Recent results of the azimuthal anisotropic flow measurements from STAR experiment

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Data Studied

- Collected data for Au+Au at $\sqrt{s_{NN}} = 200 - 7.7 \text{ GeV}$
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Collected data for different systems at $\sqrt{s_{NN}} \sim 200$
Data Studied

- Collected data for Au+Au at $\sqrt{S_{NN}} = 200 - 7.7$ GeV
- Collected data for different systems at $\sqrt{S_{NN}} \sim 200$

STAR Detector at RHIC

- TPC detector mainly get used in the current analysis
Azimuthal anisotropy measurements

Correlation function

Two-particle correlation function $C_r(\Delta \varphi = \varphi_a - \varphi_b)$,

$$C_r(\Delta \varphi) = \frac{dN}{d\Delta \varphi} \quad \text{and} \quad \nu_{ab}^n = \frac{\sum_{\Delta \varphi} C_r(\Delta \varphi) \cos(n \Delta \varphi)}{\sum_{\Delta \varphi} C_r(\Delta \varphi)}$$
Azimuthal anisotropy measurements

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Flow
Non-flow
Azimuthal anisotropy measurements

Correlation function

Two-particle correlation function $C_r(\Delta \varphi = \varphi_a - \varphi_b)$,

$$C_r(\Delta \varphi) = \frac{dN}{d\Delta \varphi}$$

and $v_{n}^{ab} = \frac{\sum_{\Delta \varphi} C_r(\Delta \varphi) \cos(n \Delta \varphi)}{\sum_{\Delta \varphi} C_r(\Delta \varphi)}$

$n > 1$

$v_{n}^{ab} = v_{n}^{a} v_{n}^{b} + \delta_{short}$

$n = 1$

$v_{1}^{ab} = v_{1}^{a} v_{1}^{b} + \delta_{long}$

Flow

Non-flow
Azimuthal anisotropy measurements

Correlation function

Two-particle correlation function $C_r(\Delta \varphi = \varphi_a - \varphi_b)$:

$$C_r(\Delta \varphi) = \frac{dN}{d\Delta \varphi} \quad \text{and} \quad \nu_n^{ab} = \frac{\sum_{\Delta \varphi} C_r(\Delta \varphi) \cos(n \Delta \varphi)}{\sum_{\Delta \varphi} C_r(\Delta \varphi)}$$

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$$\nu_n^{ab} = \nu_n^a \nu_n^b + \delta_{\text{short}}$$

$n = 1$

$$\nu_1^{ab} = \nu_1^a \nu_1^b + \delta_{\text{long}}$$

Flow

Non-flow

Short – range

CMS PbPb $\sqrt{s_{NN}} = 2.76$ TeV

$L_{int} = 120 \mu b^{-1}$

0-0.2% centrality
Azimuthal anisotropy measurements

Correlation function

Two-particle correlation function \( C_r(\Delta \varphi = \varphi_a - \varphi_b) \),

\[
C_r(\Delta \varphi) = \frac{dN}{d\Delta \varphi} \quad \text{and} \quad v_n^{ab} = \frac{\sum_{\Delta \varphi} C_r(\Delta \varphi) \cos(n \Delta \varphi)}{\sum_{\Delta \varphi} C_r(\Delta \varphi)}
\]

\( n > 1 \)

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Two-particle correlation function $C_r(\Delta \varphi = \varphi_a - \varphi_b)$,

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- $n > 1$
  $$\nu_n^{ab} = \nu_n^a \nu_n^b + \delta_{\text{short}}$$
- $n = 1$
  $$\nu_1^{ab} = \nu_1^a \nu_1^b + \delta_{\text{long}}$$

Flow

Non-flow

Short-range

HBT

Decay

Charge
Azimuthal anisotropy measurements

Correlation function

Two-particle correlation function $C_r(\Delta \varphi = \varphi_a - \varphi_b)$,

$$C_r(\Delta \varphi) = \frac{dN}{d\Delta \varphi} \quad \text{and} \quad v_n^{ab} = \frac{\Sigma_{\Delta \varphi} C_r(\Delta \varphi) \cos(n \Delta \varphi)}{\Sigma_{\Delta \varphi} C_r(\Delta \varphi)}$$

