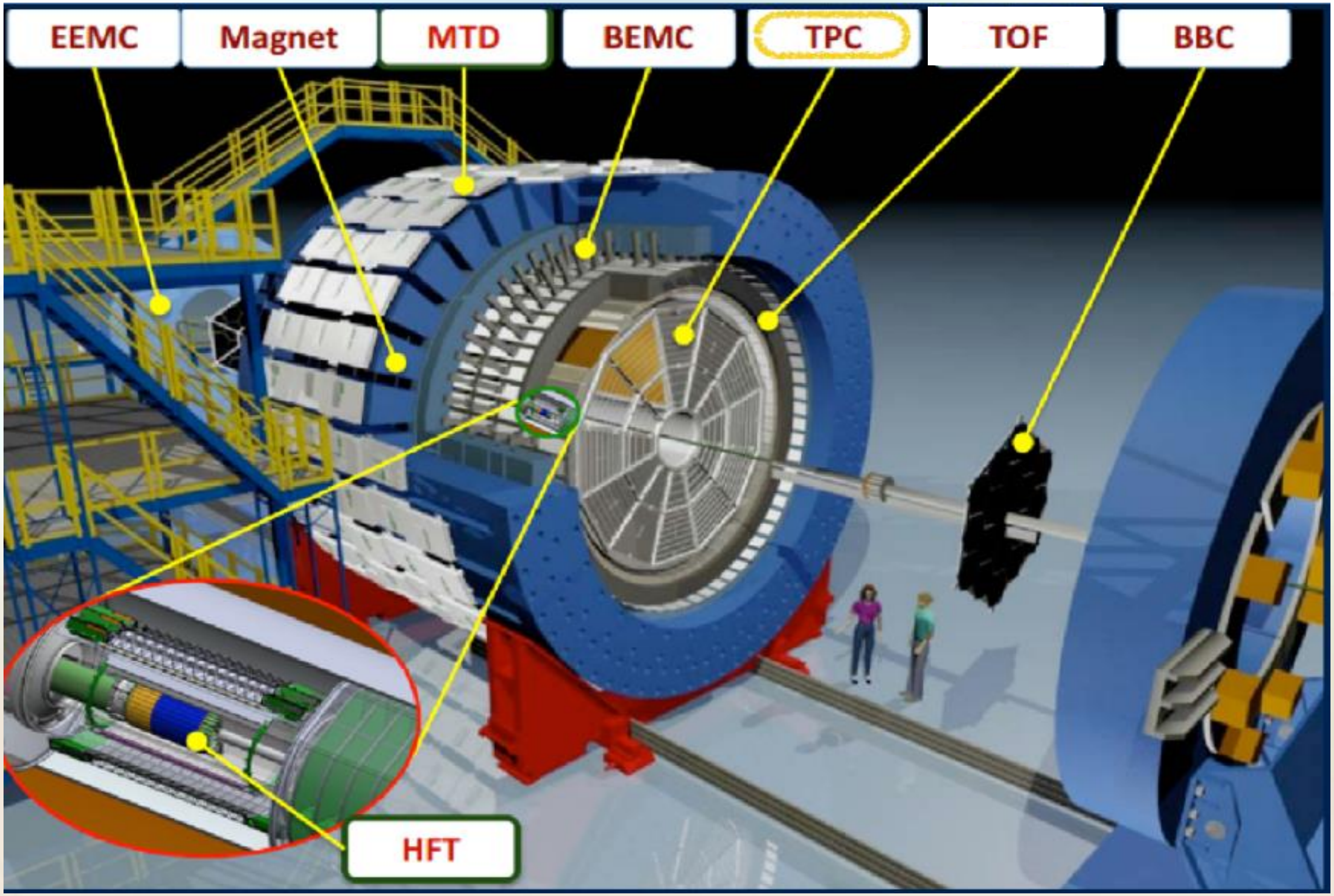
STAR Detector at RHIC



- 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 $C(\Delta\varphi = \varphi_1 - \varphi_2)$ *used in this analysis*,

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

1

PLB 708, 249 (2012)

$$v_n(pT) = \frac{v_n^2(p_{T_{ref}}, p_T)}{\sqrt{v_n^2(p_{T_{ref}})}}$$

2

- ✓ 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.

