Finite-size scaling as a tool for the search of the critical endpoint of QCD in heavy ion data

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We briefly discuss the role played by the finiteness of the system created in high-energy heavy-ion collisions (HIC's) in the experimental search of the QCD critical endpoint (CEP) and, in particular, the applicability of the predicting power of finite-size scaling (FSS) plots in data analysis of current HIC's.

Although genuine phase transitions only exist at infinite volume, its reminiscents survive at finite (realistic) systems signaling the underlying criticality. In particular, a CEP is associated with a second-order phase transition and diverging correlation length in the thermodynamic limit, giving rise to strong signatures for large media. In HIC's, however, the size scale of the system created is not always large enough in comparison with the characteristic scales of the QCD transitions, so that finite-size effects should be important and affect different features of the quark gluon plasma possibly created.

Given the short lifetime and the reduced volume of the quark-gluon plasma formed in HIC's, a possible CEP will be blurred in a region and the effects from criticality severely smoothened. A direct consequence of this fact is that all signatures of the second-order CEP based on the non-monotonic behavior [1] of particle correlation fluctuations will probe a pseudocritical endpoint, characterized by a finite correlation length, presenting smoothened divergences that can be significantly shifted from the genuine (unique) CEP position by finite-size corrections and could be in principle sensitive to boundary effects. These features, together with the even more crucial limitation on the growth of the correlation length due to the finite (short) lifetime of the plasma and critical slowing down [2], make the experimental searches of signatures of the presence of a critical point at lower energies very challenging.

For the pseudocritical chiral phase diagram within the linear sigma model with constituent

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quarks [3], it has been shown that the amplitudes of these shifts are sizable for length scales probed at current HIC's, as illustrated in Fig. 1. Therefore, the position of the CEP probed in current HIC's may differ significantly from the expected critical temperature and chemical potential in the thermodynamic limit.

On the other hand, the non-monotonic behavior of correlation functions near criticality for systems of different sizes, tagged by different centralities in heavy ion collisions, must obey FSS. In this vein, the fact that HIC's generate data from an ensemble of systems of different sizes provides an alternative signature for the presence of a CEP.

In the FSS regime, any correlation function $X(T,L)$ of the order parameter does not depend independently on the external parameter T and on the size L of the system, having the following scaling form [4]: $X(T,L) = L^{\gamma_x/\nu} f_x(tL^{1/\nu})$, where $t = (T - T_c)/T_c$ represents a dimensionless measure of the distance, in the external parameter domain, to the genuine CEP (in the thermodynamic limit), γ_x is a dimension exponent and ν is the universal critical exponent defined by the divergence of the correlation length. This scaling form implies (and is implied by) the existence of a *scaling plot* in which all the curves for different system sizes collapse into a single curve, as illustrated in Fig. 2.

One can pragmatically map these quantities to HIC's experimental observables: the correlation functions should be related to pion multiplicity fluctuations or transverse-momentum fluctuations; the distance t to the CEP is given in terms of the center-of-mass energy (which is related to a (T,μ) point in the freeze-out curve from thermal models); and the size L can be obtained, e.g., via HBT analysis. To identify FSS in the data, it is then necessary to have different measurements corresponding to the same value of the scaling variable. Since the available system sizes in HIC's are limited, the range of energies that can be compared is also restricted. Nevertheless, one can assume the presence of FSS and predict from one data set the amplitude of the fluctuations at a different energy scale. A thorough analysis of RHIC and SPS data within this prism is underway and will be presented elsewhere [5].

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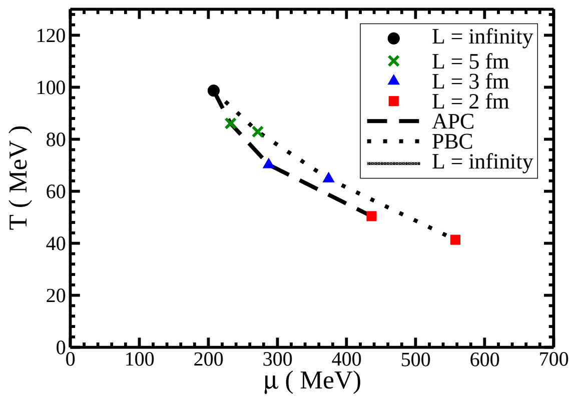

Figure 1. Trajectories of the pseudo-CEP as the system size is decreased for periodic (dotted line) and antiperiodic (dashed line) boundary conditions. For more results and details, the reader is referred to Ref. [3].

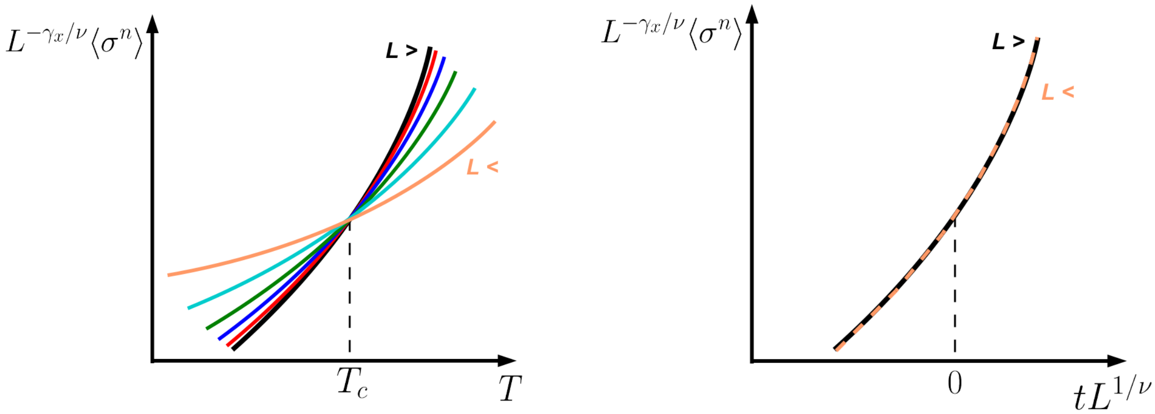

Figure 2. On the left, the normalized correlation function is shown as a function of the external parameter T, with different curves corresponding to different system sizes. The plot on the right illustrates the collapsing of curves in the appropriate scaling plot.

FIGURE CAPTIONS

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Fig.2: On the left, the normalized correlation function is shown as a function of the external parameter T, with different curves corresponding to different system sizes. The plot on the right illustrates the collapsing of curves in the appropriate scaling plot.