Probing the QCD Critical Point by Higher Moments of Net-Charge Distribution

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Abstract

The Beam Energy Scan program has been undertaken at the Relativistic Heavy Ion Collider (RHIC) to search for the QCD critical point. The presence of the critical point is expected to lead to non-monotonic behavior of several quantities. Here we report the result of higher moments of net-charge distributions for Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV as measured by the STAR experiment. The STAR results are compared with results from HIJING event generator and Hadron Resonance (HRG) Models.

1. Introduction

Lattice calculations[1] have predicted the presence of a critical point in the phase boundary of hadronic matter with Quark-Gluon Plasma (QGP). The critical point is the end point of the first order phase transition. To map the QCD phase diagram and to locate the critical point, the Beam Energy Scan program has started in the year 2010 at the Relativistic Heavy-Ion Collider at Brookhaven National Laboratory. The program aims to scan the beam energy from $\sqrt{s_{NN}} = 5$ GeV to 200 GeV corresponding to baryon chemical potentials up to as high as 550 MeV and down to 14 MeV[2]. The characteristic signature for the CP is the divergence of the susceptibilities of conserved quantities like net-charge, net-baryon, net-strangeness[4] and the correlation length(ξ)[1,3]. These quantities are related to the higher moments of the event-by-event distribution of the above conserved quantities. The variance, skewness and kurtosis are related to ξ^2, $\xi^{4.5}$ and ξ^7[3] respectively. The ratio of the fourth to the second order susceptibilities are related to the product of the kurtosis and variance($K\sigma^2$). It is expected that these higher moments will be non-monotonic, at the CP, as a function of an experimentally varied parameter such as the beam energy[5].

We present the preliminary results of higher moments and their product of net-charge distribution from Au+Au collision at 39 GeV and 200 GeV measured by the STAR experiment at the RHIC.

2. Analysis Details and Results

The STAR experiment provides the excellent particle identification and large acceptance for event-by-event fluctuation analysis. The Time Projection Chamber(TPC) is the main tracking device. It is used to identify the charge particles within full azimuthal and ± 1.8 unit of pseudo-rapidity(η). The event-by-event net-charge is measured at $\sqrt{s_{NN}} = 39$ GeV for Au +Au collisions occurring within 30 cm of the TPC center along the beam line. For this analysis, nearly 6×10^6 minimum bias events are used. The charged particles between the range $0.15 < p_T < 1.0$ GeV/c are measured at $|\eta| < 0.5$ region. Standard STAR track quality cuts are used for this analysis. For the electron and positron identification in same p_T range, which is a source of the background for the analysis, Time Of Flight(TOF) detector is used. For the centrality selection, uncorrected charged particles multiplicity measured within $|\eta| < 0.5$ from the TPC is utilized . To get the average number of participant ($< N_{part} >$) for each centrality, Glauber model calculation is done.
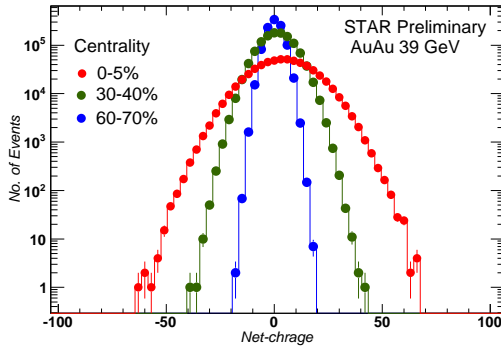

Fig. 1. Net-charge distribution for Au+Au collision at $\sqrt{s_{NN}} = 39$ GeV for 0-5%, 30-40% and 60-70% centrality .

Figure 1 shows the net-charge distribution for centrality 0-5%, 30-40% and 60-70%. The net-charge distributions are symmetric around the mean value for different centralities (small skewness values as seen in Fig. 2). The HIJING event generator is used for model comparison with data in same η and p_T region. To understand the leptonic contribution to the higher moments of net-charge distribution, both the model and the data based approaches (utilizing the TOF detector) are made. Both these studies show their contribution is negligible.

The mean, standard deviation, skewness and kurtosis of Au+Au collisions at 39 GeV are plotted as a function of $< N_{part} >$ representing different centrality in Fig. 2. These moments are fitted with the expected form of the central limit theorem(CLT) to understand the volume dependence of the higher moments[6]. Both the mean and standard deviation increase with $< N_{part} >$, where the mean shows linear dependence. The error bars include both statistical errors and systematic errors due to the range of multiplicity within each centrality bin. Reduction of the centrality bin width effect and the other systematics studies are in progress. In more central collisions, the kurtosis shows a deviation from the CLT that need more study to understand this effect.

