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Phase structure, critical points, and susceptibilities in the NJL model of QCD

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Summary

Strongly interacting matter at non-zero temperature and chemical potential is an exciting topic for physicists coming from different areas, either theoretical or experimental. One of the main goals in the heavy-ion physics program nowadays is to study the effects of several macroscopic collective phenomena occurring under extreme conditions. The discussion about the existence of a tricritical point (TCP) or a critical end point (CEP) is also a topic of recent interest. As is well known, a TCP separates the first order transition at high chemical potential from the second order transition at high temperatures. If the second order transition is replaced by a smooth crossover, a CEP which separates the two lines is found. The existence of the CEP in QCD was suggested at the end of the eighties \cite{Asakawa:1989NPA}, and its properties in the context of several models have been studied since then \cite{Hatta:2003PRD,Schaefer:2006,Costa:2007PLB}.

The possible signatures of the CEP in heavy-ion collisions have been studied in detail in \cite{Stephanov:1998PRL}. The most recent lattice results with $N_f = 2 + 1$ staggered quarks of physical masses indicate the location of the CEP at $T^{CEP} = 162 \pm 2\text{MeV}$, $\mu^{CEP} = 360 \pm 40\text{MeV}$ \cite{Fodor:2004JHEP}, however its exact location is not yet known.

We perform our calculations in the framework of the three–flavor NJL model \cite{Buballa:2004PR, Costa:2003PRC}, including the determinantal 't Hooft interaction that breaks the $U_A(1)$ symmetry. We obtain the baryonic thermodynamic potential $\Omega(\mu_i, T)$ from which the relevant equations of state for the entropy S, the pressure P and the particle number N_i can be calculated as usually \cite{Costa:2003PRC}.
The baryon number susceptibility χ_B and the specific heat C are relevant observables concerning the order of the phase transition.

As several thermodynamic quantities diverge at the CEP, we will focus on the values of a set of indices, the so-called critical exponents, which describe the behavior near the critical point of various quantities of interest (in our case ϵ and α are the critical exponents of χ_B and C, respectively). The motivation for this study arises from fundamental phase transition considerations, and thus transcend any particular system. We also stress that, due to the lack of information from the lattice simulations, the universality arguments should be confronted with model calculations.

We verified that the phase diagram in the SU(3) NJL reproduces the essential features of QCD: a first order phase transition for low temperatures and the existence of the CEP occur when realistic values of current quark masses are used. For $m_u = m_d = 0$ and $m_s > m_s^{crit}$ ($m_s^{crit} = 18.3$ MeV) the transition is second order ending in a first order line at the TCP. As m_s

increases we have a \textquotedblleft line\textquotedblright of TCPs. For $m_u = m_d \neq 0$ there is a crossover for all the values of m_s and the \textquotedblleft line\textquotedblright of TCPs becomes a \textquotedblleft line\textquotedblright of CEPs. The location of the CEP depends strongly of the strange quark mass. Around the CEP we have studied the baryon number susceptibility and the specific heat which are related with event-by-event fluctuations of μ_B or T in heavy-ion collisions. In the NJL model, for χ_B, we conclude that the obtained critical exponents are consistent with the mean field values $\epsilon = \epsilon' = 2/3$. From our study of the critical exponent for the specific heat, we conclude that α is different from ϵ. This means that the specific heat is sensitive to the way we approach the CEP.

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