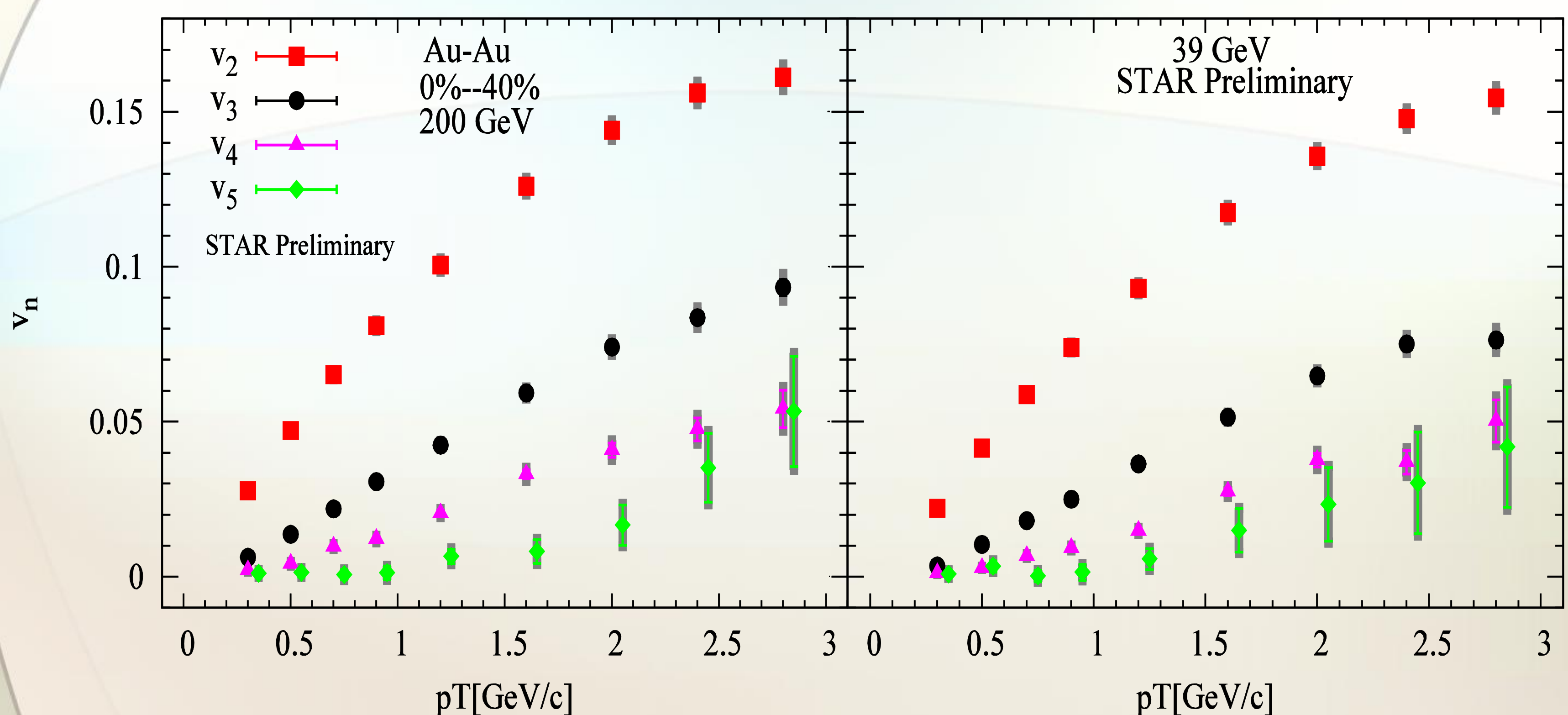
Results

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

n > 1

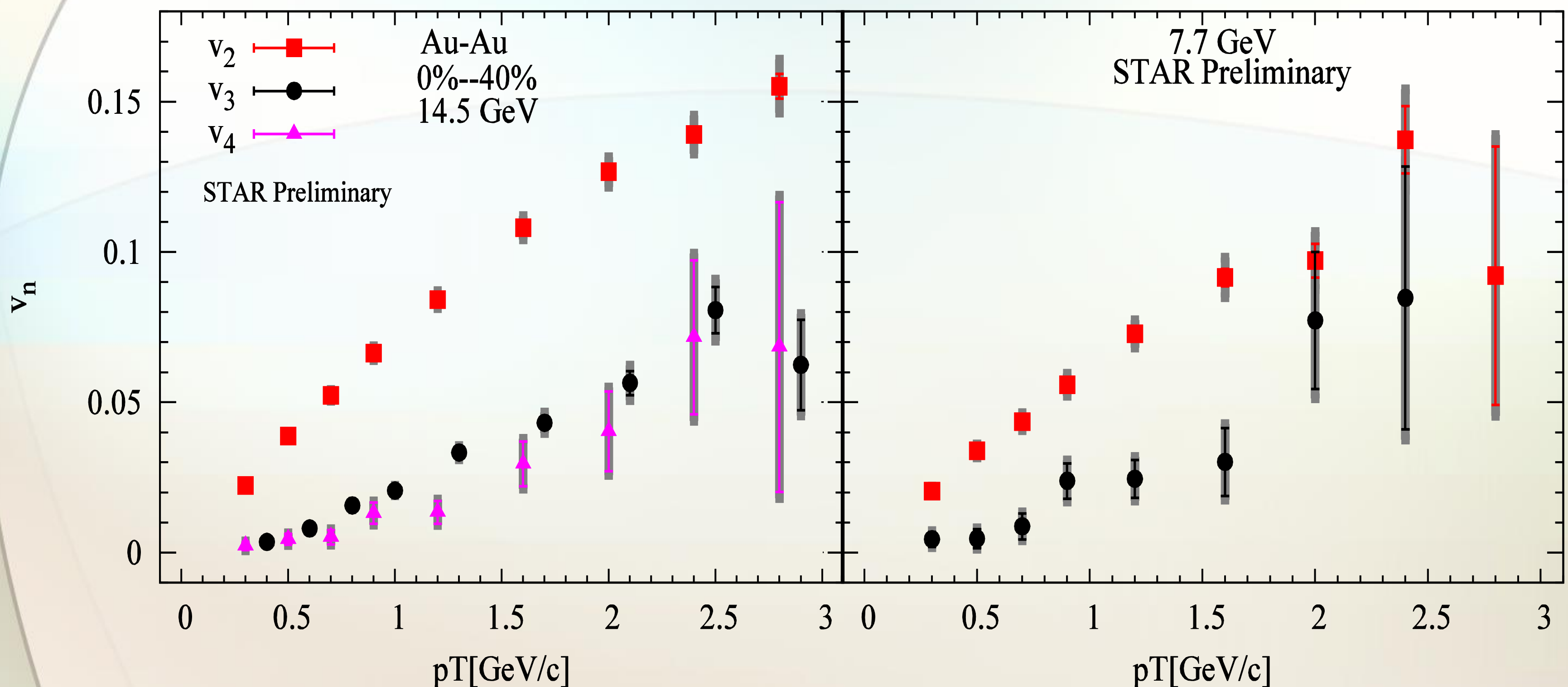
- v_n p_T dependence
  - ✓ $v_n(p_T) = \frac{v_n^2(p_{T_{ref}}, p_T)}{\sqrt{v_n^2(p_{T_{ref}})}}$
- $v_n(Centrality)$
- $v_n\left(\sqrt{s_{NN}}\right)$

