Higher moments measurement of net-Kaon, net-charge and net-proton multiplicity distribution at STAR

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Outline

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  - Net-charge
  - Net-proton

❖ Summary
Motivation
QCD phase diagram, critical point, BES

• Smooth crossover at $\mu_B \sim 0$.
  

• 1st order transition at large $\mu_B$ is expected.
  

• End point of the 1st order transition line
  
  ➢ Critical Point (CP)
  

STAR Note 0598

RHIC BES program in STAR

Varying $\sqrt{s_{\text{NN}}} \implies$ vary $T$ and $\mu_B$

QCD phase diagram can be mapped

The Beam Energy Scan (BES) program was carried out in the years 2010 & 2011.
It extended $\mu_B$ range from 20 MeV to 400 MeV.
Higher Moments

Relation with the correlation length

**Definition:**
- **N:** Event by Event Multiplicity Distribution
  - **Mean:** $M = \langle N \rangle$
  - **St. Deviation:** $\sigma = \sqrt{\langle (N - \langle N \rangle)^2 \rangle}$
  - **Skewness:** $s = \frac{\langle (N - \langle N \rangle)^3 \rangle}{\sigma^3}$
  - **Kurtosis:** $\kappa = \frac{\langle (N - \langle N \rangle)^4 \rangle}{\sigma^4}$

**Non-linear sigma model (NLSM):**
- A strong dependence of experimentally measured moments on the correlation length ($\xi$)

- $\sigma^2 \sim \xi^2$, $S \sim \xi^{4.5}$, $k \sim \xi^7$


**NLSM**
- Near the critical point $\xi$ diverges.
- Higher order moments of multiplicity distribution
- Susceptibilities calculated on the lattice.
- Experimental observable for critical point
- Non-monotonic variation of moments with center of mass energy

**For Gaussian distribution, the skewness and kurtosis are equal to zero. Ideal probe of the non-Gaussian fluctuations near the QCD Critical Point.**

**Source:** Wikipedia

QM 2014, Darmstadt

Amal Sarkar
Experimental setup

The STAR detector

STAR detector has full $2\pi$ coverage and uniform acceptance at mid-rapidity.


<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>Year</th>
<th>Events (10^7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7</td>
<td>2010</td>
<td>5</td>
</tr>
<tr>
<td>11.5</td>
<td>2010</td>
<td>12</td>
</tr>
<tr>
<td>19.6</td>
<td>2011</td>
<td>36</td>
</tr>
<tr>
<td>27</td>
<td>2011</td>
<td>70</td>
</tr>
<tr>
<td>39</td>
<td>2010</td>
<td>130</td>
</tr>
<tr>
<td>62.4</td>
<td>2010</td>
<td>67</td>
</tr>
<tr>
<td>200</td>
<td>2010</td>
<td>340</td>
</tr>
</tbody>
</table>
Data analysis

Particle identification and centrality selection

Particle Identification

<table>
<thead>
<tr>
<th>net-charge</th>
<th>net-proton</th>
<th>net-Kaon</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.2 &lt; p_T \text{ (GeV/c)} &lt; 2.0$ \quad $</td>
<td>\eta</td>
<td>\leq 0.5$</td>
</tr>
</tbody>
</table>

Centrality Selection

The centrality selection utilized the uncorrected charged particle multiplicity measured by the TPC within the pseudo rapidity $0.5 < |\eta| < 1.0$ for net-charge & net-Kaon. Pion and Kaons in $|\eta| < 1$ for net-proton.
Results Net-Kaon

Event by event net-Kaon

Moments of net-Kaon distribution
Lines are CLT expected

Delta Theorem has been used for error estimation X. Luo, J. Phys. G 39, 025008 (2012)

These results are not efficiency corrected.
Results Net-Kaon

So value is greater than Poisson baseline for beam energy below 200 GeV.

So increase with decreasing collision energies.

$\kappa^2$ is fairly constant with centrality

These results are not efficiency corrected.

The systematic error study and efficiency correction is ongoing for this analysis.

“Baseline for the energy dependence of higher moments of net-proton multiplicity distribution”
Dr. Xiaofeng Luo
Results

These results are not efficiency corrected.

The systematic error study and efficiency correction is ongoing for this analysis.
Results

Weak centrality dependence is observed for both $S\sigma$ and $\kappa\sigma^2$ at all energies. All net-charge results are corrected for detector efficiency.

Submitted to PRL
arXiv.1402.1558
Results Net-charge

We observe that the $\sigma^2/M$ values increase monotonically with increasing beam energy.

The $S\sigma$ values increase with decreasing beam energy. These values deviate from Poisson baseline, but are close to NBD baseline.

The values of $\kappa\sigma^2$ are observed to be within the two baseline distributions.

Lattice and HRG analysis of STAR net-charge data for central collisions give a freeze out temperature in the range 135-151 MeV and for $\mu_B$ values in the range 326-23 MeV for center of mass energy 7.7-200 GeV.

