$\Delta \eta$ dependence of net-charge fluctuations in Au+Au collisions from the Beam Energy Scan at the STAR experiment

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Introduction

Beam Energy Scan (BES1)  
2010-2014

Varying the center of mass energy $\sqrt{s_{NN}} = 7.7, 11.5, 14.5, 19.6, 39, 27, 62.4,$ and 200 GeV in Au+Au collision

QCD phase diagram

(small $\mu_B$ value at higher beam energy)

Main goal
- Exploring the QCD phase diagram
- Searching for critical point
Event by Event fluctuation

Event by Event fluctuation is a powerful tool to explore the QCD phase diagram and searching critical point.

\[ N : \text{net charge} \cdots \quad N_+ - N_- \]

r-th non-central moment is defined by

\[ \mu'_r = \langle N^r \rangle \]

n-th order cumulant is written as

\[ c_n = \mu'_n - \sum_{m=1}^{n-1} \binom{n-1}{m-1} c_m \mu'_{n-m} \]

\[ M = c_1, \quad \sigma^2 = c_2 \]

\[ S = \frac{C_3}{(C_2)^{3/2}}, \quad \kappa = \frac{C_4}{(C_2)^2} \]

Cumulant ratios (Independent of volume)

\[ \frac{\sigma^2}{M} = \frac{C_2}{C_1} \quad S\sigma = \frac{C_3}{C_2} \quad \kappa\sigma^2 = \frac{C_4}{C_2} \]
Motivation 1

$$D = 4 \frac{\langle \delta Q^2 \rangle}{\langle N_{ch} \rangle}$$

$$Q = N^+ - N^-$$

$$N_{ch} = N^+ + N^-$$

Theoretically

QGP fluctuation: $D = 1-1.5$

Hadron fluctuation: $D = 3-4$

- $D$-measure decreases with $\Delta \eta$.
- $D$-measure decreases when going from peripheral to central.

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Motivation

- Interesting results of D-measure as a function of $\Delta \eta$ were measured by ALICE at 2.76 TeV.
  - We measured $\Delta \eta$ dependence of D-measure at RHIC BES energies (from 7.7 to 200 GeV).
- $\Delta \eta$ dependence of 3rd and 4th order fluctuation have’t been measured yet.
  - We measured $\Delta \eta$ dependence of $S \sigma (c_3/c_2)$ and $\kappa \sigma^2 (c_4/c_2)$.

Earlier studies

<table>
<thead>
<tr>
<th></th>
<th>$\Delta \eta$ (corrected for charge conservation)</th>
<th>Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALICE (2.76 TeV)</td>
<td>$\Delta \eta = 0$ to $1.6$</td>
<td>2nd (D-measure)</td>
</tr>
<tr>
<td>STAR (7.7 to 200 GeV)</td>
<td>fixed $\Delta \eta = 1$</td>
<td>up to 4th</td>
</tr>
</tbody>
</table>

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Baryon-to-Meson Ratios

Significant enhancement in baryon-to-meson ratio has been observed in central heavy-ion collisions compared to peripheral heavy-ion collisions in the intermediate rapidity region. The enhancement is particularly pronounced for baryons such as \( \Lambda \) and \( \Sigma \). The enhancement factor is estimated to be around \( 6.35\% \) for \( \Lambda \) and \( 4.00\% \) for \( \Sigma \) relative to \( D^0 \). The enhancement is observed for transverse momenta \( p_T \) up to \( 2.25 \) GeV/c.

The enhancement is measured using topological cuts optimized by the Toolkit for Multivariate Data Analysis (TMVA). The invariant yield of baryons and mesons is corrected for the acceptance of the STAR detector, which includes contributions from the Hijing model. The corrected yield is expressed as:

\[
\frac{dN}{dy} = \frac{1}{N} \sum_{i} \frac{1}{dt_{ij}} \left( \frac{1}{dN_{ij}} + \frac{1}{dP_{ij}} \right)
\]

The STAR Collaboration has also studied the slanting two-particle correlations and found that the enhancement is consistent with the predictions of the coalescence model. The coalescence model calculates the correlation function as a function of rapidity and transverse momentum, and the observed enhancement is in good agreement with the model predictions.

The STAR Collaboration is continuing to study the enhancement in baryon-to-meson ratios in heavy-ion collisions using a variety of kinematic windows. The results will be reported at the upcoming conference.