$n > 1$

$v_n^{ab} = v_n^a v_n^b + \delta_{\text{short}}$

$n = 1$

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Flow

Non-flow

Long – range

Short – range

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Two-particle correlation function $C_r(\Delta \varphi = \varphi_a - \varphi_b)$,

$$C_r(\Delta \varphi) = \frac{dN}{d\Delta \varphi}$$ \text{ and } \nu_n^{ab} = \frac{\sum_{\Delta \varphi} C_r(\Delta \varphi) \cos(n \Delta \varphi)}{\sum_{\Delta \varphi} C_r(\Delta \varphi)}$$

$$n > 1$$

$$\nu_n^{ab} = \nu_n^a \nu_n^b + \delta_{\text{short}}$$

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Flow

Non-flow

Long – range

Short – range

Momentum Conservation

HBT

Decay

Charge
Azimuthal anisotropy measurements

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C_r(\Delta \varphi) = \frac{dN}{d\Delta \varphi} \quad \text{and} \quad v_n^{ab} = \frac{\sum_{\Delta \varphi} C_r(\Delta \varphi) \cos(n \Delta \varphi)}{\sum_{\Delta \varphi} C_r(\Delta \varphi)}
\]

- \( n > 1 \)
  \[ v_n^{ab} = v_n^a v_n^b + \delta_{\text{short}} \]
- \( n = 1 \)
  \[ v_1^{ab} = v_1^a v_1^b + \delta_{\text{long}} \]

Flow

Non-flow

Non-flow suppression is needed
Short-range non-flow effect get reduced using $|\Delta \eta| > 0.7$ cut
Long-range non-flow suppression

\[ \nu^a_b = \nu^a_1 \nu^b_1 + \delta_{long} \quad n = 1 \]

\[ \nu^1_{11}(p^a_T, p^b_T) = \nu^e_{1}(p^a_T)\nu^e_{1}(p^b_T) - C \; p^a_T \; p^b_T \]

\[ C \propto \langle \text{Mult} \rangle^{-1} \]
Long-range non-flow suppression

\[ v_{11}^{ab} = v_1^a v_1^b + \delta_{long} \quad n = 1 \]

\[ v_{11}(p_T^a, p_T^b) = v_1^{even}(p_T^a)v_1^{even}(p_T^b) - C \, p_T^a p_T^b \]

\[ v_{11} \text{ in Eq}(1) \text{ represents NxM matrix which we fit with N+1 parameters} \]
Long-range non-flow suppression

\[ v_{1}^{ab} = v_{1}^{a} v_{1}^{b} + \delta_{\text{long}} \quad n = 1 \]

\[ v_{11}(p_{T}^{a}, p_{T}^{b}) = v_{1}^{\text{even}}(p_{T}^{a}) v_{1}^{\text{even}}(p_{T}^{b}) - C \, p_{T}^{a} p_{T}^{b} \]

\( C \propto (\langle \text{Mult} \rangle)^{-1} \)

\( v_{11} \) in Eq(1) represents NxM matrix which we fit with N+1 parameters

\[ \times 10^{-3} \]

- (a) Au+Au
  - 0-5%
  - 200 GeV
  - \( 0.2 < p_{T}^{a} < 0.6 \) (GeV/c)
- (b) 1.0 < \( p_{T}^{a} < 1.4 \) (GeV/c)
- (c) 1.4 < \( p_{T}^{a} < 1.8 \) (GeV/c)
- (d) 1.8 < \( p_{T}^{a} < 2.6 \) (GeV/c)

\[ \chi^2 \]

\[ \text{ndf} \]

\[ \sim 1.1 \]

Good simultaneous fit \( \left( \frac{\chi^2}{\text{ndf}} \sim 1.1 \right) \) obtained with Eq. 1
Long-range non-flow suppression

\[ \nu_{1}^{ab} = \nu_{1}^{a} \nu_{1}^{b} + \delta_{\text{long}} \quad n = 1 \]

\[ \nu_{11}(p_{T}^{a}, p_{T}^{b}) = \nu_{1}^{\text{even}}(p_{T}^{a})\nu_{1}^{\text{even}}(p_{T}^{b}) - c \cdot p_{T}^{a} p_{T}^{b} \]

\[ C \propto (\langle \text{Mult} \rangle)^{-1} \]

\( \nu_{11} \) in Eq(1) represents NxM matrix which we fit with N+1 parameters.

