Volume dependence of baryon number cumulants and their ratios†

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Experiments with ultrarelativistic heavy-ion collisions at RHIC and LHC explore the phase structure of Quantum ChromoDynamics (QCD) at nonzero temperature and density, and so probe the phase transitions associated with deconfinement and the restoration of chiral symmetry. Two of the most promising observables are the fluctuations of the net baryon number and electric charge. The cumulants and related quantities of these fluctuations may provide experimental evidence for a chiral critical endpoint or chirally inhomogenous phases.

However, there are many other effects besides the critical dynamics which might be important in the interpretation of the data. Those include the conservation of baryon number, corrections for efficiency in the detectors, hadronic rescattering, non-equilibrium effects, and finally volume fluctuations. The latter are important due to a finite size of a domain passing through the critical region during the evolution of the fireball. Usually one tries to minimize the effects of fluctuations in the volume by considering the ratios of cumulants. As we describe in the main text, in such ratios the explicit dependence on the volume cancels out, making the analysis of volume fluctuations trivial. However, we show that the implicit dependence on the volume might be very strong if the characteristic system size is below 5 fm.

In this study we use the quark-meson model as a realization of the chiral symmetry in QCD at low energies. The quark-meson (QM) model consists of a $O(4)$ multiplet of mesons, $\phi = (\sigma, \vec{\pi})$, coupled to quark fields through a Yukawa-type coupling.

In order to formulate a non-perturbative thermodynamics in the QM model we adopt a method based on the functional renormalization group (FRG). The FRG is based on an infrared regularization with the momentum scale parameter, where the full propagator is derived from a corresponding effective action.

We consider systems in which there is a true critical point in infinite volume. In finite volume, instead there is an *apparent* critical point (ACP). There is some degree of arbitrariness in how one defines an apparent critical point. We define the position of the apparent critical point from the maximum in the corresponding chiral susceptibility, which is equivalent to the minimum in the sigma mass. We stress, however, that unlike the case of infinite volume, that in finite volume other definitions will give different positions for the apparent critical point.

With our definition, we show that at some intermediate system size, the system has *two* apparent critical points, located at different values of T and μ. One of the apparent critical points, which we call ACP I, approaches the true critical point in the limit of infinite volume; we show that for the ACP I, it approaches the zero temperature axis as the volume decreases. The second apparent critical point, which we call ACP II, appears near the zero temperature axis, and evolves to *higher* temperature as the volume decreases. The location of the two apparent critical points is depicted in Fig. 1. The emergence of a second apparent critical point influences the cumulants of baryon number.

In Fig. 2, we show the dependence of the kurtosis χ_4/χ_2 on the temperature for different system sizes and different anisotropy parameters. The calculations are done for zero μ.

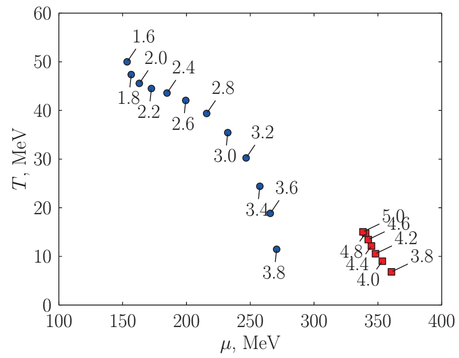

Fig. 1. The location of the apparent critical points (ACP) as a function of the system size, L. The squares (circles) denote ACP I (II), see text.

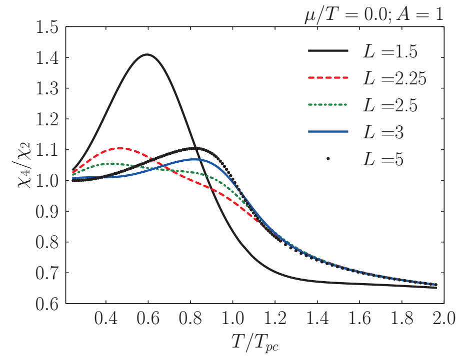

Fig. 2. The ratio of the fourth to the second order susceptibilities as a function of temperature for different systems sizes; the results are computed at zero chemical potential.

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