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



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

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



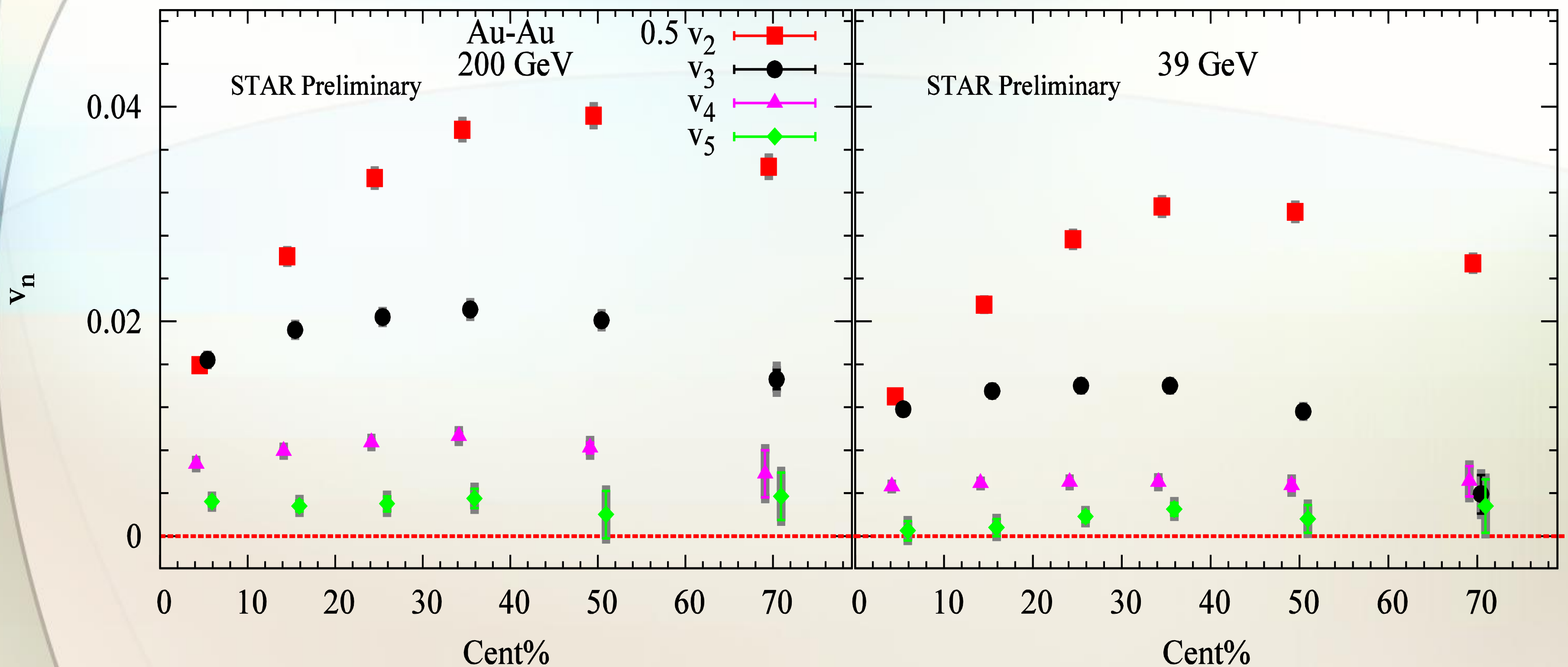
- $v_n(p_T)$ indicate a similar trend for different beam energies.
- $v_n(p_T)$ decreases with harmonic order n.

$v_n(Cent)$

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

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

$n > 1$



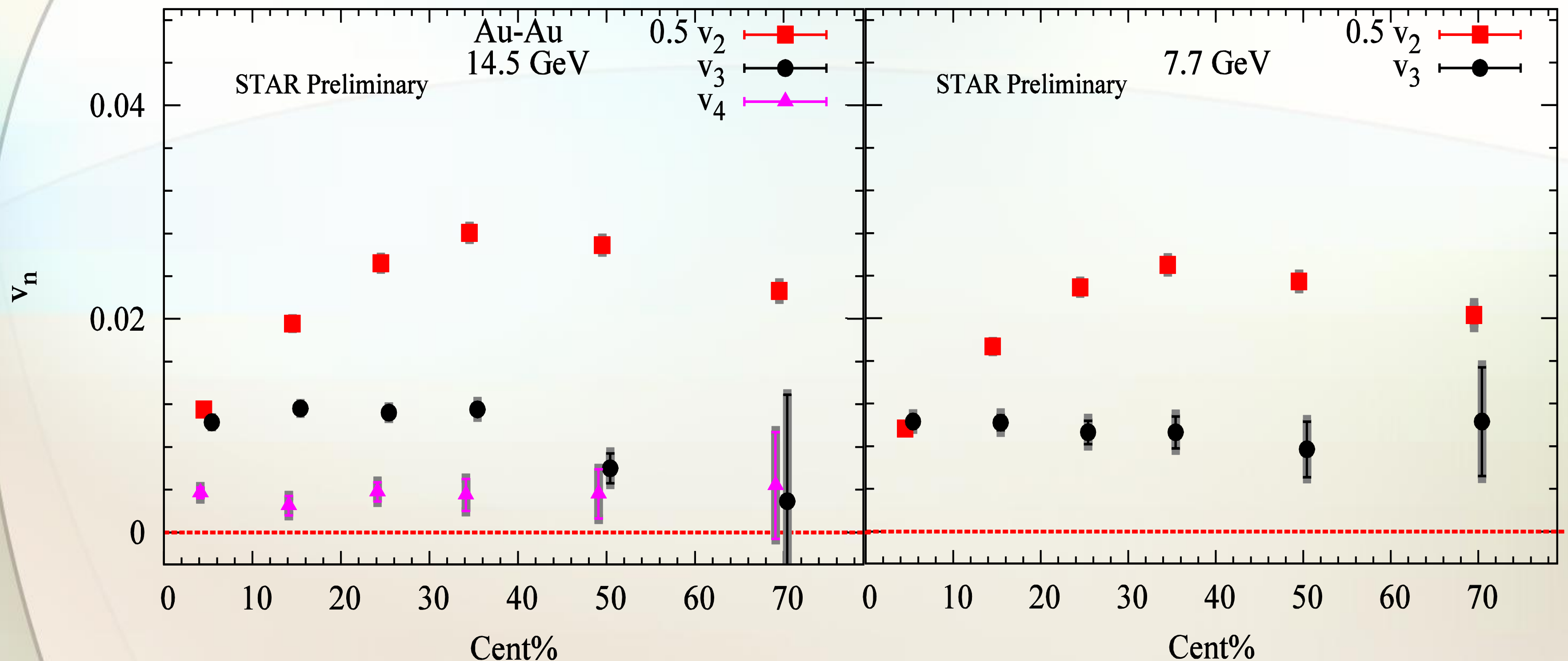
- $v_n(Cent)$ indicate a similar trend for different beam energies.
- $v_n(Cent)$ decreases with harmonic order n.

