QCD Critical Point: Role of Strange Quark Mass and Axial U(1) Anomaly ◇

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The Polyakov loop extended Nambu–Jona-Lasinio (PNJL) model with two light (u, d) quarks and one heavier (s) quark is used to study the QCD phase diagram. The model combines two important features of QCD: spontaneous chiral symmetry breaking with the chiral quark condensate as an approximate order parameter, and color confinement controlled by the Polyakov loop. The Polyakov loop parameters are fixed to reproduce lattice results in the pure-gauge scenario [1].

In QCD, the axial U(1) symmetry is broken at the quantum level. This is implemented by the 't Hooft determinant, a maximally flavor-mixing interaction term with a coupling strength K in the effective Lagrangian. This quantity is fixed along with the other NJL parameters (4-point interaction strength G, current quark masses, three-momentum cutoff Λ) by vacuum properties of the pseudoscalar mesons: f_π, m_π, m_K, m_η, $m_{\eta'}$. Several different calculations of parameter sets (see e. g. [2,3,4]), resulting in different 't Hooft interaction strength values, are available.

The QCD phase diagram at non-zero quark chemical potential is generally believed to feature a first-order transition of the chiral condensate up to a critical point and a crossover at higher temperatures. In our work we investigate whether and how the location of this critical point depends on K and on the strange-quark mass m_s. This is motivated in part by considerations in [5] and similar work done in [6]. In our studies we varied the parameter of interest while keeping all other parameters fixed. The results can be seen in fig. 1 and fig. 2.

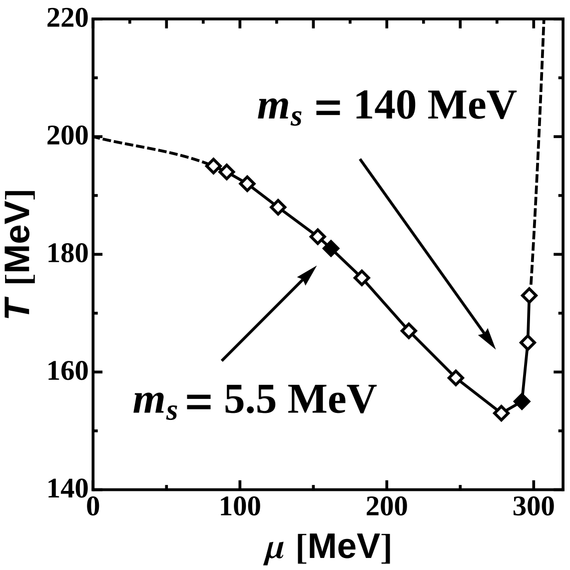

Fig. 1: Dependence of the location of the critical point on the strange-quark mass m_s. Starting from the solid diamond for $m_s = 140\,$MeV, each step to the left signifies half the current mass and each step to the right twice the mass. For reference, another solid diamond for the case of three degenerate quark masses is also shown.

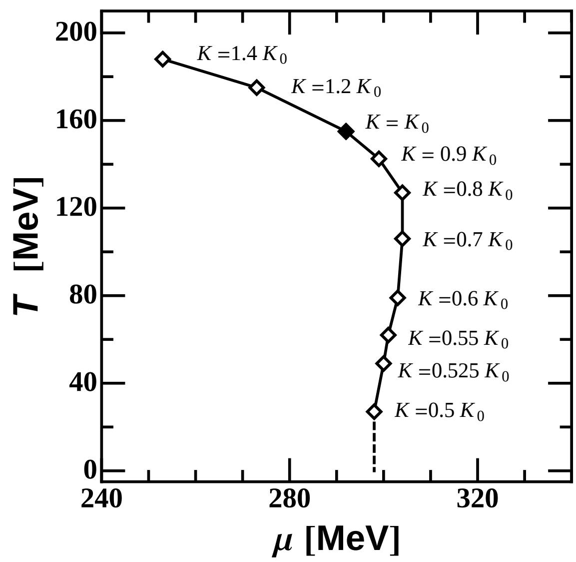

Fig. 2: Trajectory of the location of the critical point as a function of the 't Hooft interaction strength K. K_0 designates the standard value for K as a result of the NJL parameter fixing.

Regarding the dependence on m_s, we can state that, according to fig. 1, the location of the critical point does not vary greatly as long as m_s stays in the relatively wide range between 70 and 280 MeV with acceptable masses for the model usually located between 120 and 150 MeV. We notice, however, significant changes in the case of three degenerate quark masses (5.5 MeV each).

Fig. 2 shows that there is a strong dependence of the location of the critical point on the 't Hooft interaction strength K. At certain values of K there may not be a critical point at all. In our calculation it vanishes from the phase diagram if K is less than half the value resulting from the NJL parameter fixing (K_0).

This suggests that a critical point may not exist at all in the phase diagram. It remains to be investigated how much and in which way the inclusion of diquark degrees of freedom, i. e. the appearance of color-superconducting phases, influences this phenomenon. These questions are addressed by work in progress.

References

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