IMPORTANCE OF THE VACUUM SIZE IN FINITE VOLUME EFFECTS ON THE QCD PHASE DIAGRAM

Győző Kovács[1,2], Péter Kovács[1,2], György Wolf[1], Pok Man Lo[3], Krzysztof Redlich[3]

[1] Wigner Research Centre for Physics, Budapest, Hungary.
[2]Eötvös Loránd University, Budapest, Hungary.
[3]University of Wrocław, Wroclaw, Poland.

Introdution

Contrary to the field theoretical calculations in the thermodynamic limit where the volume is assumed to be infinitely large, the heavy-ion collisions always carry the effects of the finite size. A sufficiently small system size is expected to affect the thermodynamic quantities and the phase diagram of the strongly interacting matter. To study these effects within the framework of an effective model, the finite spatial extent of the system can be taken into account by the resulting restriction in momentum space.
In the present work, we used a low momentum cutoff in a vector meson extended Polyakov linear sigma model and investigated the phase diagram and within that the influence of the fermionic vacuum contribution on the finite size effects. The modification of the phase structure, when the size of the vacuum is kept infinite is similar to previous LSM results, in which no vacuum contribution was taken into account.

kovacs.gyozo@wigner.hu

ELSM

The vector and axial vector meson **E**xtended Polyakov **L**inear **S**igma **M**odel is an advanced quark-meson model, including four full meson nonets and $2+1$ flavor constituent quarks in the fermion sector [1]. The mesonic part of the Lagrangian contains the dynamical and the meson-meson interaction terms up to the fourth order, taking care of the symmetry properties and also symmetry breaking ($U(1)_A$ anomaly, explicit breaking). The constituent quarks are included in a Yukawa-type Lagrangian

$$\mathcal{L}_Y = \bar{\psi}\left(i\gamma^\mu\partial_\mu - g_F(S - i\gamma_5 P)\right)\psi.$$

Functional integration over the fermionic fields and the Matsubara summation is carried out. The finite volume is taken into account in the resulting (renormalized) vacuum and thermal contribution via momentum space restriction (presently a low momentum cutoff),

$$\Omega^L_{\bar{q}q}(T,\mu_q) = \Omega^{vac,L}_{\bar{q}q,ren} - 2T\sum_f \int \frac{d^3p}{(2\pi)^3}\left[\ln g_f^+(p) + \ln g_f^-(p)\right]\Theta\left(p - \pi/L\right),$$

with $g_f^\pm(p)$ being the modified Fermi-Dirac distribution containing the Polyakov loop parameters and L being the finite linear size.

The thermodynamics is determined from the mean-field level grand potential built up from

- the classical potential,
- the fermionic one-loop correction,
- and the Polyakov loop potential.

$$\Omega(T,\mu_q) = U_{Cl} + \Omega_{\bar{q}q}(T,\mu_q) + U_{Pol}(\Phi,\bar{\Phi})$$

The field equations are given by minimizing $\Omega(T,\mu_q)$ with respect to the order parameters, ϕ_N, ϕ_S, Φ, and $\bar{\Phi}$, being the scalar-isoscalar meson condensates and the Polyakov loop variables, respectively. The parameterization of the model was carried out at $T=0$, $\mu=0$ and infinite size with χ^2 method using ~30 physical quantities.