- Good simultaneous fit \( \left( \frac{\chi^{2}}{n_{\text{df}}} \sim 1.1 \right) \) obtained with Eq. 1
- \( \nu_{11} \) characteristic behavior gives a good constraint for \( \nu_{1}^{\text{even}}(p_{T}) \) extraction.
Long-range non-flow suppression

\[ v_{11}(p_T^a, p_T^b) = v_{1}^{even}(p_T^a)v_{1}^{even}(p_T^b) - C p_T^a p_T^b \]

The extracted \( v_{1}^{even}(p_T) \) and the momentum conservation parameter \( C \) at \( \sqrt{s_{NN}} = 200 \)

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

Fit to \( v_{1}^{even}(p_T) \) data shows \( v_{1}^{even}(p_T) \) centrality dependent

The characteristic behavior of \( v_{1}^{even}(p_T) \) shows a weak centrality dependence
Long-range non-flow suppression

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

The extracted $v_1^{\text{even}}(p_T)$ and the momentum conservation parameter $C$ at $\sqrt{s_{NN}} = 200$

- Fit to $v_1^{\text{even}}(p_T)$ data shows $v_1^{\text{even}}(p_T)$ centrality dependent

- The characteristic behavior of $v_1^{\text{even}}(p_T)$ shows a weak centrality dependence

- The momentum conservation parameter $C$ scales as $<\text{Mult}>^{-1}$
Non-flow suppression

- $\eta$ gap between particles in each pair used to suppress the short-range non-flow
Non-flow suppression

- η gap between particles in each pair used to suppress the short-range non-flow
- Simultaneous fit used to suppress long-range non-flow associated with momentum conservation
Non-flow suppression

- Long – range
- Short – range
- Momentum Conservation
- HBT
- Decay
- Di–jets

- $\eta$ gap between particles in each pair used to suppress the short-range non-flow
- Simultaneous fit used to suppress long-range non-flow associated with momentum conservation
- Multi-particle correlations also used to further suppress non-flow
Multi-particle correlations and the non-flow suppression

\[ c_2\{4\} \equiv \langle 4 \rangle - 2\langle 2 \rangle^2 \]

In the subevent method, particles are correlated across all subevents (long-range)

\[ \langle 4 \rangle \equiv \left\langle e^{i\pi(\phi_i + \phi_j - \phi_k - \phi_l)} \right\rangle \]

Short-range non-flow dominate
Multi-particle correlations and the non-flow suppression

\[ c_2\{4\} \equiv \langle 4 \rangle - 2\langle 2 \rangle^2 \]

In the subevent method, particles are correlated across all subevents (long-range).

Three subevent cumulant can further suppress away-side jet contribution

Short-range non-flow dominate

\[ \langle 4 \rangle \equiv \left\langle e^{in(\phi_i + \phi_j - \phi_k - \phi_l)} \right\rangle \]

Long-range non-flow dominate

\[ \langle 4 \rangle \equiv \left\langle e^{in(\phi_i + \phi_j - \phi_k - \phi_l)} \right\rangle \]

arXiv: 1701.03830
Multi-particle correlations and the non-flow suppression

\[ c_2 \{4\} \equiv \langle 4 \rangle - 2 \langle 2 \rangle^2 \]

In the subevent method, particles are correlated across all subevents (long-range)

Three subevent cumulant can further suppress away-side jet contribution

Both \( \langle 4 \rangle \) and \( 2 \langle 2 \rangle^2 \) are much smaller with subevent

Subevent cumulant measures long-range collectivity.

Short-range non-flow dominate

\[ \langle 4 \rangle \equiv \left\{ e^{in(\phi_i+\phi_j-\phi_k-\phi_l)} \right\} \]

Long-range non-flow dominate

\[ \langle 4 \rangle \equiv \left\{ e^{in(\phi_i+\phi_j-\phi_k-\phi_l)} \right\} \]

arXiv: 1701.03830
Results

Au+Au Beam Energy Scan

\[ \nu_n(\eta) \]

\[ \nu_n(\sqrt{s_{NN}}) \]
Pseudorapidity dependence of $v_{n>1}$

The extracted $v_{n>1}(\eta)$ at all BES energies

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

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

$\triangleright v_n(\eta)$ has similar trends for different beam energies.

