Fluctuations and correlations of conserved charges in PNJL model

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Introduction

It has now been established that strongly interacting matter under extreme conditions undergoes a phase transition and we are on the way to draw the phase diagram of quantum chromodynamics (QCD), which is the theory of strong interactions. The best way to go about it is to perform numerical simulations on the discretized version of QCD - the so-called lattice QCD (LQCD). This formulation however has some inherent technical problems and it would take some time to find the final answers. Meanwhile one can look into the properties of strongly interacting matter through effective models of QCD. The Polyakov loop extended Nambu-Jona-Lasinio (PNJL) model is one such model that successfully captures various properties of strongly interacting matter. For $2 + 1$ flavors, fluctuations have been recently measured in LQCD as well as in PNJL model with the usual unbound effective potential (UEP). In this work we investigate the diagonal and off-diagonal susceptibilities which are respectively related to the fluctuations and the correlations among different conserved charges of heavy ion collisions, but with an improved bounded effective potential (BEP).

Formalism

Here we grossly follow the notations of Ref.[1, 2]. Our first job is to minimize the thermodynamic potential numerically with respect to the mean fields σ_u, σ_d, σ_s, Φ and $\bar{\Phi}$. These values of the fields can then be used to evaluate the pressure. Then we can expand the scaled pressure at a given temperature in a Taylor series for the chemical potentials μ_B, μ_Q, μ_S as,

$$\frac{P(T,\mu_B,\mu_Q,\mu_S)}{T^4} = \sum_{n=i+j+k} c^{B,Q,S}_{i,j,k}(T)(\frac{\mu_B}{T})^i(\frac{\mu_Q}{T})^j(\frac{\mu_S}{T})^k \quad (1)$$

where,

$$c^{B,Q,S}_{i,j,k}(T) = \frac{1}{i!j!k!}\frac{\partial^i}{\partial(\frac{\mu_B}{T})^i}\frac{\partial^j}{\partial(\frac{\mu_Q}{T})^j}\frac{\partial^k(P/T^4)}{\partial(\frac{\mu_S}{T})^k}\Big|_{\mu_{B,Q,S}=0} \quad (2)$$

The flavor chemical potentials μ_u, μ_d, μ_s are related to μ_B, μ_Q, μ_S by,

$$\mu_u = \frac{1}{3}\mu_B + \frac{2}{3}\mu_Q, \quad \mu_d = \frac{1}{3}\mu_B - \frac{1}{3}\mu_Q,$$
$$\mu_s = \frac{1}{3}\mu_B - \frac{1}{3}\mu_Q - \mu_S \quad (3)$$

To extract the Taylor coefficients, first the pressure is obtained as a function of different combinations of chemical potentials for each

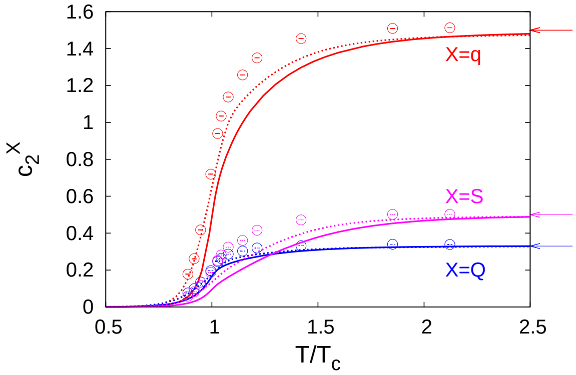

FIG. 1: Second order cumulant of pressure w.r.t. different chemical potential. The dotted line corresponds to the UEP case where we consider upto six quark interaction and the solid line corresponds to the BEP modification by including of eight quark interaction. Lattice data are taken from Ref.[6].

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value of T and fitted to a polynomial about zero chemical potential using the gnuplot fit program. Stability of the fit has been checked by varying the ranges of fit and simultaneously keeping the values of least squares to 10^{-10} or even less.

Results and Discussions

It has already been shown from universality argument [3] and tested in LQCD that second order cumulants of pressure always jump to a high value in chirally restored phase when coming from low T hadronic phase without showing any critical behavior. This kind of order parameter like behavior are closely related to the fact that quark liberates at QCD phase transition [4]. In PNJL model we also have the smooth crossover around T_C as shown in Fig.1. For all cases of conserved numbers our model results are very close to lattice data and correctly reproduces high temperature SB limit. But in the case of fourth order cumulant there are pronounced peak structure near T_C due to relics of critical behavior similar to the case of specific heat. Kurtosis is very sensitive probe to deconfinement. In our model low and high T limits of kurtosis corresponding to baryon number and electric charge are well within limits. Another important quantity, which is related to strangeness enhancement in heavy ion collision, is called Wrólewski parameter. We found its value at T_C is around 0.4, whereas RHIC estimate is around 0.47.

For the off-diagonal susceptibilities we first focus on B-S and Q-S sectors. As the lowest lying baryons (mostly protons and neutrons) and lowest lying charged particles (mainly pions) do not carry strangeness, so c_{11}^{BS} and c_{11}^{QS} remain zero at low T. At high T in the partonic phase these quantum numbers are strongly correlated through quark quasiparticles. This 'quasiquark' description of high T plasma can be well understood using $\mathrm{C_{BS}}$ and $\mathrm{C_{QS}}$. It can be shown that;

$$\mathrm{C_{BS}} = -\frac{3}{2}\frac{\mathrm{c_{11}^{BS}}}{\mathrm{c_2^S}} = 1 + \frac{\mathrm{c_{11}^{us}}}{\mathrm{c_2^s}}$$
$$\mathrm{C_{QS}} = \frac{3}{2}\frac{\mathrm{c_{11}^{QS}}}{\mathrm{c_2^S}} = 1 - \frac{1}{2}\frac{\mathrm{c_{11}^{us}}}{\mathrm{c_2^s}} \qquad (4)$$

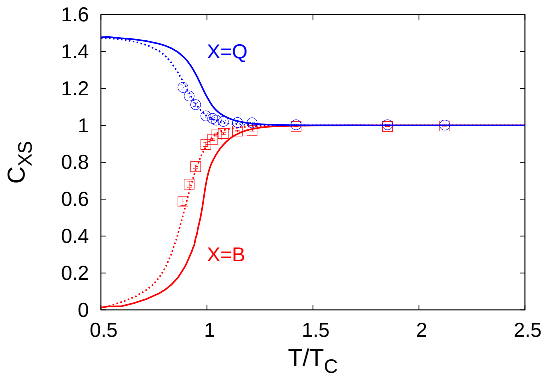

FIG. 2: Correlation coefficients in B-S and Q-S sectors. Dotted line corresponds to UEP case and solid line corresponds to improved BEP case. Lattice data are taken from Ref.[6].

Both of the ratios jumping to unity after T_C indicating that above T_C different flavors are uncorrelated. In the B-Q sector second order correlation vanishes at both low and high T regime. At low T charged baryon (minimally proton) population vanishes due to their heavy mass giving rise to vanishing correlation. At high temperature although B and Q are related through quark quasiparticles, but their mutual cancellation for 2+1 flavors gives rise to zero.

Acknowledgments

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