Modification of the phase diagram at finite volume

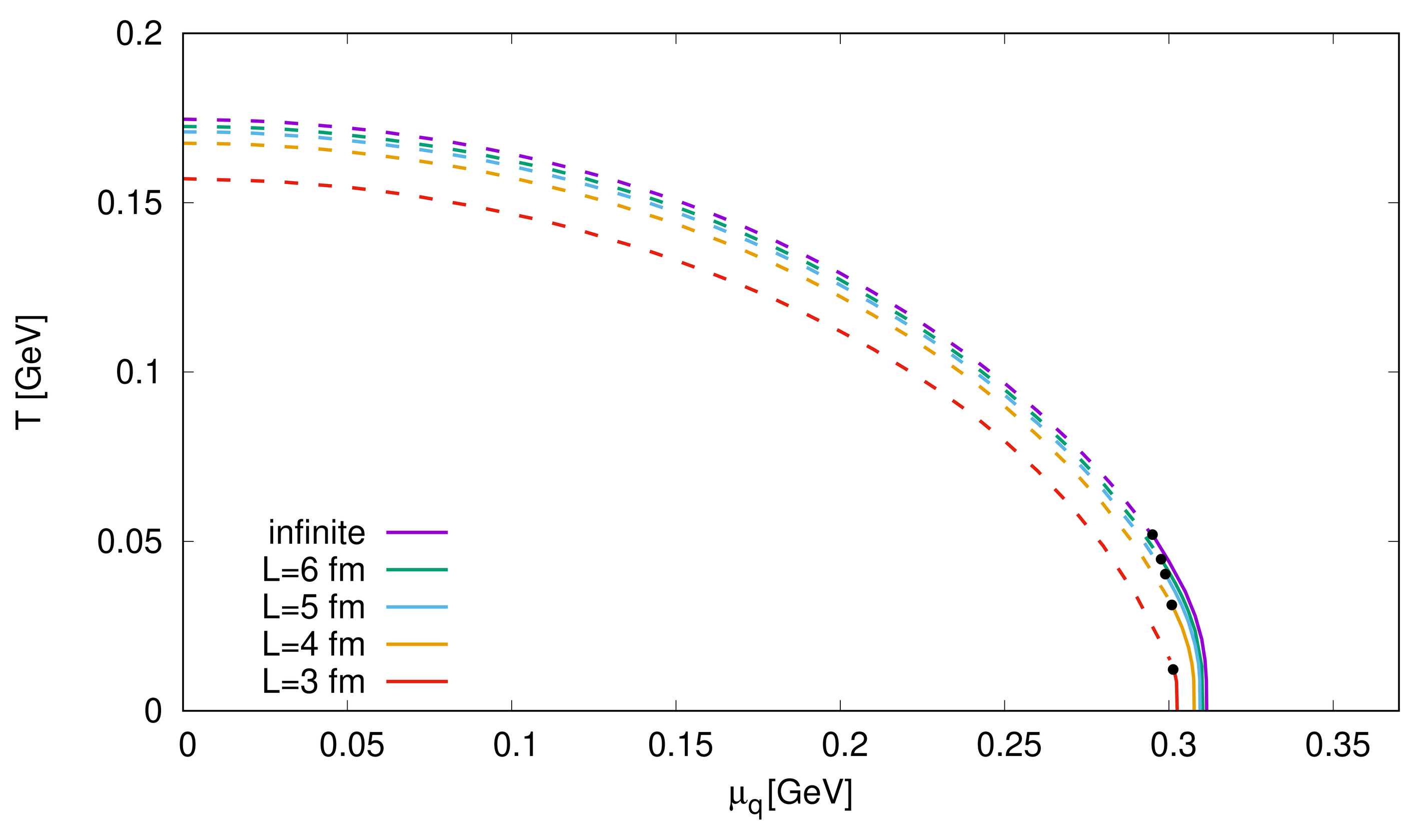

Fig. 1. The phase diagram with volume-dependent vacuum for several sizes.