Using different kinematic window to avoid auto-correlation.
Data set

RHIC STAR experiment, Beam Energy Scan, Au+Au

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>Event</th>
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</thead>
<tbody>
<tr>
<td>7.7</td>
<td>1.5M</td>
</tr>
<tr>
<td>11.5</td>
<td>2.5M</td>
</tr>
<tr>
<td>14.5</td>
<td>12M</td>
</tr>
<tr>
<td>19.6</td>
<td>15M</td>
</tr>
<tr>
<td>27</td>
<td>28M</td>
</tr>
<tr>
<td>39</td>
<td>74M</td>
</tr>
<tr>
<td>62</td>
<td>46M</td>
</tr>
<tr>
<td>200</td>
<td>87M</td>
</tr>
</tbody>
</table>

Corrections

- Centrality Bin Width Correction
- Efficiency Correction
- Charge conservation correction (D-measure only)

Error estimation

- **Statistical errors**
  Estimated by Bootstrap method (100 times)

- **Systematic errors**
  Estimated by varying DCA cut, nHitsFit, nHitsDedx cuts and tracking efficiency from -5% to +5%.
$\Delta \eta$ dependence of D-measure

- D-measure is closest to the baseline at $\sqrt{s_{NN}}=7.7$ GeV.
- The deviation gets larger at large $\Delta \eta$ and $\sqrt{s_{NN}}$

Consistent with ALICE results

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Δη dependence of Sσ

- **Sσ** (c3/c2)
  - Increase with Δη from poisson baseline for all energies.
  - (without 200GeV central collisions)

Published data
(Δη=1, shifted to x-axis +0.1, using average efficiency)

Poisson baseline


Δη

$\Delta \eta$ dependence of $\kappa \sigma^2$

- $\kappa \sigma^2 (c_4/c_2)$
  - $\Delta \eta=1$, shifted to x-axis +0.1, using average efficiency

- Consistent with Poisson baseline in most of energies, but deviations more than 2$\sigma$ from the poisson baseline are seen at 7.7 and 27GeV.

Published data

- 70-80%
- 40-50%
- 20-30%
- 0-5%

Published data

Summary

- $\Delta \eta$ dependence of net-charge fluctuations (from 1st to 4th order) are measured in Au+Au collisions at BES energies.
- D-measure decreases at large $\Delta \eta$ and $\sqrt{s_{NN}}$ which is similar to ALICE observation in Pb-Pb collisions at 2.76TeV.
- $S \sigma$ increase with $\Delta \eta$ from Poisson baseline in all energies.
  (without 200GeV central collisions)
- $\kappa \sigma^2$ is consistent with Poisson baseline in most of the energies, but deviations more than $2\sigma$ from the Poisson baseline are seen at 7.7 and 27GeV.

Outlook

- $p_T$ and particle species dependent efficiency corrections.
back up
Correction method

Charge conservation correction have done in order to the charge charge conservation and system size effects.

\[ D \rightarrow D + 4 \frac{\langle N_{\text{ch}} \rangle}{\langle N_{\text{total}} \rangle} \]

Charged multiplicity in measured acceptance

Total charged multiplicity in all acceptance

If this correction is applied, D-measure become large.
Data set

RHIC STAR experiment, Beam Energy Scan
Au+Au 7.7, 11.5, 14.5 19.6, 27, 39.5, 62, 200GeV

Event selection

<table>
<thead>
<tr>
<th></th>
<th>Vz</th>
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<th>Vr</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;30</td>
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<td>&lt;2</td>
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<tr>
<td>VpdVz-Vz</td>
<td></td>
<td>&lt;4 (39-200GeV only)</td>
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</tbody>
</table>

Pile up event cut

Tof matched>0.46*(Refmult)-10
Track cut

- $p_T$: 0.2 to 2 (GeV)
- $\eta$: -0.5 to 0.5
- nFitPoints: $>20$
- DCA: $<1\text{cm}$
- Track Quality Cut: $>0.52$
- nhitsdedx: $>10$
- spallation proton cut: nSigmaProton $< 2$

Centrality

- $|\eta|$: 0.5 to 1
- z-vertex correction: done
- DCA: $<3\text{cm}$
- nFitPoint: $>10$