Polyakov Loop, Quasiparticles and QCD Phase Diagram ◇

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QCD thermodynamics has been the subject of intense investigations in recent years. In order to interpret corresponting lattice QCD results the Polyakov-loop extended Nambu Jona-Lasinio (PNJL) model is a promising field theoretical quasiparticle model [1,2,3,4] combining the two principal non-perturbative features of low-energy QCD: confinement and spontaneous chiral symmetry breaking. In the PNJL model quarks develop quasiparticle masses by propagating in the chiral condensate, while they couple at the same time to a homogeneous background (temporal) gauge field representing Polyakov loop dynamics. Recent investigations [2,3] have focused on PNJL calculations in comparison with lattice QCD thermodynamics including finite quark chemical potentials μ. An example is shown in Fig. 1.

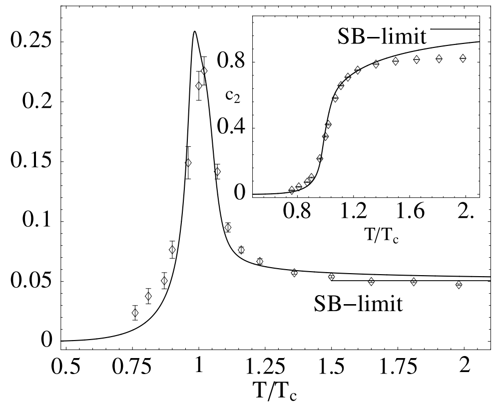

Fig. 1: PNJL result for the fourth moment of the pressure with respect to μ/T compared to lattice data [5]. The inset shows the corresponding second moment of the pressure.

Of particular interest is the location of the critical endpoint at which the chiral and deconfinement crossover transitions at lower μ turn into a first-order phase transition above some critical μ. In Fig. 2 we show the phase diagrams in the (T, μ)-plane derived from the PNJL model [2] using different current quark masses. The change of the critical endpoint with varying quark mass mainly reflects the dependence of the critical chemical potential on the quark mass. The presence of the diquark dominated phase at large μ stabilizes the temperature of the critical endpoint at rather high values.

The PNJL models with and without inclusion of diquarks show some qualitative difference concerning the critical endpoint of the first order transition line. In the case without inclusion of diquarks the critical endpoint lies on top of the merging chiral and deconfinement crossover transition lines, while in the case including diquarks the critical endpoint is shifted away from this line.

We have recently explored [3] the quark number susceptibilities. This observable is particularly interesting since it is known to diverge at the critical temperature for a first order phase transition. The observed peak in the lattice results for this observable [5] has been often interpreted as a signal of the tricritical point in the QCD phase diagram. Within our model [3] we have compared the full result for χ_q with the truncated one given by a Taylor expansion.

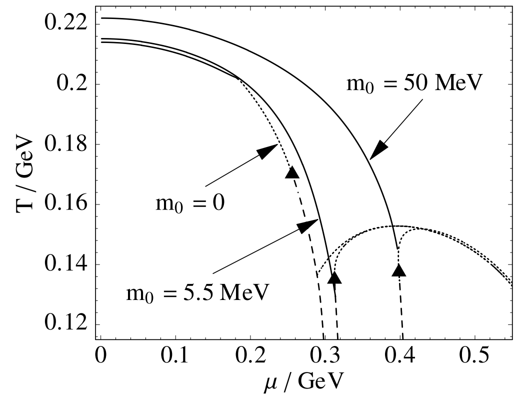

Fig. 2: Phase diagram predicted by the PNJL model including scalar diquarks. The graph illustrates the current quark mass dependence of the phases and the critical point.

The conclusions that we can draw are the following: the PNJL model gives a good description of the lattice data for a large variety of thermodynamical quantities. The comparison between the full PNJL results at finite chemical potential and the truncated ones show good convergence of the Taylor series up to $\mu/T \leq 0.4$ - 0.6. For larger values of μ/T, significant discrepancies are observed between full and truncated results in the region around the phase transition, in particular for the quark number susceptibilities. The singular behaviour of the susceptibilities observed in the expanded result is not present in the full calculation. The transition predicted by our model for $\mu/T = 1$ is still a crossover, reflected by the finite height of the peak in the corresponding quark number susceptibilities.

The good agreement of the calculated quark number susceptibilies with results from lattice calculations [5] encourages us to study isovector susceptibilies in the framework of the PNJL model. Further developments now aim for an extension of the present framework to $N_f = 3$ in order to explore the rich structure of colour superconducting (diquark) phases with three quark flavours and the additional effects of Polyakov loop dynamics.

References

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