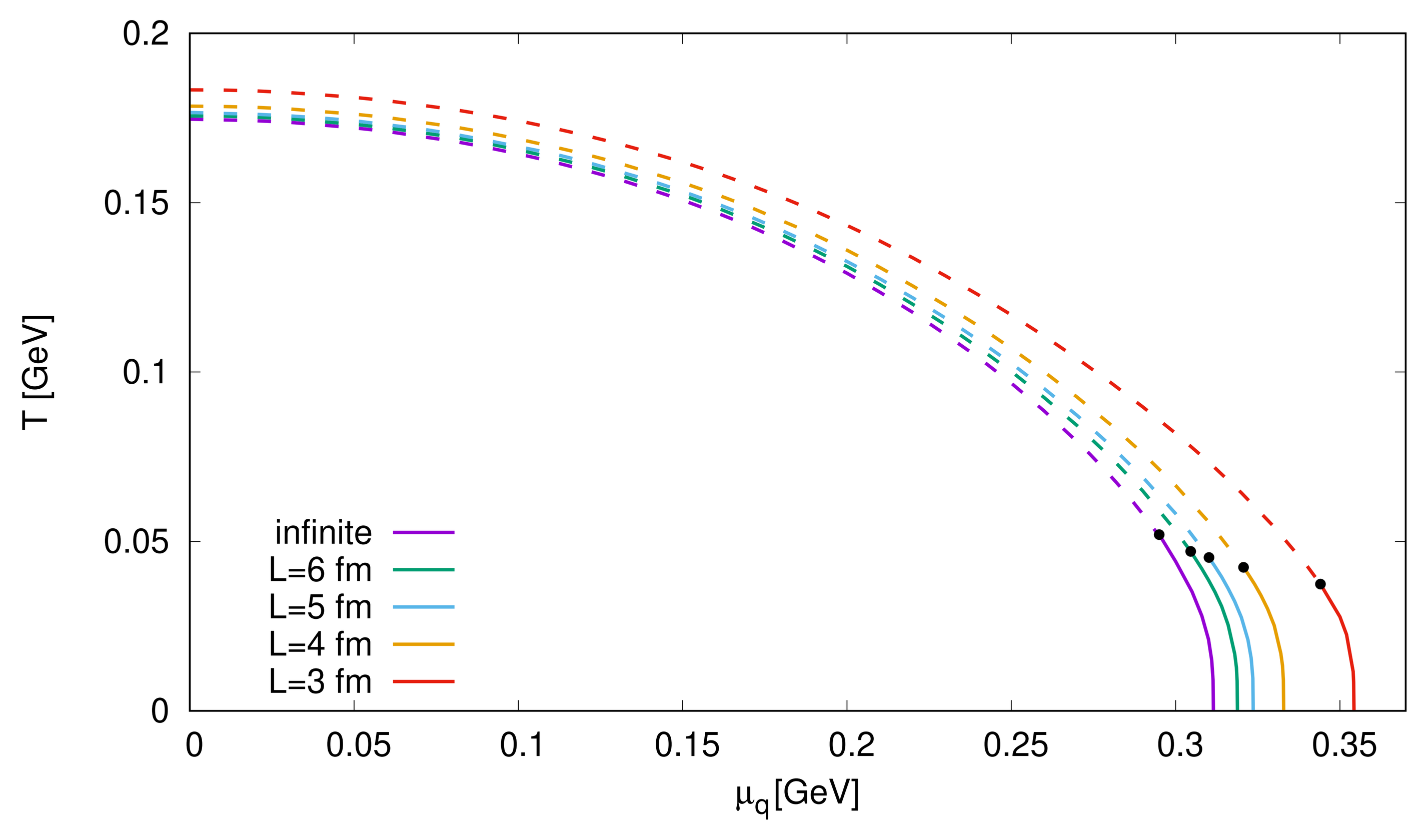

Fig. 2. The phase diagram without modification of the vacuum contribution.

Existance of chirally broken phase

- The pseudocritical temperature at $\mu_q = 0$ increases with the decreasing volume when the vacuum is not modified and the chirally broken phase extends to larger temperatures.
- With finite size modified vacuum contribution the transition temperature decreases with the decreasing system size.
- In this scenario the chirally broken phase vanishes around $L \approx 2-2.5$ fm, which can be seen from the size-dependent behavior of vacuum physical quantities. The mass of the axial partners becomes degenerate and the constituent quark masses, especially for the light quarks, decrease.