$v_n(Cent)$

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

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

$n > 1$



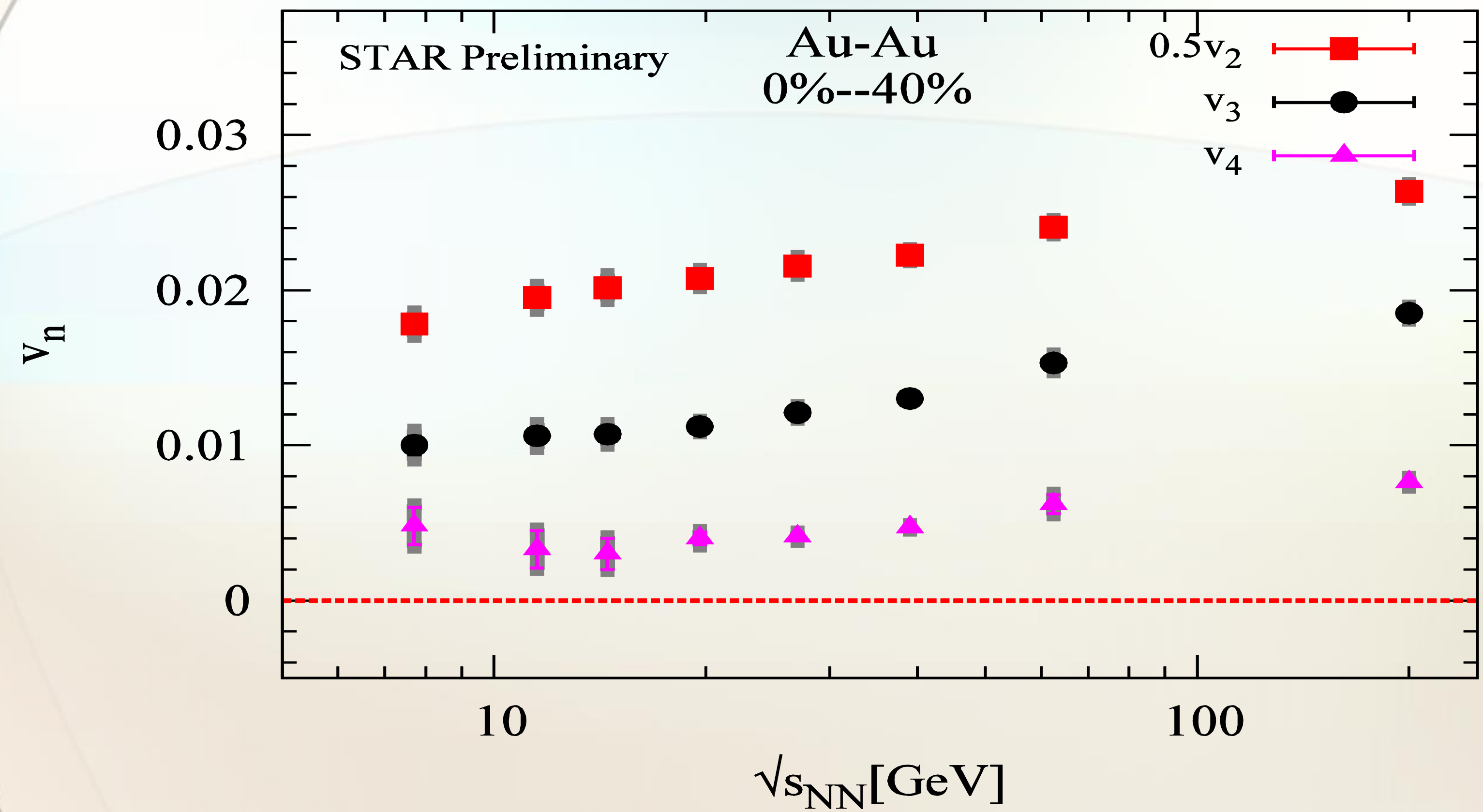
- $v_n(Cent)$ indicate a similar trend for different beam energies.
- $v_n(Cent)$decreases with harmonic order n.

