Probing the QCD critical point by higher moments of the net-charge distribution at RHIC energies

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Introduction

At high temperature and/or high baryonic chemical potential (μ_B) the hadronic mater transit to QCD matter, where color degrees of freedom play important role, known as quark gluon plasma (QGP). Lattice QCD calculations reveal, close to $\mu_B = 0$, a cross over from hadronic state to a state where the relevant degree of freedom is partonic. At large μ_B, the transition from hadronic to partonic degrees of freedom is speculated to be the first order phase transition. In the QCD phase diagram, the end point of the first order phase transition is called as QCD critical point (CP). The characteristic signature for the CP is the divergence of the thermodynamic susceptibilities of conserved quantities like net-charge, net-baryon, net-strangeness [1] and the correlation length(ξ) [2]. These quantities are related to the higher moments (such as mean(M), standard deviation(σ), skewness(S) and kurtosis(κ)) 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 [2] respectively. The presence of the CP is expected to lead to non-monotonic behavior of the above higher moments and their products as a function of the beam energy [2]. Beside the search for CP, these experimentally measured higher moments of the net-charge distribution can be used to extract freeze-out temperature and chemical potential by direct comparison with recent lattice calculation [3, 4].

The Beam Energy Scan (BES) program has been undertaken at the Relativistic Heavy Ion Collider (RHIC), at BNL, to search for the QCD critical point (CP) and the phase boundary. In BES program, STAR experiment has taken data of Au+Au collisions at $\sqrt{s_{NN}}$ = 39, 27, 19.6, 11.5 and 7.7 GeV. Along with BES energies STAR experiment also has taken data of Au+Au collisions at 200 and 62.4 GeV, which covers the baryon chemical potential ranging from 20 MeV to 410 MeV [5] in the QCD phase diagram.

Analysis Details

The STAR experiment has taken data for Au+Au collisions at $\sqrt{s_{\rm NN}}$= 7.7 to 200 GeV in last two years. The STAR detector system provides the excellent particle identification and large acceptance for the event-by-event fluctuation analysis. The Time Projection Chamber (TPC) is the main tracking device. Extensive quality assurance is performed for each energy in order to minimize the fluctuation of detector efficiency. The event-by-event net-charge distribution is measured for Au+Au collisions occurring within $\pm$30 cm along the z position of the interaction point from the TPC center and 2.0 cm radius in the transverse plane. The charged particles are measured between the transverse momentum (p_T) range 0.2<p_T <2.0 GeV/c and pseudo-rapidity (η) range at $|\eta| < 0.5$ region. The standard STAR track quality cuts are used for this analysis. The contamination of spallation protons, produced due to beam pipe interaction, are suppressed by removing protons within 200 <p_T < 400 MeV/c. To avoid the auto-correlation effect in the higher moments analysis, the centrality selection has been done by uncorrected charged particles measured within $0.5 < |\eta| < 1.0$ from the TPC detector. The heavy ion collision geometry of each centrality class is characterized by the average number of participating nucleons ($\langle N_{\rm part}\rangle$) which is calculated by the Monte

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Carlo Glauber simulation. The finite centrality bin width effect has been avoided by using centrality bin width correction [9, 10]. For the statistical error estimation, Delta theorem is used [8]. The efficiency correction for the uncorrected cumulants has also been performed by using centrality dependance of efficiency for all BES energies.

Results

For the non-CP baseline at the above energies, the Poisson and Negative Binomial (NB) expectations are studied. In these approach, the positive and negative charged particles distributions are assumed to be independently Poisson and NB distributions where no dynamical correlations among the positive and negative charge particles are taken into account. Beside this, pQCD based model (HIJNIG), Transport model (UrQMD) containing various hadronic resonances and re-scattering, and thermal model (THERMINATOR) have also been studied [10]. Having no CP physics in these models set baseline for the CP search. It is observed that the width of net-charge multiplicity distributions increases with increase in centrality and mean of the net-charge multiplicity distributions shift towards positive side with decreasing colliding energies. The M and σ values increase in going from peripheral to central collisions for the above seven colliding energies, whereas S and κ values decrease with increase in collision centrality. The evolution of these higher moments can be understood by the central limit theorem (CLT) [10], which explain the $\langle N_{\rm part}\rangle$(proxy of volume) dependence of these moments. The values of $S\sigma$ and $\kappa\sigma^2$ are estimated as a function of $\langle N_{\rm part}\rangle$for the above seven energies and corresponding Poisson expectations are also compared for each energy. The deviation between $S\sigma$ and that of Poisson expectation are observed to be increasing as decreasing colliding energy. Whereas in $\kappa\sigma^2$, deviation from Poisson expectations are observed almost similar in all energies. The energy dependence of the product of moments such as, $\frac{\sigma^2}{M}$, $S\sigma$ and $\kappa\sigma^2$ are compared with Poisson expectation and Hadron Resonance Gas (HRG) model predictions. The values of $\frac{\sigma^2}{M}$ increases with increase in colliding energy for three centrality bins whereas in case of the $S\sigma$, it increases with decreasing colliding energies. The $\kappa\sigma^2$ shows no energy dependence and all the values are above unity, except for most central events at 7.7 GeV with large statistical uncertainty. The energy dependence of the $S\sigma$ shows systematically large deviation from its Poisson expectation below $\sqrt{s}_{\rm NN}$=27 GeV as compared at higher energies. The HRG predictions of $\kappa\sigma^2$ are very close to data whereas that of $S\sigma$ over-predicts the data.

1. Summary

The higher moments of the net-charge multiplicity distributions have been measured for Au+Au collisions at $\sqrt{s}_{\rm NN}$= 7.7 to 200 GeV. The centrality dependence of the moments follows the expectation from the CLT. The values of $\frac{\sigma^2}{M}$ increase with increase in colliding energy. The values of $S\sigma$ increase with decreasing colliding energies and deviates from Poisson expectation below $\sqrt{s}_{\rm NN}$= 27 GeV. Within statistical uncertainty, $\kappa\sigma^2$ is seen to be independent of collision energy.

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