Fluctuations at finite volume in strongley interacting matter

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Chiral symmetry breaking and confinement-deconfinement transition are novel aspects of strongly interacting matter. Strongly interacting matter in extreme conditions (nonzero temperature and density) show rich phase structure. In ultrarelativistic Heavy Ion Collisions in laboratories such exotic states are created. Experiments are being conducted in CERN and BNL and will be conducted at GSI to study the properties of the transition from hadronic states to quark-gluon plasma(QGP). In these experiments QGP thus produced has a finite volume depending on the nature of the colliding nuclei, the centre of mass of energy ($\sqrt{s}$) etc.

The thermodynamic aspect of the phase transition from hadronic phase to QGP phase can be understood properly if we study susceptibilities of conserved charges. 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 zero chemical potential, charge fluctuations are sensitive indicators of the transition from hadronic matter to QGP. Also the existence of the CEP can be signalled by the divergent fluctuations. For the small net baryon number, which can be met at different experiments, the transition from hadronic to QGP phase is continuous and the fluctuations are not expected to have any singular behavior. Recently, the computations have been performed for many of these susceptibilities at zero chemical potentials [1, 2]. It was shown that at vanishing chemical potential the susceptibilities rise rapidly around the continuous crossover transition region. Here we study the fluctuation at finite volume using an effective theory of QCD namely PNJL model. Such studies would shed some light on the nature of phase transition as the size of the system changes.

The pressure of the strongly interacting matter can be written as,

$$P(T, \mu_q) = -\frac{\partial \Omega(T, \mu_q)}{\partial V} \qquad (1)$$

where Ω is the thermodynamic potential, T is the temperature and μ_q is the quark chemical potential. One should note that the thermodynamic potential changes as the size of the system changes. From the usual thermodynamic relations we can show that the first derivative of pressure with respect to μ_q gives the quark number density and the second derivative is the quark number susceptibility (QNS).

Our first job is to minimise the thermodynamic potential numerically with respect to the fields $\sigma_u = \bar{\psi}_u \psi_u$ and Polyakov loop (Φ). The values of the fields can then be used to evaluate the pressure using the equation (1). Then we can expand the scaled pressure at a given temperature in a Taylor series for the chemical potentials μ_q

$$\frac{P(T, \mu_q)}{T^4} = \sum_i c_i (\frac{\mu_q}{T})^i \qquad (2)$$

where,

$$c_i(T) = \frac{1}{i!} \frac{\partial^i (P/T^4)}{\partial (\frac{\mu_q}{T})^i}\Big|_{\mu_q=0} \qquad (3)$$

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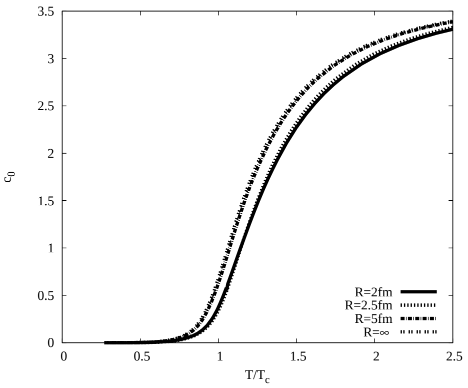

FIG. 1: Variation of c_0 with temperature for different system sizes.

Here we will use the expansion around $\mu_q = 0$, where the odd terms vanish due to CP symmetry. We evaluate the expansion coefficients up to fourth order. To obtain the Taylor coefficients, first the pressure is obtained as a function of μ_q for each value of T, then fitted to a polynomial about $\mu_q = 0$. All orders of derivatives are then obtained from the coefficients of the polynomial extracted from the fit. For the stability of the fit we have checked the values of least squares.

In figures 1-3 we have plotted c_0, c_2 and c_4. The c_0 behaves as the pressure and it

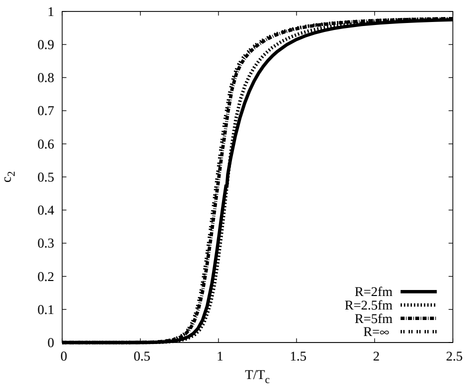

FIG. 2: Variation of c_2 with temperature for different system sizes.

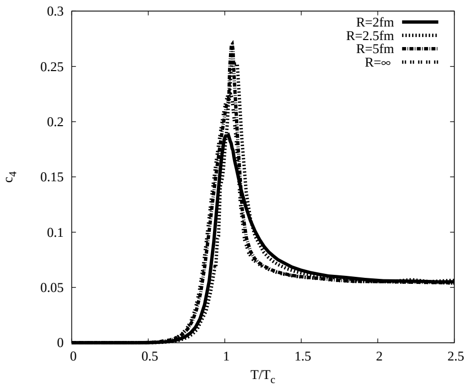

FIG. 3: Variation of c_4 with temperature for different system sizes.

has strong volume dependence. At T_c the value of c_0 for $R = \infty$ is about twice that at $R = 2fm$. As the temperature is increased c_2 increases for all the system sizes and smoothly passes from the hadronic phase to the quark phase. Around T_c, c_2 is strongly dependent on the system size. If we compare the values for $R = 2fm$ and $R = \infty$ we can observe more than a factor of 2 difference. So one can conclude that depending on the colliding ions and also on the $\sqrt{s}$ the fluctuations may change drastically. As the temperature is further increased c_2 approaches the Stefan-Boltzman limit for all the system sizes. For all the system sizes c_4 peaks around T_c and approaches the Stefan-Boltzman limit at large temperature. The most interesting part is that the behaviour of c_4, as a function of R, is not monotonic. The peak height is maximum for $R = 5fm$. This features needs some further study.

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References

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