Probing Anisotropic and Radial Flow with Di-hadron Correlations in the BES

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In 2010 and 2011 RHIC completed phase I of the BES program with data sets at 7.7, 11.5, 19.6, 27 and 39 GeV, and in 2014, 14.5 GeV.

Goals of the BES program:

- Determine the energy at which key QGP signatures turn off.
- Search for the critical point.
- Search for the first order phase transition.

The QCD phase diagram
Di-hadron correlations from RHIC and LHC

Di-hadron correlations are a key observable in probing the collectivity of the system. How does the collectivity evolve in the BES?


CMS pPb $\sqrt{s_{NN}} = 5.02$ TeV, $N_{trk}^{\text{offline}} \geq 110$

Anisotropic flow

Long range correlations (i.e. the ridge) are dominated by the anisotropic flow. So the following analysis will mostly concentrate on long range correlations \((1 < |\Delta \eta| < 2)\) in an anisotropic flow study.

\[
\frac{dN}{d\Delta \phi} \propto 1 + 2 \sum_{n=1}^{\infty} v_n^2 \cos(n\Delta \phi)
\]

\(C(\Delta \phi)\) for particle pairs at \(|\Delta \eta| > 0.8\). The Fourier harmonics for \(V_{1\Delta}\) to \(V_{5\Delta}\) are superimposed in color. (arXiv:1109.2501v1)
Radial flow

Short range correlations (i.e., the near-side peak) will be influenced by radial flow. Pairs produced via charge conservation will be narrowed by radial flow.

A schematic view of the charge balancing mechanism, producing pairs of particles with opposite charges. The rectangles indicate fluid elements moving outward with a collective velocity u. The dot indicates the space-time location of the emission of the pair of opposite-charge particles of momenta \( p_1 \) and \( p_2 \). The dashed line represents a neutral resonance, decaying into a pair particles (Phys. Rev. Lett. 109, 062301 (2012))
Data sets and event/track selections

Au+Au collisions by center of mass energy $\sqrt{s_{NN}} = 7.7 \sim 39$ GeV

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>pvz cut (cm)</th>
<th>Number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7</td>
<td>±70</td>
<td>4.7M</td>
</tr>
<tr>
<td>11.5</td>
<td>±50</td>
<td>12M</td>
</tr>
<tr>
<td>19.6</td>
<td>±40</td>
<td>21M</td>
</tr>
<tr>
<td>27</td>
<td>±40</td>
<td>38M</td>
</tr>
<tr>
<td>39</td>
<td>±40</td>
<td>117M</td>
</tr>
</tbody>
</table>

-track cuts:

- $|\eta| < 1.0$
- $0.2 < p_T < 2\text{GeV/c}$
- number of TPC hits > 15
- fitted hits/Maximum possible hits > 0.52
- DCA < 2cm
Pair loss corrections for the correlation function

In STAR BES energies, track crossing is the dominant factor for pair loss.

For example, in the positive B field, the two tracks may cross if:

++: \( \Delta \phi \Delta p_T < 0 \)

--: \( \Delta \phi \Delta p_T > 0 \)

+-: \( \Delta \phi > 0 \)

-+: \( \Delta \phi < 0 \)

reversely in negative B field.
Correlation function

Mixed events are used to determine the uncorrelated yield and to correct for non-uniform acceptance.
The correlation function we extract is:

$$C(\Delta \phi, \Delta \eta) = \frac{N_{\text{mixed}}}{N_{\text{same}}} \times \frac{N_{\text{same}}(\Delta \phi, \Delta \eta)}{N_{\text{mixed}}(\Delta \phi, \Delta \eta)}$$

two-particle Fourier coefficients:

$$v_n\{2\}^2 = \sum_i C_i \cos(n\Delta \phi_i) / \sum_i C_i$$
Di-hadron correlations in BES energies

AuAu 7.7 GeV, 0~5%

STAR preliminary

AuAu 11.5 GeV, 0~5%

AuAu 19.6 GeV, 0~5%

AuAu 27 GeV, 0~5%
Centrality evolution of di-hadron correlations

Take AuAu $\sqrt{s_{NN}} = 19.6$ GeV as an example to illustrate the centrality evolution of the di-hadron correlations:

0~5%

5~10%

20~30%

50~60%

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$\nu_n \{2\}^2$ vs energy

**Au+Au 0-5%**

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**Au+Au 20-30%**

STAR Preliminary
\[ \frac{v_n\{2\}^2}{v_2\{2\}^2} \text{ vs energy} \]

As higher harmonics are damped more by finite viscosities, the ratios have an inverse relationship to viscosity. (D. Teaney, L. Yan, Phys. Rev. C 83 (2011) 064904, G. Y. Qin, H. Petersen, S. A. Bass, B. Muller, Phys. Rev. C82, 064903 (2010))
Charge-dependent correlations

By subtracting like-sign correlations from unlike-sign correlations \(C(+-, -+) - C(++, --)\), contributions from anisotropic flow are eliminated, isolating the radial flow.

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Fit to the projection in $\Delta \phi$

We fit those data points with Gaussian functions $A e^{-\frac{1}{2} \left( \frac{x - \mu}{\sigma} \right)^2} + B$ in the $|\Delta \phi| > 0.3$ region excluding $e^+e^-$ pairs. (B. Abelev et al (STAR Collaboration), arXiv:0806.0513)
\( \sigma \) decreases with energy, which implies increasing radial flow.
Summary

- Di-hadron correlations evolve with energy in the BES region.
- Ridge $v_n$ coefficients generally increase with energy.
- US-LS near-side peak narrows with increasing energy.