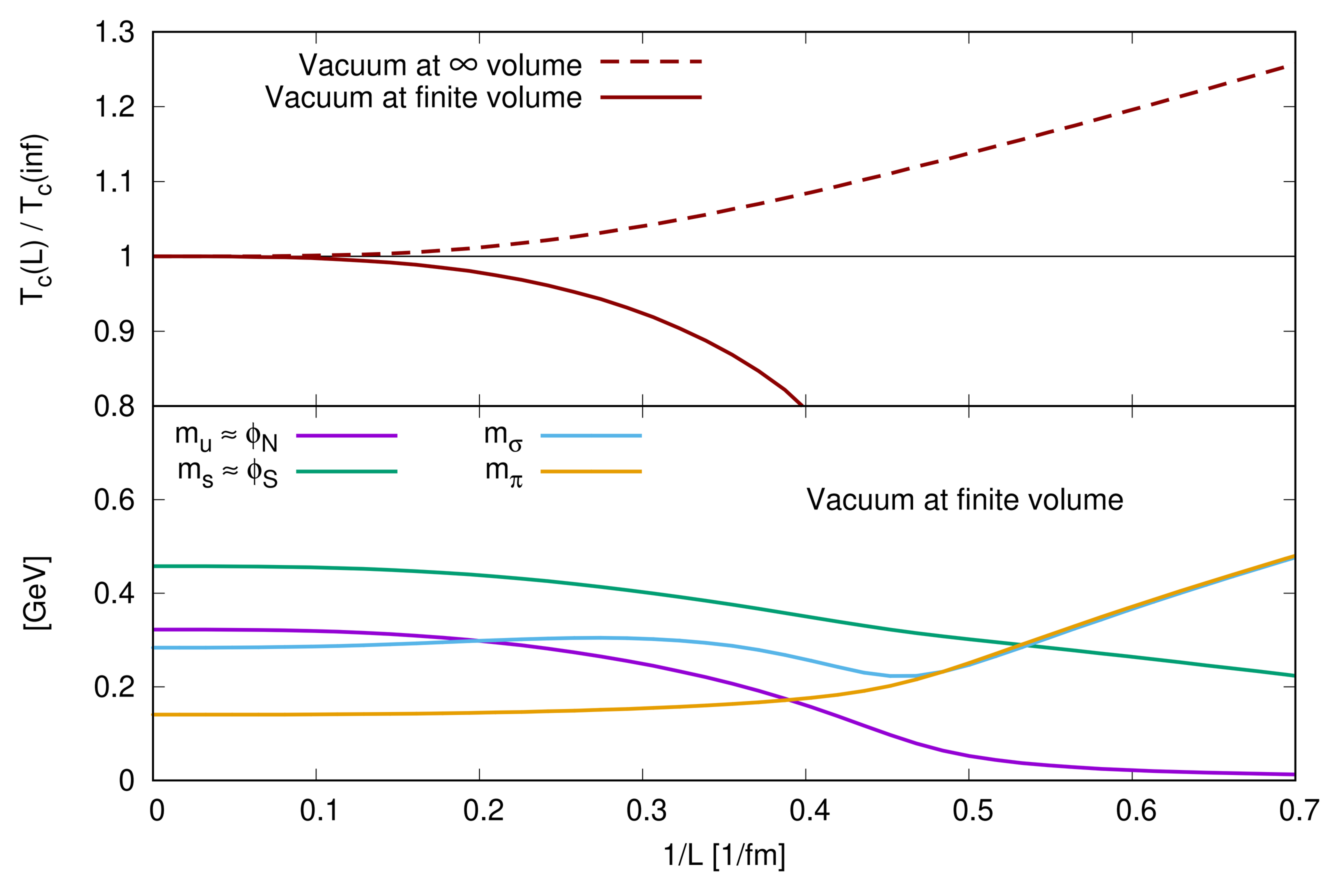

Fig. 3. $T_c(\mu_q = 0)$ for the two scenarios (top) and the modification of physical quantities at $T=0$, $\mu=0$ when the vacuum is L dependent (bottom) as a function of $1/L$.

Summary and outlook

- The finite volume effects on the thermodynamics and the phase diagram of strong interaction were studied via a low momentum cutoff.
- With infinite size vacuum the phase diagram shows similar L dependence to previous results with LSM [2, 3], where the vacuum contribution was absent.
- With volume-dependent vacuum contribution the physical quantities change with the system size under 10 fm, which pushes the system towards the chirally symmetric phase.
- The volume-dependent vacuum gives a decreasing trend in the transition temperature with the decreasing size and leads to the disappearance of the chirally broken phase.
- Using momentum discretization to study the finite size effects might lead to different behavior in ELSM, depending on the shape of the volume and the boundary condition.
- Studying the finite size effects via momentum discretization with different boundary conditions is under progress.

References

[1] P. Kovács, Z. Szép and G. Wolf, Phys. Rev. D **93**, no.11, 114014 (2016) [arXiv:1601.05291 [hep-ph]].
[2] L. F. Palhares, E. S. Fraga and T. Kodama, J. Phys. G **38**, 085101 (2011) doi:10.1088/0954-3899/38/8/085101 [arXiv:0904.4830 [nucl-th]].
[3] N. Magdy, M. Csanád and R. A. Lacey, J. Phys. G **44**, no.2, 025101 (2017) [arXiv:1510.04380 [nucl-th]].