$\triangleright v_n(\eta)$ decreases with harmonic order n.
Pseudorapidity dependence of $\nu_{n>1}$

The extracted $\nu_{n>1}(\eta)$

- $|\eta| < 1$ and $|\Delta\eta| > 0.7$
- $0.2 < p_T < 4$ GeV/c

$\nu_n(\eta)$ has similar trends for different beam energies.

$\nu_n(\eta)$ decreases with harmonic order $n$. 
Longitudinal decorrelation of $v_2$ in Au+Au 200 GeV

\[ r_n(\eta) = \frac{\langle v_n(-\eta)v^*_n(\eta_{\text{ref}}) \rangle}{\langle v_n(\eta)v^*_n(\eta_{\text{ref}}) \rangle} \]

- $r_n(\eta)$ decrease linearly for different centrality studied
Longitudinal decorrelation of $v_2$ in Au+Au 200 GeV

$$r_n(\eta) = \frac{\langle v_n(-\eta)v_n^*(\eta_{\text{ref}}) \rangle}{\langle v_n(\eta)v_n^*(\eta_{\text{ref}}) \rangle}$$

- $r_n(\eta)$ decrease linearly for different centrality studied

- The decorrelation effect gets stronger as the collision become more peripheral

- More information will be given today by Maowu Nie
Beam-energy dependence of $v_{n>1}$

The extracted $v_{n>1}$ vs $\sqrt{s_{NN}}$ for TPC($|\eta| < 1$) and FTPC($2.5 < |\eta| < 4$)

- At mid and forward rapidity;
  - $v_n(\sqrt{s_{NN}})$ shows a monotonic increase with beam-energy.
  - $v_n(\sqrt{s_{NN}})$ decreases with harmonic order $n$ (viscous effects).
Summary-1

- $\eta$ gap between particles in each pair used to suppress the short-range non-flow
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- The longitudinal decorrelation of $v_2$ was observed for Au+Au at 200 GeV
Summary-1

- $\eta$ gap between particles in each pair used to suppress the short-range non-flow

- Simultaneous fit used to suppress long-range non-flow associated with momentum conservation

- The longitudinal decorrelation of $v_2$ was observed for Au+Au at 200 GeV

- At mid and forward rapidity;
  - $v_n(\sqrt{s_{NN}})$ shows a monotonic increase with beam-energy.
  - $v_n(\sqrt{s_{NN}})$ decreases with harmonic order n (viscous effects).
Collectivity in small systems

$\nu_n(p_T)$

$\nu_n\{2,4\}(N_{ch})$
Collectivity in small systems

- The correlation function $C(\Delta \phi)$ for all systems at one $\langle N_{ch} \rangle$ value
- $c_2\{4\}$ vs $\langle N_{ch} \rangle$ for 4 systems

$C(\Delta \phi)$ shows similar trend for all systems

$c_2\{4\}$ shows negative value for different systems
\( \nu_n \) measurements for different systems are sensitive to system shape (\( \varepsilon_n \)), dimensionless size (\( RT \)) and transport coefficients \( \left( \frac{\eta}{s}, \frac{\zeta}{s}, \ldots \right) \).
Acoustic ansatz

- $\nu_n$ measurements for different systems are sensitive to system shape ($\varepsilon_n$), dimensionless size ($RT$) and transport coefficients ($\frac{\eta}{s}$, $\frac{\zeta}{s}$, ...).

$$\frac{\nu_n}{\varepsilon_n} \propto e^{-A \left( \frac{\eta}{s} \frac{n^2}{RT} \right)}$$

$A$ is a constant
\[ \nu_n/\varepsilon_n \propto e^{-A\left(\frac{n}{s} \frac{n^2}{RT}\right)} \]

S \sim (RT)^3 \sim \langle N_{Ch} \rangle \text{ then } RT \sim \langle N_{Ch} \rangle^{1/3}

\[ \ln \left( \frac{\nu_n}{\varepsilon_n} \right) \propto -A \left( \frac{n}{s} \right) \langle N_{Ch} \rangle^{-1/3} \]

\( A \) is a constant
\( \nu_n \) measurements for different systems are sensitive to system shape (\( \varepsilon_n \)), dimensionless size (\( RT \)) and transport coefficients \( (\frac{\eta}{s}, \frac{\zeta}{s}, \ldots) \).