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

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

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

n > 1



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

Viscous coefficient

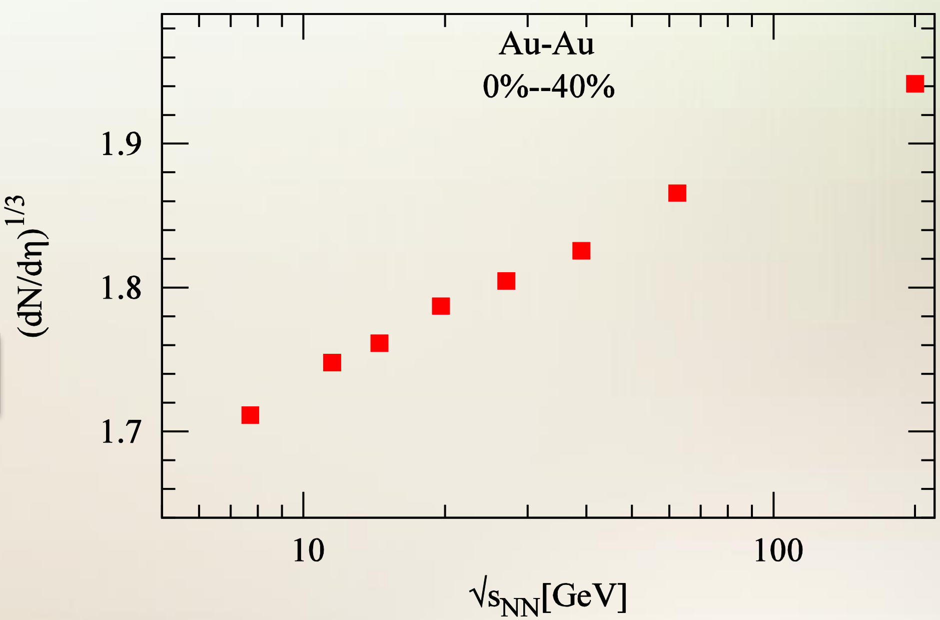
- **Use v_n(pT, cent) to extract the viscous coefficient as a function of $\sqrt{s_{NN}}$**
  - ✓ **the viscous coefficient proportional to the transport coefficient $\frac{\eta}{s}$**

Viscous coefficient

- The v_n measurement 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, $\frac{v_n}{\varepsilon_n} \propto e^{-\beta n^2}$, $\beta \propto \frac{\eta}{s}\frac{1}{RT}$ arXiv:1305.3341 3
- From macroscopic entropy considerations $(RT)^3 \propto \frac{dN}{d\eta}$ arXiv:1601.06001
- The viscous coefficient ζ proportional to the transport coefficient $\frac{\eta}{s}$,

$$\ln\left(\frac{(v_n)^{\frac{1}{n}}}{(v_2)^{\frac{1}{2}}}\right) - \ln\left(\frac{(\epsilon_n)^{\frac{1}{n}}}{(\epsilon_2)^{\frac{1}{2}}}\right) = A\left[-(n-2)\frac{\boldsymbol{\eta}}{\boldsymbol{s}}\right] / \left(\frac{dN}{d\eta}\right)^{\frac{1}{3}} + \ln(c)$$ 4

$$\boldsymbol{\zeta} = \ln\left(\frac{(v_n)^{\frac{1}{n}}}{(v_2)^{\frac{1}{2}}}\right)\left(\frac{dN}{d\eta}\right)^{\frac{1}{3}}$$ 5



