Looking for possible volume scaling violations in finite volume Polyakov–Nambu–Jona-Lasinio model

K. Saha[1],* S. Upadhaya[1], A. Bhattacharyya[2], S. K. Ghosh[1], and R. Ray[1]
[1]*Department of Physics, Bose Institute, 93/1, A. P. C Road, Kolkata - 700009, INDIA.*
[1]*Center for Astroparticle Physics & Space Science, Block-EN, Sector-V, Salt Lake, Kolkata-700091, INDIA and*
[2]*Department of Physics, University of Calcutta, 92, A.P.C Road, Kolkata-700009, INDIA*

Introduction

The matter formed in high-energy heavy ion collision experiments have finite volumes, which depend on the size of the colliding nucei as well as the center of mass energy and the centrality of collisions. There have been various attempts applying HBT technique and UrQMD to estimate the freeze out volumes of the systems produced in such collisions. Previously in PNJL model [1, 2] the cross-over and the possibility of chiral symmetry restoration in a color confined state with finite system size has been discussed. Fluctuations of conserved charges in this regard are viable indicators for a transition from partonic state to hadronic matter. Alongwith their study, we also intend to focus on the possible volume scalings along the phase transition line within the framework of 2+1 flavor PNJL model. The PNJL model has been formed by a suitable modification of the NJL model through introduction of a background field that mimics the behavior of Polyakov loop. The details of the model, recent developments and the methodology adopted for this work can be found in [3]. The results for the cross-over temperatures at zero chemical potential for selected set of finite volume systems in our model is given in table I. They are obtained from the peak in thermal susceptibilities of the mean fields.

R(fm)	2	3	4	∞
T_c(MeV)	160	174	178	181

TABLE I: Cross-over temperatures corresponding to various system sizes at vanishing chemical potential.

Results and Discussions

Fluctuations of conserved charges like quark number (q), charge (Q) or strangeness (S) are related to corresponding susceptibilities which are given by,

$$c_n^X(T) = \frac{1}{n!}\frac{\partial^n(-\Omega(T,\mu_X)/T^4)}{\partial(\frac{\mu_X}{T})^n}|_{\mu_X=0} \quad (1)$$

where, X stands for either of q, Q or S. In order to make connections between experimental findings and theoretical predictions it is always important to study the occurence of volume scaling violation. We find in Fig. 1 the susceptibilities themselves being volume dependent, the free energy need not be directly proportinal to the volume. From ratios of similar order fluctuations as seen in Fig. 2 it seems that the large distance behavior of fluctuations change with the order of fluctuations. Next it will interesting to move along the positive μ_q(quark chemical potential) direction in a sufficiently wide temperature window in order to observe similar effects. In Fig. 3 we have plotted ratios of net quark density c_1^q and quark number fluctuations c_2^q at few fixed temperatures. At these representative temperatures we observe dips and subsequent discontinuities occuring around the phase diagram with volume scaling getting violated. The discontinuities indicate the first order transition regime. Therefore it is justified to conclude that violation of volume scaling happens near

*Electronic address: `kinkar@jcbose.ac.in`

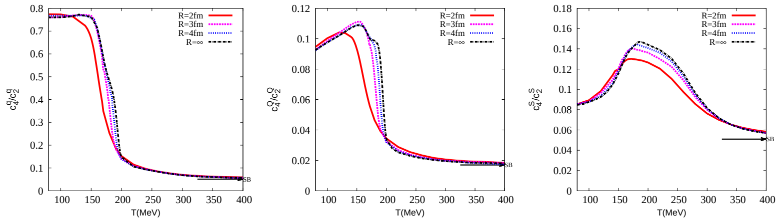

FIG. 1: (color online) Ratio of fourth order to second order susceptibilities for quark (left column), electric charge (middle column) and strangeness (right column) chemical potentials as a function of T/T_c.

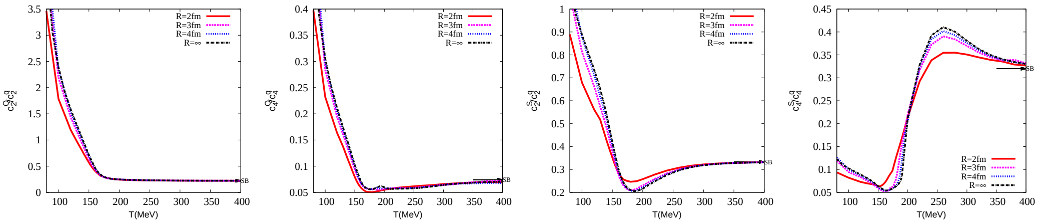

FIG. 2: (color online) Ratios of various susceptibilities of same order as function of temperature.

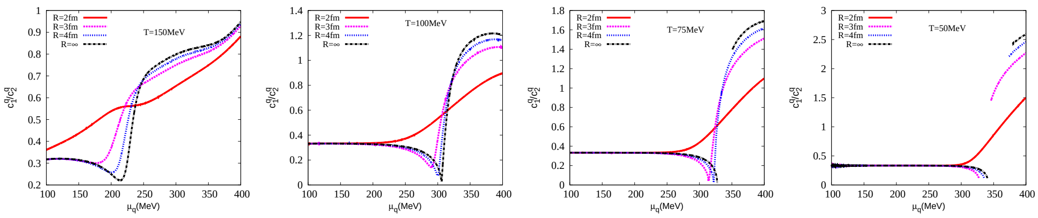

FIG. 3: (color online) Ratios of net quark number density to the quark number fluctuations as functions of quark chemical potential at different temperatures.

the transition region where large scale correlations prevail leading to separate finite size behavior of the free-energy derivatives.

Conclusions

As we observe from the ratios of susceptibilities of conserved charges at vanishing chemical potential, the free energy of strongly interacting systems need not be strictly linear in volume. Also moving along the positive μ_q direction, the violation of volume scaling possibly occurs around the transition region where large scale correlations come into play.

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