Phase diagram of the three-flavor color superconducting PNJL model

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Abstract. The phase diagram of a three-flavor Polyakov-loop Nambu-Jona-Lasinio model is analyzed for symmetric matter with a parametrization consistent with the 2 $M_{\odot}$ mass constraint from the pulsars PSR J1614-2230 and PSR J0348+0432. A coexistence of partial chiral symmetry restoration, diquark condensation (2SC phase) and the hadronic (confined) phase is conjectured that entails the existence of a quadruple point and is accessible by trajectories of constant entropy per baryon for heavy-ion collisions in the NICA/FAIR energy range.

1. Three-flavor color superconducting PNJL model and phase diagram

The phase diagram (PD) of quantum chromodynamics (QCD) is at the center of attention in modern physics. It is an object of intensive study at already existing heavy-ion collision facilities (LHC, RHIC, SPS) and will also be investigated at the planned ones (FAIR, NICA). In light of the difficulties of lattice simulations at a finite chemical potential, the class of Nambu–Jona-Lasinio (NJL) models has been applied in order to extract information and cast predictions on the phase structure of the QCD at high densities. Models extended by the Polyakov-loop (PNJL) have been shown to reproduce lattice results at $\mu = 0$ [1] and have been used to predict the PD [2]. In this contribution we report on the PhD for three-flavor quark matter described with the Polyakov-loop extension of Ref. [3]. By solving the gap equations for the order parameters related to symmetries and their breaking in the color superconducting three-flavor PNJL model [3] as functions of temperature T and baryochemical potential μ one arrives at a PhD with three order parameters characterizing the phase structure:

(i) chiral condensates (quark masses) - chiral symmetry breaking in light and strange sectors;
(ii) diquark gaps (color superconductivity) - 2SC and CFL phases;
(iii) Polyakov loop (confinement) - Z(3) symmetry breaking.

2. Results and Discussion

We consider the isospin symmetric case. The model parameters were constrained such that in applications for hybrid compact stars with quark matter core [4] the condition from the measurement of high masses $\sim 2\ M_{\odot}$ for the two pulsars PSR J1614-2230 and PSR J0348+0432 [5] would be fulfilled. The results are shown in the left panel of Fig. 1. The colored lines with

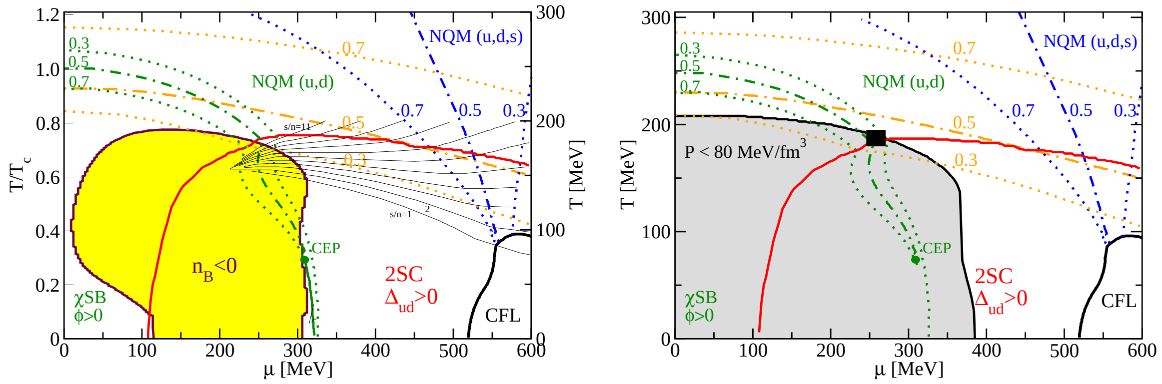

Figure 1. (Color online) Phase diagram of the 3FCS PNJL model for symmetric quark matter without (left) and with (right) hadron confinement. For details see text.

label "0.5" show the 50% reduction of the maximum value of the order parameter and serve as indicators of the crossover transition for light (green) and strange (blue) quark condensate as well as Polyakov loop (orange). The red (black) bold solid line denotes the second order transition to the 2SC (CFL) diquark condensate. Lines of constant entropy per baryon indicate paths for the dynamical evolution of a fireball in a heavy-ion collisions at NICA/FAIR energies which traverse the region of the color superconducting 2SC phase.

The occurrence of negative baryon densities and pressures (yellow region) in the phase diagram due to adjustment of color neutrality [6] is a feature this model has in common with other quark matter approaches which attempt to model confinement, e.g., bag models [7] and nonlocal covariant models with complex-conjugated mass poles [8]. Both, the pressure instability and color neutrality problem, can be removed simultaneously when color neutral hadronic bound states of quarks are introduced. Their dominance with positive pressure in the confined, chiral symmetry broken phase cures these problems. We define the phase border of confined hadronic matter (grey region in the right panel of Fig. 1) by $P_{\rm crit} \sim 80 \pm 3$ MeV/fm^3, the conjectured universal pressure at chemical freezeout [9]. We emphasize the accessibility at NICA/FAIR energies of a "quarkyonic matter" region with partial chiral symmetry restoration inside the hadronic world, as well as a quadruple point (black square) where the four phases meet.

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