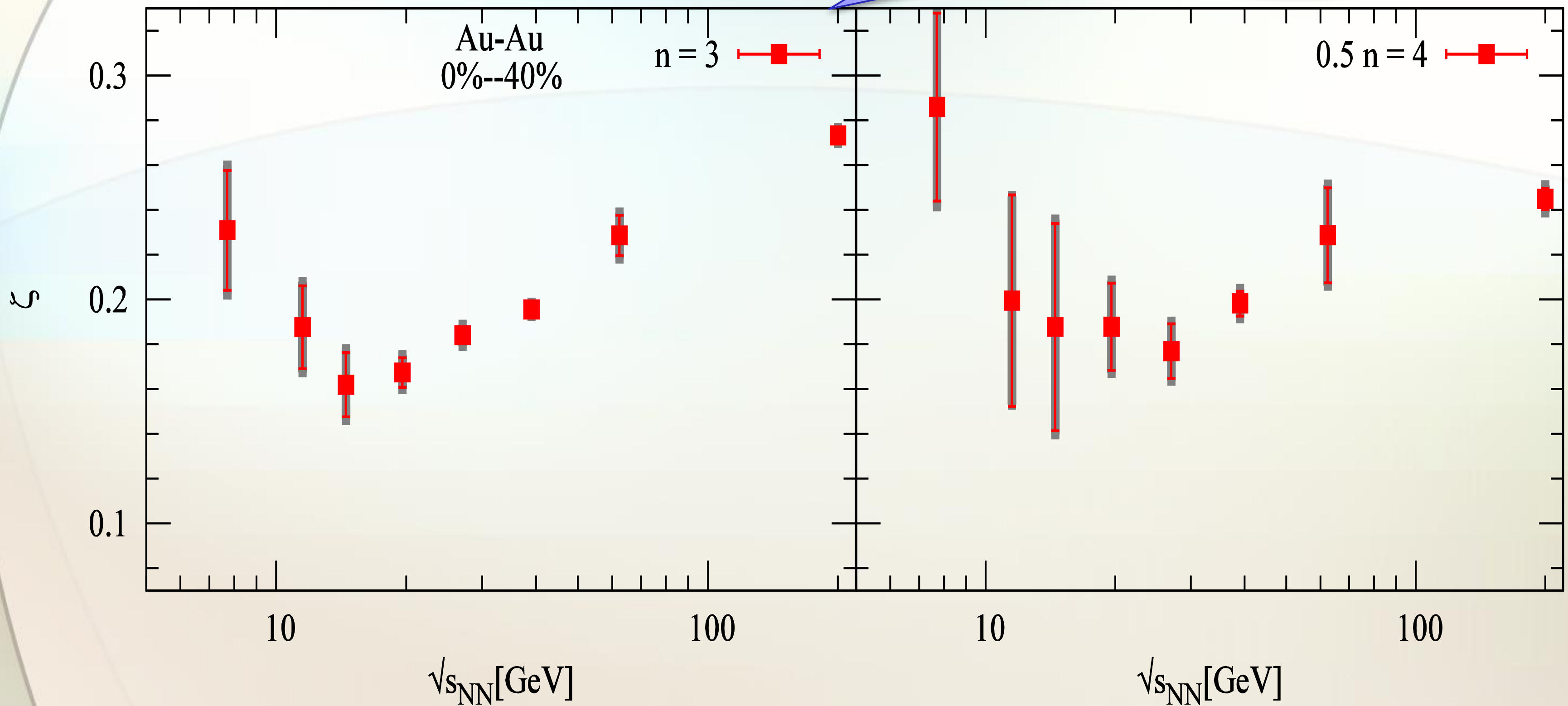
Viscous coefficient

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

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

$$\zeta = ln\left(\frac{(v_n)^{\frac{1}{n}}}{(v_2)^{\frac{1}{2}}}\right)\left(\frac{dN}{d\eta}\right)^{\frac{1}{3}}$$

$$\zeta \propto \frac{\eta}{s}$$



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

STAR Non-monotonic behavior

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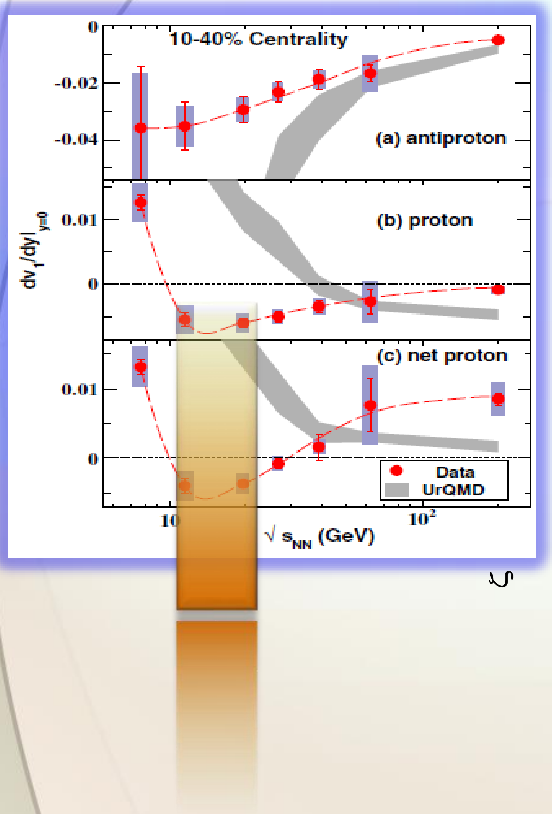