\[
\frac{\nu_n}{\varepsilon_n} \propto e^{-A \left( \frac{\eta n^2}{RT} \right)}
\]

\( A \) is a constant

\[
S \sim (RT)^3 \sim \langle N_{Ch} \rangle \text{ then } RT \sim \langle N_{Ch} \rangle^{1/3}
\]

\[
\ln \left( \frac{\nu_n}{\varepsilon_n} \right) \propto -A \left( \frac{\eta}{s} \right) \langle N_{Ch} \rangle^{-1/3}
\]

At the same \( \frac{\eta}{s} \) and \( \langle N_{Ch} \rangle^{-1/3} \) driven by

\[
\nu_n \quad \text{driven by} \quad \varepsilon_n + \ldots
\]
\( \nu_n \) measurements for different systems are sensitive to system shape (\( \varepsilon_n \)), dimensionless size (\( RT \)) and transport coefficients (\( \left( \frac{n}{s}, \frac{\zeta}{s}, \ldots \right) \)).

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\]

**Odd Harmonic \( \nu_3 \)**

At the same \( \frac{n}{s} \) and \( \langle N_{Ch} \rangle^{-1/3} \)

\( \nu_n \) driven by \( \varepsilon_n + \ldots \)

\[
\varepsilon_3 \propto \frac{1}{\sqrt{N}}
\]

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**References**

- PRC 84, 034908 (2011) P. Staig and E. Shuryak.
- PRC 88, 044915 (2013) E. Shuryak and I. Zahed
$\nu_n$ measurements for different systems are sensitive to system shape ($\epsilon_n$), dimensionless size ($RT$) and transport coefficients ($\frac{\eta}{s}, \frac{\zeta}{s}, \ldots$).

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\frac{\nu_n}{\epsilon_n} \propto e^{-A \left( \frac{\eta}{s} \frac{n^2}{RT} \right)}
\]

$S \sim (RT)^3 \sim \langle N_{Ch} \rangle$ then $RT \sim \langle N_{Ch} \rangle^{1/3}$

\[
\ln \left( \frac{\nu_n}{\epsilon_n} \right) \propto -A \left( \frac{\eta}{s} \right) \langle N_{Ch} \rangle^{-1/3}
\]

Even Harmonic $\nu_2$

$\epsilon_2$ scaling is needed

At the same $\frac{\eta}{s}$ and $\langle N_{Ch} \rangle^{-1/3}$

$\nu_n$ driven by $\epsilon_n + \ldots$

Odd Harmonic $\nu_3$

$\epsilon_3 \propto \frac{1}{\sqrt{N}}$
- \( \nu_n \) measurements for different systems are sensitive to system shape (\( \varepsilon_n \)), dimensionless size (\( RT \)) and transport coefficients (\( \frac{\eta}{s}, \frac{\zeta}{s}, ... \)).

\[
\frac{\nu_n}{\varepsilon_n} \propto e^{-A\left(\frac{\eta}{s} \frac{n^2}{RT}\right)}
\]

\( A \) is a constant.

- Even Harmonic \( \nu_2 \)
  - \( \varepsilon_2 \) scaling is needed

At the same \( \frac{\eta}{s} \) and \( \langle N_{Ch} \rangle^{-1/3} \)

\( \nu_n \) driven by \( \varepsilon_n + ... \)

- Odd Harmonic \( \nu_3 \)
  - \( \varepsilon_3 \propto \frac{1}{\sqrt{N}} \)

**Expectations**

- \( \nu_{even} \) and \( \nu_3 \) are system independent

- \( \nu_2 \) is system dependent
$v_n$ for large systems ($A + B$)

$v_n$ vs $p_T$ at fixed $\langle N_{Ch} \rangle = 270$

$\ln \left( \frac{v_n}{\varepsilon_n} \right) \propto -A (\eta/s) \langle N_{Ch} \rangle^{-1/3}$

- Odd harmonics are system independent.
- Even harmonics are system dependent, with weak system dependence for the higher harmonics.

