Measurements of Longitudinal Flow Decorrelation in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV from the STAR Collaboration

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Initial Stages 2017
Origin of the flow decorrelation

- Shape of an overlapping region is driven by eccentricities of Forward-going and Backward-going participants

\[ \varepsilon_n^F e^{i n \Psi_n^F} \quad \rightarrow \quad \varepsilon_n^B e^{i n \Psi_n^B} \]
Origin of the flow decorrelation

- Shape of an overlapping region is driven by eccentricities of Forward-going and Backward-going participants

\[ \varepsilon_n^F e^{i n \Psi_n^F} \neq \varepsilon_n^B e^{i n \Psi_n^B} \]

- Consequence:

\[ V_n(\eta) = v_n(\eta) e^{i n \Psi_n(\eta)} \]

Asymmetry of a flow magnitude  Torque/twist of an event plane

\[ v_n(\eta_1) \neq v_n(\eta_2) \quad \Psi_n(\eta_1) \neq \Psi_n(\eta_2) \]
Method

- Factorization ratio $r_n$ is constructed to measure of the flow decorrelation

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


- $r_n$ measures relative fluctuation between $v_n(-\eta)$ and $v_n(\eta)$

A large $\eta$ gap is required to avoid short-range correlation.
Method

Factorization ratio $r_n$ is constructed to measure of the flow decorrelation

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

$$= \frac{\langle v_n(-\eta)v_n(\eta_{\text{ref}})\cos n(\Psi_n(-\eta) - \Psi_n(\eta_{\text{ref}})) \rangle}{\langle v_n(\eta)v_n(\eta_{\text{ref}})\cos n(\Psi_n(\eta) - \Psi_n(\eta_{\text{ref}})) \rangle}$$

$r_n$ measures relative fluctuation between $v_n(-\eta)$ and $v_n(\eta)$. A large $\eta$ gap is required to avoid short-range correlation.

If no decorrelation

$$\langle v_n(-\eta)v_n(\eta_{\text{ref}}) \rangle = \langle v_n(\eta)v_n(\eta_{\text{ref}}) \rangle$$

$$r_n(\eta) = 1$$

If decorrelation

$$\langle V_n(\eta)V_n^*(\eta_{\text{ref}}) \rangle = \langle v_n(\eta)v_n(\eta_{\text{ref}})\cos n(\Psi_n(\eta) - \Psi_n(\eta_{\text{ref}})) \rangle$$

$$r_n(\eta) \neq 1$$

The current longitudinal dynamics study in the experiment

\[ r_n = 1 - 2F_n \eta \frac{F_n(2.76 \text{ TeV})}{F_n(5.02 \text{ TeV})} \]

- Evidence of flow decorrelation has been observed at LHC.
- From 5.02 TeV to 2.76 TeV, stronger decorrelation is observed.

\approx 10\% / 16\% higher for v2/ v3
The current longitudinal dynamics study in the experiment

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- Evidence of flow decorrelation has been observed at LHC.
- From 5.02 TeV to 2.76 TeV, stronger decorrelation is observed.
  
  \(~10\% / 16\%\) higher for \(v_2/ v_3\)

- How about the flow decorrelation at the RHIC energy?
The STAR detector

**Forward Meson Spectrometer (FMS)**

TPC acceptance $-1 < \eta < 1$

FMS acceptance $2.5 < \eta < 4$
Performance of the FMS detector

The maximum event plane resolution from FMS can reach 50% (15%) for $v_2$($v_3$).

Both $v_2$ and $v_3$ are consistent with the published results from 200 GeV Au+Au collisions.

FMS can be used as an event-plane detector.
Longitudinal decorrelation of $v_2$ in Au+Au

- Decorrelation of $v_2(\eta)$

$$r_2(\eta) = \frac{\langle V_2(-\eta)V_2^*(\eta_{\text{ref}}) \rangle}{\langle V_2(\eta)V_2^*(\eta_{\text{ref}}) \rangle}$$

- $r_2(\eta)$ decreases linearly for different centralities.

- Stronger decorrelation effect in more peripheral collisions.
Longitudinal decorrelation of $v_3$ in Au+Au

Decorrelation of $v_3(\eta)$

$$r_3(\eta) = \frac{\langle V_3(-\eta) V_3^*(\eta_{\text{ref}}) \rangle}{\langle V_3(\eta) V_3^*(\eta_{\text{ref}}) \rangle}$$

$r_3(\eta)$ roughly linear decreasing along with $\eta$.