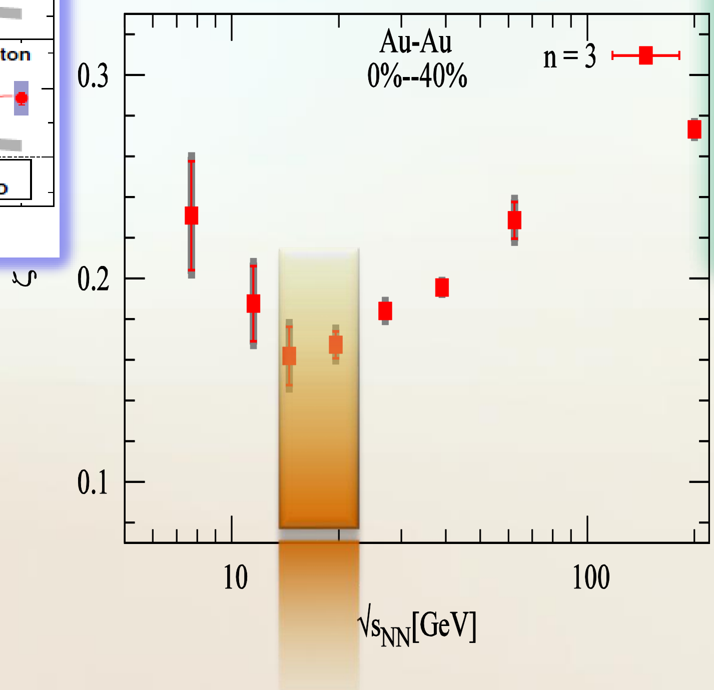

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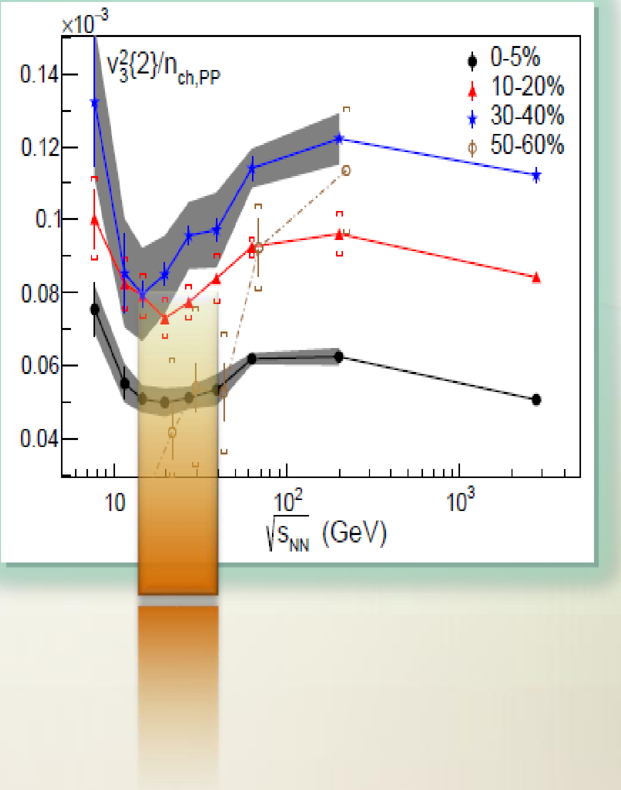

- Different STAR measurement shows a non-monotonic behavior about the same beam energy domain.

III. Conclusion

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

- *For a given* $\sqrt{s_{NN}}$ v_n decrease with the harmonic order.
  - ✓ Similar patterns but different magnitude for different $\sqrt{s_{NN}}$
- Mid rapidity $v_n(\sqrt{s_{NN}})$ shows a monotonic increase with beam energy.
- The viscous coefficient ζ, which proportional to the transport coefficient $\frac{\eta}{s}$, indicates a non-monotonic pattern for the beam energy range studied.

THANK YOU