Critical end point search using higher moments of net-charge distributions in heavy-ion collisions

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Introduction

Quantum chromodynamics (QCD), the theory of strong interaction, predicts that nuclear matter at high temperature and/or densities undergoes a phase transition from a state with hadrons as dominant degrees of freedom to a state where partonic degrees of freedom prevail. One of the major goal of recent theoretical and experimental study is to discover an important feature of the QCD phase diagram, namely the critical end point (CEP) at which a line of the first order phase transitions separating quark-gluon plasma from hadronic matter comes to an end [1]. The presence of CEP would result in large correlation lengths *i.e.* large fluctuations in various thermodynamic quantities. Higher moments of the conserved quantities like net-baryon (ΔB), net-electric charge (ΔQ) and net-strangeness (ΔS), which can be related to the susceptibility of the system, are generally considered to be sensitive indicators to search for CEP in heavy-ion collisions.

Heavy-ion models

Experimentally these fluctuations will be observable, if at the time of hadronization the thermal system generated in the heavy-ion collision has kept the memory of the plasma phase or the expansion period during which it may have passed by the CEP. On the other hand, in the heavy-ion experiment, a lot of information has been collected from particle yields in a wide range of beam energies. The particle multiplicities are well described in a thermal model using the partition function of a hadron resonance gas (HRG) [2].

In the exploration of the QCD phase diagram at non-zero baryon chemical potential, higher order moments of net-charge distributions play a particularly important role. Lattice QCD predicts that these moments, mean (M), sigma (σ), skewness (S) and kurtosis (κ), of conserved quantities are sensitive to large correlation lengths [3]. The sensitivity increases for the mixed moments such as $S\sigma$ and $\kappa\sigma^2$. Thus one can consider HRG model as theoretical baseline for experimental search for the CEP and any deviation from HRG model predictions would constitute evidence for the new phenomena.

The basic quantity that describes thermodynamics at non-vanishing chemical potential is pressure which can be obtained from the logarithm of grand-canonical partition function. In the HRG model the partition function is given by

$$\ln Z(T, \mu_B, \mu_Q, \mu_S) = \frac{VT}{2\pi^2} g_i m_i^2 \sum_{k=1}^{\infty} \frac{(\pm 1)^{k+1}}{k^2} K_2(km_i/T) \ \exp(k\vec{c}_i\vec{\mu}/T)$$

where $\vec{c}_i = (B_i, Q_i, S_i)$, and $\mu = (\mu_B, \mu_Q \mu_S)$ and $K_2(x)$ is modified Bessel function. The positive and negative sign is for bosons and fermions respectively.

On the other hand, heavy-ion jet interaction generator (HIJING) [4] is an event generator based on perturbative QCD-inspired model that produces multiple minijet partons; these later get transformed into string configurations and then fragment into hadrons. The fragmentation is based on the Lund jet fragmentation model. Such a model does not have the mechanism to generate phase-transitions; however, it would be interesting to know how much of the correlations among hadrons

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from minijets contribute to these higher moments study. Recently STAR experiment has shown the mixed moments for various colliding beam energies for the net-proton distributions. They have reported no deviation of these mixed moments from the central limit theorem and in general agreement with results from various models without CEP [5].

Results

In this work, we have calculated the different moments of net-charge distributions both from HRG model as well as HIJING (version 1.37), which are based on the scenario without phase transitions.

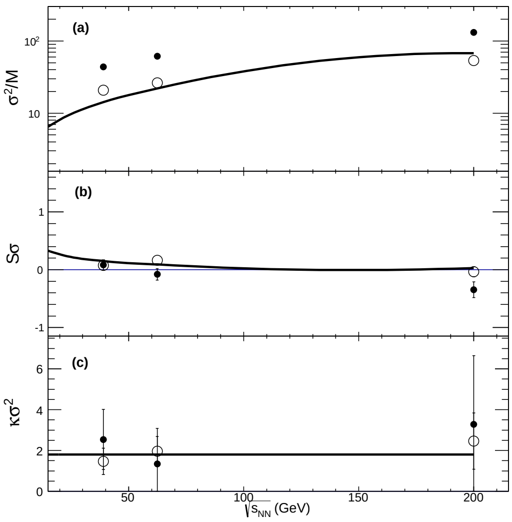

FIG. 1: Net-charge mixed moments (a) σ^2/M, (b) $S\sigma$ and (c) $\kappa\sigma^2$ are shown for various colliding beam energies for HRG (solid line) and HIJING model (solid symbol). Also shown are HIJING results without resonance decays (open symbol).

Figure shows the HRG (solid line) and HIJING (solid symbol) model predictions at different collision energies ($\sqrt{s_{NN}}$ = 39, 62.4 and 200 GeV) for the most central 0-5% Au+Au collisions. The data from HIJING was calculated by using the PHENIX detector acceptance for the central region. This would even allow us to test the feasibility of such studies with a limited acceptance detectors. The σ^2/M seems to increase slightly with $\sqrt{s_{NN}}$ for both HRG and HIJING model where as $S\sigma$ and $\kappa\sigma^2$ seems to be independent of $\sqrt{s_{NN}}$. We have also shown (open symbol) in fig the effect of resonance decay in these mixed moments calculation using HIJING model. All the hadronic resonances were switched off to study the net-charge distributions. The results of HRG model and with HIJING no decays seems to agree well for all the mixed moments. The effect of results from HIJING with and without decay seems to be negligible in $S\sigma$ and $\kappa\sigma^2$ within the statistical errors but has a effect on σ^2/M. This should be included in systematic uncertainties while calculating the net-charge higher/mixed moments as in real experiment data it is difficult to remove this effect.

Summary

We have presented the study of net-charge higher moments from HRG and HIJING model. The results from HIJING are in agreement with the models predicting no CEP. We have also studied the effect of resonance decays in the calculation of mixed moments and found that within the PHENIX acceptance the resonance decays have a negligible effect on the results. These studies would also encourage the detector systems, like PHENIX, with limited acceptance to search for CEP in heavy-ion collisions.

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