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

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QCD Phase Diagram

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

⦁ Investigate signatures for the first-order phase transition

⦁ Investigate transport coefficients as a function of \((\mu_B, T)\)

⦁ Possible non-monotonic patterns

⦁ Search for critical fluctuations

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PRL 112, 032302 (2014)

PRL 116, 112302 (2016)
STAR Detector at RHIC

- TPC detector covers $|\eta| < 1$
Correlation function technique

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

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

$$\nu_n(p_T) = \frac{\nu_n^2(p_{T,ref}, p_T)}{\sqrt{\nu_n^2(p_{T,ref})}}$$

- Factorization ansatz for $\nu_n$ 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

\[ |\eta| < 1 \text{ and } |\Delta \eta| > 0.7 \]
\[ n > 1 \]

\[ \nabla v_n \rho_T \text{ dependence} \]

\[ \checkmark v_n(\rho_T) = \frac{\sqrt{v_n^2(\rho_{T\text{ref}},\rho_T)}}{\sqrt{v_n^2(\rho_{T\text{ref}})}} \]

\[ \nabla v_n(\text{Centrality}) \]

\[ \nabla v_n(\sqrt{s_{NN}}) \]
\( v_n(p_T) \) indicate a similar trend for different beam energies.

\( v_n(p_T) \) decreases with harmonic order \( n \).

\[ |\eta| < 1 \text{ and } |\Delta\eta| > 0.7 \]

\[ n > 1 \]
\[ \nu_n(p_T) \] indicate a similar trend for different beam energies.

\[ \nu_n(p_T) \] 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 $n$. 

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\( v_n(\text{Cent}) \) indicate a similar trend for different beam energies.

\( v_n(\text{Cent}) \) decreases with harmonic order \( n \).

\(|\eta| < 1 \) and \(|\Delta\eta| > 0.7\)

\( 0.2 < p_T < 4 \text{GeV/c} \)

\( n > 1 \)
\( v_n(\sqrt{s_{NN}}) \) for \(|\eta| < 1\) 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 $\nu_n(pT, \text{cent})$ 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 $\varepsilon_n$, transport coefficient $\eta/s$ and the expanding parameter $RT$.
- Acoustic ansatz
  - Sound attenuation in the viscous matter reduces the magnitude of $v_n$.
- Anisotropic flow attenuation, $\frac{v_n}{\varepsilon_n} \propto e^{-\beta n^2}$, $\beta \propto \frac{\eta}{s} \frac{1}{R T}$
- From macroscopic entropy considerations $(RT)^3 \propto \frac{dN}{d\eta}$

The viscous coefficient $\zeta$ proportional to

$$\ln \left( \frac{(v_n)^{\frac{1}{n}}}{(v_2)^{\frac{1}{2}}} \right) - \ln \left( \frac{(\varepsilon_n)^{\frac{1}{n}}}{(\varepsilon_2)^{\frac{1}{2}}} \right) = A \left[ -(n-2) \frac{\eta}{s} \right] / \left( \frac{dN}{d\eta} \right)^{\frac{1}{3}} + \ln(c)$$

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

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Viscous coefficient

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

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

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

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

$$\zeta \propto \frac{\eta}{S}$$
Different STAR measurement shows a non-monotonic behavior about the same beam energy domain.
III. Conclusion

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

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

- Mid rapidity $\nu_n(\sqrt{s_{NN}})$ shows a monotonic increase with beam energy.

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