Study of charge fluctuations in interacting hadron resonance gas model

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Introduction

A reliable way to look at the phase transition of strongly interacting matter is to study the susceptibilities, correlations and fluctuations of some conserved charges like baryon number, electric charge and strangeness. Susceptibilities are related to fluctuations via the fluctuation-dissipation theorem. A measure of the intrinsic statistical fluctuations in a system close to thermal equilibrium is provided by the corresponding susceptibilities. At finite temperature and chemical potential fluctuations of conserved charges are sensitive indicators of the transition from hadronic matter to QGP. Also the existence of the critical point (CP) can be signaled by the divergent fluctuations. Several experimental programs have been launched to study the phase transition of strongly interacting matter. The Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory has been performing a beam energy scan program to locate CP in the phase diagram. The phase transition at high μ_B will be explored at the new Facility for Anti-proton and Ion Research (FAIR). In this paper we have analysed fluctuations of electric charge using interacting Hadron Resonance Model (HRG).

HRG model

The grand canonical partition function of a hadron resonance gas [1] can be written as $\ln Z^{id} = \sum_i \ln Z_i^{id}$, where sum is over all the hadrons upto mass 3GeV. id refers to ideal i.e., non-interacting HRG. For particle i,

$$\ln Z_i^{id} = \frac{V g_i}{2\pi^2} \int_0^\infty \pm p^2\, dp \ln[1 \pm \exp(-(E_i - \mu_i)/T)], \quad (1)$$

where V is the volume of the system, g_i is the degeneracy factor, T is the temperature, $E_i = \sqrt{p^2 + m_i^2}$ is the single particle energy, m_i is the mass and $\mu_i = B_i\mu_B + S_i\mu_S + Q_i\mu_Q$ is the chemical potential where B_i, S_i, Q_i are the baryon number, strangeness and charge of the particle respectively and μ's are corresponding chemical potentials. The (+) and (-) signs correspond to fermions and bosons respectively. The partition function is the basic quantity from which one can calculate various thermodynamic quantities of the thermal system. For example, the partial pressure P_i can be calculated as, $P_i^{id} = \frac{T}{V} \ln Z_i^{id}$. The n^{th} order susceptibility is defined as $\chi_q^n = \frac{1}{VT^3} \frac{\partial^n (lnZ^{id})}{\partial(\frac{\mu_q}{T})^n}$, where μ_q is the chemical potential for conserved charge q.

Moments such as mean (M), standard deviation (σ), skewness (S), kurtosis (κ) of conserved charges are measured experimentally and those are used to characterize the shape of charge distribution. Products of moments are related to susceptibilities (χ_q) by the following relations,

$$\frac{\chi_q^2}{\chi_q^1} = \frac{\sigma^2}{M_q}, \quad \frac{\chi_q^3}{\chi_q^2} = S_q\sigma_q, \quad \frac{\chi_q^4}{\chi_q^2} = \kappa_q\sigma_q^2. \quad (2)$$

The advantage of using the above mentioned products of moments is that they are independent of the volume of the system.

In HRG model non-interacting hadrons are considered. However, in excluded volume hadron resonance gas (EVHRG) model

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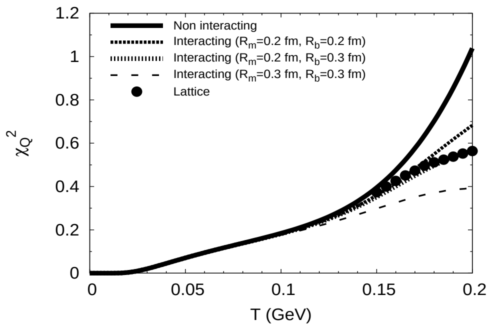

FIG. 1: Variation of χ^2_Q with T at $\mu = 0$.

hadronic phase is modeled by a gas of interacting hadrons, where the geometrical size of the hadrons are explicitly incorporated to approximate a short-range repulsive hadron-hadron interaction. In EVHRG model pressure can be written as $P(T, \mu_1, \mu_2, ..) = \sum_i P_i^{id}(T, \hat{\mu}_1, \hat{\mu}_2, ..)$, with $\hat{\mu_i} = \mu_i - V_{ev,i}P(T, \mu_1, \mu_2, ..)$, where $V_{ev,i} = 4.\frac{4}{3}\pi R_i^3$ is the volume excluded for the i th hadron with radius R_i. In an iterative procedure one can get the total pressure and hence various thermodynamic quantities and susceptibilities.

Results and discussions

In Fig. 1 we have shown variation of second order susceptibility χ^2_Q with temperature at $\mu = 0$. It can be seen that there is almost no effect of interaction till $T = 130$ MeV, above which we see quite a substantial change. We compare our result with LQCD data [2]. It can be seen that χ^2_Q is in good agreement with LQCD if we consider radii of mesons and baryons to be 0.2 fm and 0.3 fm respectively.

In Fig. 2 we have shown energy dependence of σ^2/M, $S\sigma$ and $\kappa\sigma^2$ for net-charge. σ^2/M for net-charge increases rapidly with increase of $\sqrt{s_{NN}}$ in our model. We compare our result for $S\sigma$ and $\kappa\sigma^2$ with experimental data of net-charge fluctuations for $(0-5)\%$ central Au-Au collisions measured at STAR [3]. $S\sigma$ for net-charge matches within error-bar with our model at $\sqrt{s_{NN}} \geq 62.4$ GeV and $\sqrt{s_{NN}} \leq 11.5$ GeV but at intermediate energies our model over estimate the experimental data. At all $\sqrt{s_{NN}}$, $\kappa\sigma^2$ for net-charge lie between 1.6 to 1.8 in both HRG and EVHRG model which is in agreement with experiment within error-bar at $\sqrt{s_{NN}} \geq 11.5$ GeV. Products of moments are showing monotonic behaviour along the freeze-out line.

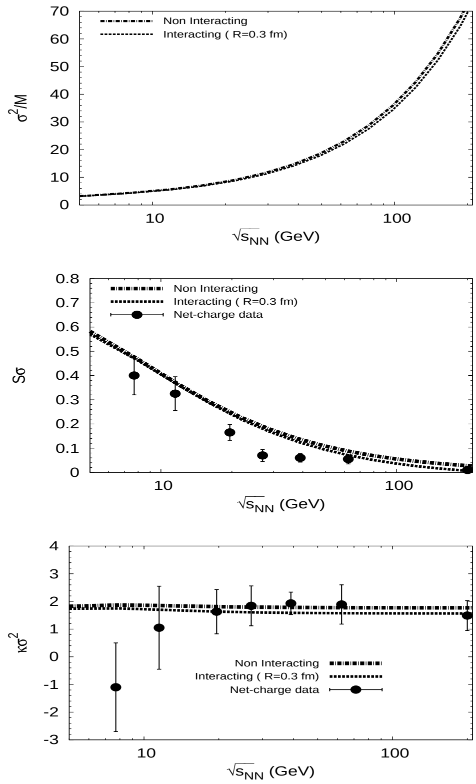

FIG. 2: Energy dependence of σ^2/M, $S\sigma$ and $\kappa\sigma^2$ for net-charge.

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