S. Borsanyi et al., arXiv:1403.4576 [hep-lat]
P. Alba et al., arXiv:1403.4903 [hep-ph]
A. Bazavov et al., PRL 109, 192302 (2012)

All net-charge results are corrected for detector efficiency.
The results from independent production are found to be in good agreement with the data.

All net-proton results are corrected for detector efficiency.
Results

The significance of deviations of 0%-5% Au + Au data from Skellam expectations, are found to be greatest for 19.6 and 27 GeV, with values of 3.2σ and 3.4σ for $\kappa\sigma^2$ and 4.5σ and 5.6σ for $S\sigma$, respectively.

For the top 0-5% central collisions $k\sigma^2$ show some deviation from Skellam expectation below 39 GeV.

All net-proton results are corrected for detector efficiency.

Summary

1. The higher moments of net-charge ($\Delta N_{\text{ch}}$), net-Kaon ($\Delta N_{\text{K}}$) and net-proton ($\Delta N_{\text{p}}$) distribution studied for BES energies.

2. Within the uncertainty no non-monotonic behavior has been observed in the product of moments of Net-charge ($\Delta N_{\text{ch}}$) distribution as a function of collision energy.

3. The systematic errors study and efficiency correction are going on in net-Kaon ($\Delta N_{\text{K}}$) analysis.

4. Significant deviations of moment products from Skellam expectations, are found in net-proton analysis. The deviation are found to be greatest for 19.6 and 27 GeV.

5. Lattice and HRG analysis of STAR net-charge and net-proton data for central collisions give a freeze out temperature in the range 135-151 MeV and $\mu_B$ values in the range 326-23 MeV for center of mass energy 7.7-200 GeV
Looking forward for the BES-II program.

Thank you ...
Back up

Skellam distribution \( f(k; \mu_1, \mu_2) = e^{-(\mu_1+\mu_2)} \left( \frac{\mu_1}{\mu_2} \right)^{k/2} I_{|k|}(2\sqrt{\mu_1\mu_2}) \)

The Poisson baseline has been calculated from the mean value of the \( N_K^+ (\mu_1) \) and \( N_K^- (\mu_2) \) distribution.

Mean \((M) = \mu_1 - \mu_2 \)

Variance \((\sigma^2) = \mu_1 + \mu_2 \)

Skewness \((S) = (\mu_1 - \mu_2)/(\mu_1 + \mu_2)^{3/2} \)

and \( \kappa = 1/(\mu_1 + \mu_2) \)

And the volume independent moment products,

\[ S\sigma = (\mu_1 - \mu_2)/(\mu_1 + \mu_2) \]

and \( \kappa \sigma^2 = 1 \)
Results: Net-charge

Net-charge distribution

The mean of net-charge ($\Delta N_{ch}$) distribution shifts towards zero from low to high energies.
Results

Net-charge

The four moments (M, σ, S, and k) which describe the shape of the ΔN_{charge} distributions at various collision energies are plotted as a function of average number of participants < N_{part} >. The results are corrected for the finite centrality bin width effects. X. Luo [STAR Collaboration], J. Phys. Conf. Ser.316, 445 012003 (2011).

Moments fitted with it’s predicted dependence function from Central Limit Theorem (CLT), goes as it’s volume’s x, √x, 1/√x and 1/x respectively (the dotted lines).

The moments follow the CLT well.

All net-charge results are corrected for detector efficiency.

Sangaline at WWND’13

Submitted to PRL

arXiv1402.1558
Results: Net-Proton

The mean of net-Proton ($\Delta N_p$) distribution shifts towards zero from low to high energies.

Results Net-proton

The four cumulants which describe the shape of the $\Delta N_p$ distributions at various collision energies are plotted as a function of average number of participants $< N_{\text{part}} >$. The results are corrected for the finite centrality bin width effects. X. Luo [STAR Collaboration], J. Phys. Conf. Ser.316, 445 012003 (2011).

The cumulants fitted with linear function, (the dotted lines). The cumulants follow linear dependency with average number of participants.

All net-Proton results are corrected for detector efficiency.


QM 2014, Darmstadt
Net-Kaons as a proxy for Net-Strangeness in Higher moments calculation

Experimentally, event-by-event net strangeness is very difficult to calculate.

We study: Higher moments of net-Strangeness and net-kaon (From UrQMD model)

*\[ |\eta| < 0.5, \; 0.2 < p_T < 1.6 \]

*\[ \langle N_{part} \rangle \]

*\[ \kappa \]

Good agreements with higher moments of net-Strangeness and Net-Kaon
Net-Kaons as a proxy for Net-Strangeness in Higher moments calculation

The volume independent moment product $k_{\sigma^2}$ of net-Strangeness and net-Kaon are also in good agreement with in the statistical uncertainty.

Net-Kaon As a proxy of net-strangeness.