$|\eta| < 1$ and $|\Delta\eta| > 0.7$
$v_n$ for large systems ($A + B$)

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

$v_n$ vs $\langle N_{Ch} \rangle$ at fixed $p_T[0.2:4 \text{ GeV/c}]$

\[ \ln \left( \frac{v_n}{\varepsilon_n} \right) \propto -A \left( \frac{\eta}{s} \right) \langle N_{Ch} \rangle^{-1/3} \]

- Odd harmonics are system independent.
- Even harmonics are system dependent, with weak system dependence for the higher harmonics.
\( \nu_n \) for different systems

\[
\ln \left( \frac{\nu_n}{\varepsilon_n} \right) \propto -A \left( \frac{\eta}{s} \right) \langle N_{ch} \rangle^{-1/3}
\]

\( \nu_1^{\text{even}} \) and \( \nu_3 \) vs \( p_T \) at different \( \langle N_{ch} \rangle \) for all systems

\( \nu_1^{\text{even}} \) and \( \nu_3 \) show similar trends and magnitudes for all systems.

\( \nu_1^{\text{even}} \) and \( \nu_3 \) are system independent.
$\nu_n$ for different systems

\[
\ln \left( \frac{\nu_n}{\varepsilon_n} \right) \propto -A \left( \frac{\eta}{s} \right) (N_{ch})^{-1/3}
\]

$\nu_{1}^{even}$ and $\nu_3$ vs $\langle N_{ch} \rangle$ for all systems

$\nu_{1}^{even}$ and $\nu_3$ show similar trends and magnitudes for all systems.

$\nu_{1}^{even}$ and $\nu_3$ are system independent.
\( \nu_n \) for different systems

\[
\ln \left( \frac{\nu_n}{\varepsilon_n} \right) \propto -A \left( \frac{\eta}{s} \right) \langle N_{Ch} \rangle^{-1/3}
\]

\( \nu_2 \) vs \( p_T \) at different \( \langle N_{Ch} \rangle \) for all systems

\( \langle N_{Ch} \rangle = 140 \)

\( \langle N_{Ch} \rangle = 70 \)

\( \langle N_{ch} \rangle \sim 25 \)

\[ \Rightarrow \nu_2 \text{ is system dependent (shape).} \]

\[ \Rightarrow \frac{\nu_2}{\varepsilon_2} (p_T) \text{ for all systems scales to a single curve.} \]
$\nu_n$ for different systems

$$\ln \left( \frac{\nu_n}{\varepsilon_n} \right) \propto -A \frac{\eta/s}{\langle N_{Ch} \rangle}^{-1/3}$$

$\nu_2$ vs $\langle N_{Ch} \rangle$ for all systems

- $\nu_2$ show similar trends but different magnitudes for different systems.
- $\nu_2$ is system dependent (shape).

$|\eta| < 1$ and $|\Delta \eta| > 0.7$
\( \nu_n \) for different systems

\[
\ln \left( \frac{\nu_n}{\varepsilon_n} \right) \propto -A \left( \frac{\eta}{s} \right) \langle N_{ch} \rangle^{-1/3}
\]

\[
\ln \left( \frac{\nu_2}{\varepsilon_2} \right) \text{ vs } \langle N_{ch} \rangle^{-1/3} \text{ for all systems}
\]

\( \frac{\nu_2}{\varepsilon_2} \) for all systems scales to a single curve.

\( \frac{\nu_2}{\varepsilon_2} \) for all systems scales to a single curve.

Similar slopes implies similar viscous coefficient ( \( A \eta/s \) ) for all systems.
Conclusion

Comprehensive set of STAR measurements presented for $\nu_n(\eta, p_T, \langle N_{ch} \rangle)$ for several collision systems/energies.

- Non-flow suppression
  - $\Delta \eta$ cut used to suppress the short range non-flow
  - $c_2\{4\}$ shows negative value for all presented systems.
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- Scaling the system size;
  - The odd harmonics are system independent
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  - $v_2$ is system dependent
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- Scaling the system size;
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  - $v_2$ is system dependent
  - $\frac{v_2}{\varepsilon_2}$ for all systems scaled onto one curve to $\sim 10\%$ in slope
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- **Scaling the system size;**
  - The odd harmonics are system independent
  - $v_2$ is system dependent
  - $v_2/\varepsilon_2$ for all systems scaled onto one curve to $\sim$10% in slope

At the same energy, the scaling features suggest similar viscous coefficient ($A \frac{\eta}{s}$) for different systems.