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

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Strangeness in Quark Matter 2016
Outline

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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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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,

$$C(\Delta \varphi) = \frac{dN/d\Delta \varphi(\text{same})}{dN/d\Delta \varphi(\text{mix})}$$

and

$$\nu_n^2 = \frac{\Sigma_{\Delta \varphi} C(\Delta \varphi) \cos(n \Delta \varphi)}{\Sigma_{\Delta \varphi} C(\Delta \varphi)}$$

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

- 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

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

$n > 1$

- $v_n$ $p_T$ dependence

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

- $v_n(Centrality)$

- $v_n(\sqrt{s_{NN}})$
\[ \nu_n(p_T) \]

| \eta | < 1 and |\Delta \eta| > 0.7  
\hline
n > 1

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

\[ \nu_n(p_T) \] decreases with harmonic order n.
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\[ \nu_n(Cent) \]

|\(|\eta| < 1 \text{ and } |\Delta\eta| > 0.7 |
0.2 < p_T < 4\text{GeV}/c 
\( n > 1 \)

- \( \nu_n(Cent) \) indicate a similar trend for different beam energies.
- \( \nu_n(Cent) \) decreases with harmonic order \( n \).
\( \nu_n (\text{Cent}) \)

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\[ \nu_n (\text{Cent}) \]

- \( \nu_n (\text{Cent}) \) indicate a similar trend for different beam energies.
- \( \nu_n (\text{Cent}) \) 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 $n$. 

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

- From macroscopic entropy considerations $\left(\frac{R T}{3}\right) \propto \frac{d N}{d \eta}$

- The viscous coefficient $\zeta$ proportional to the transport coefficient $\frac{\eta}{s}$,

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

\[
\zeta = \ln\left(\frac{(v_n)^{\frac{1}{n}}}{(v_2)^{\frac{1}{2}}}\right) \left(\frac{d N}{d \eta}\right)^{\frac{1}{3}}
\]
The viscous coefficient $\xi$ shows a non-monotonic behavior with beam energy in both cases, $n = 3$ and $n = 4$. 

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

\[ \zeta \propto \frac{\eta}{S} \]
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.
THANK YOU