$v_3$ shows relatively stronger decorrelation than $v_2$. 
Centrality dependence of \( r_n \)

- \( r_n \) is parameterized with a linear function

\[
  r_n = 1 - 2F_n \eta
\]

- Slope parameter \( F_n \) is extracted to quantify the decorrelation effect.
- For \( v_2 \), from mid-central to peripheral, the decorrelation effect gets stronger.
\( \eta_{\text{ref}} \) dependence of \( r_n \)

- \( r_n \) for different \( \eta_{\text{ref}} \) range

check for short-range correlation

\[ r_2(\eta) \]

\( \eta \)

Au+Au 200 GeV 30-40%

- \( \eta \)
- TPC
- FMS

\(-\eta\)

- All \( 2.5 < \eta_{\text{ref}} < 4 \)
- Inner \( 3 < \eta_{\text{ref}} < 4 \)
- Outer \( 2.5 < \eta_{\text{ref}} < 3.4 \)

\( N_{\text{ch}}^{\text{sel}} \) \( 0.8 \text{GeV} < p_T < 4 \text{GeV} \)

\( r_2(\eta) \)

\( \eta \)

40-50%

\( \eta \) is consistent for different \( \eta_{\text{ref}} \)

- Large \( \Delta \eta \) suppress short-range correlation (SRC).
$\eta_{\text{ref}}$ dependence of $r_n$

$r_n$ for different $\eta_{\text{ref}}$ range

check for short-range correlation

$r_2$ is consistent for different $\eta_{\text{ref}}$

$r_3$ is consistent for different $\eta_{\text{ref}}$

- Large $\Delta \eta$ suppress short-range correlation (SRC).
- SRC is significantly suppressed.
- For longitudinal correlations, $r_n$ shows weak $\eta_{\text{ref}}$ dependence.
$p_T$ dependence of $r_n$

$r_n$ for different $p_T$ range

$r_2(\eta)$

$r_2$ shows weak $p_T$ dependence

- For longitudinal correlations, $r_n$ almost independent of $p_T$ within error.
$p_T$ dependence of $r_n$

$r_n$ for different $p_T$ range

$r_2(\eta)$

$r_3(\eta)$

$r_2$ shows weak $p_T$ dependence

$r_3$ shows weak $p_T$ dependence

- For longitudinal correlations, $r_n$ almost independent of $p_T$ within error.
- The independence of $p_T$ Indicates of an initial-state effect.
Comparison to the LHC results

- Decorrelation of $v_2(\eta)$
Comparison to the LHC results

✧ Decorrelation of $v_2(\eta)$

A clear energy dependence is observed.

5.02 TeV $\xrightarrow{\text{LL}}$ 2.76 TeV $\xrightarrow{\text{LL}}$ 200 GeV, decorrelation for $v_2$ gets stronger.
Comparison to the LHC results

- Decorrelation of $v_2(\eta)$

$$r_n = 1 - 2F_n \eta$$

<table>
<thead>
<tr>
<th>Cent</th>
<th>$F_2(Au + Au \ 200 GeV)$</th>
<th>$F_2(Pb + Pb \ 2.76 TeV)$</th>
<th>$F_2(Au+Au)$/$F_2(Pb+Pb)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-30%</td>
<td>0.013 ±0.00027</td>
<td>0.014 ±0.00035</td>
<td>0.017 ±0.000575</td>
</tr>
<tr>
<td>30-40%</td>
<td>0.0061 ±0.0002</td>
<td>0.0071 ±0.0002</td>
<td>0.0090 ±0.0002</td>
</tr>
<tr>
<td>40-50%</td>
<td>2.2 ±0.084</td>
<td>1.9 ±0.073</td>
<td>1.9 ±0.076</td>
</tr>
</tbody>
</table>

- A clear energy dependence is observed.
- $5.02\text{TeV} \rightarrow 2.76\text{TeV} \rightarrow 200\text{GeV}$, decorrelation for $v_2$ gets stronger.
- ~2 times stronger decorrelation effect than at the LHC energy 2.76 TeV.
Comparison to the LHC results

Decorrelation of $v_3(\eta)$

$r_3$ show similar energy dependence.

5.02 TeV $\rightarrow$ 2.76 TeV $\rightarrow$ 200 GeV, decorrelation gets stronger.
After the rapidity normalization, energy dependence is still observed.

Model calculation can roughly describe the LHC energy, but overestimate the decorrelation effect at RHIC.
At LHC energies, decorrelation of $v_3(\eta)$ is observed.

- Model calculations roughly describe the LHC energy, but overestimate the decorrelation.
- A test for the model to describe both the LHC and RHIC data.
Summary

- The first direct measurement of longitudinal flow decorrelation at RHIC.
- Longitudinal correlation of anisotropy flow:
  - For $v_2$, centrality dependence is observed.
  - Longitudinal flow decorrelation reflects global property of the event.
- Compared to LHC, ~2 times stronger decorrelation effect at RHIC energy.
- The results will help to constrain the initial state of the models.
Backup
Systematics

Default

FMS All

All $2.5 < \eta_{\text{ref}} < 4$
Inner $3 < \eta_{\text{ref}} < 4$
Outer $2.5 < \eta_{\text{ref}} < 3.4$

Quantify the systematics:

\[ r_n(\eta)_{\text{change}} - r_n(\eta)_{\text{default}} \]

\[ \frac{r_n(\eta)_{\text{change}} - r_n(\eta)_{\text{default}}}{r_n(\eta)_{\text{default}}} \]