To eliminate the volume dependence in moments, the product of the kurtosis and variance ($K\sigma^2$) and that of the skewness and standard deviation ($S\sigma$) are used. $K\sigma^2$ and $S\sigma$ are plotted versus $< N_{part} >$ in Fig. 3 for Au+Au collisions at 39 GeV and 200 GeV. Here Au+Au 200 GeV results are taken from [7]. The results from the Hadron Resonance Gas(HRG) model[8] are consistent with the data within the errors. The results
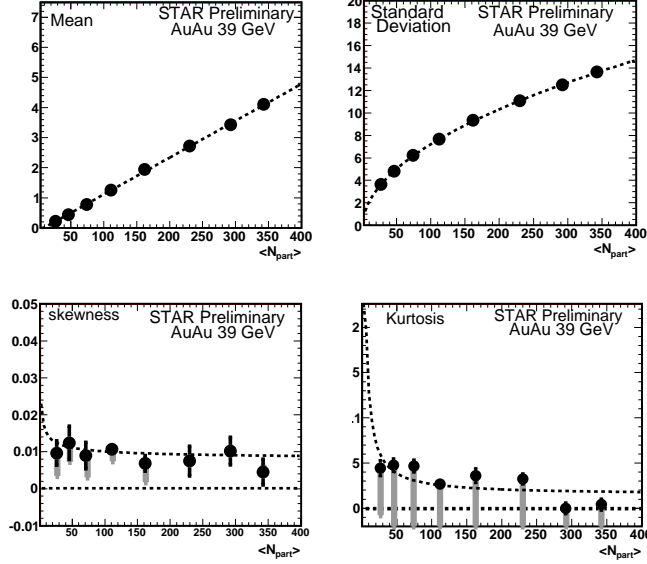

Fig. 2. The mean(top left), standard deviation(top right), skewness(bottom left) and kurtosis(bottom right) are plotted versus $< N_{part} >$. The dotted lines are the expected values from the central limit theorem. The error bars are statistical and the grey lines represent systematic error due to the centrality bin width effect.
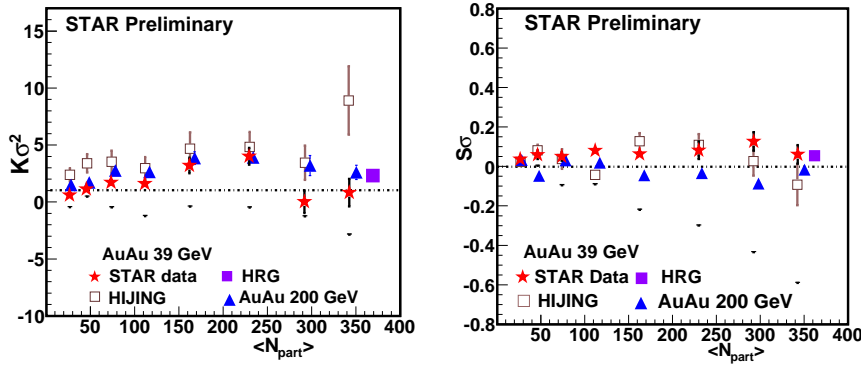

Fig. 3. The $K\sigma^2$ (left-panel) and $S\sigma$ (right panel) of the net-charge distribution are plotted versus $< N_{part} >$ respectively from the data. The filled rectangle represent the HRG model results from [8]. The blank rectangles are the HIJING model results for the Au+Au at 39 GeV. The red star and the blue triangle represent Au+Au 39 and 200 GeV results from the data. The error bars are statistical error and black caps represent systematic error due to the centrality bin width effect.

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from HIJING are also agreement with the data. The $K\sigma^2$ values are larger than unity where the $S\sigma$ values are close to zero for different centralities. The $K\sigma^2$ and $S\sigma$ values are similar for Au+Au collisions at $\sqrt{s_{NN}} = 39$ and 200 GeV.

3. Summary

The STAR preliminary results of the higher moments of the net-charge distribution for Au+Au collision at $\sqrt{s_{NN}} = 39$ and 200 GeV are presented. The results are compared with the HRG and HIJING models. Within current experimental uncertainties, the $K\sigma^2$ and $S\sigma$ values are comparable for collision at 39 and 200 GeV. The results are in agreement with the HRG model. The results from HIJING model, which does not include CP physics, are consistent with those from data. The data analysis and the model studies are in progress for the other BES energies.

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