Modelling the Chiral and Deconfinement Crossover Transitions ◇

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The Polyakov loop extended Nambu and Jona-Lasinio model (PNJL model) in a mean field framework shows astonishingly good agreement with lattice QCD calculations (see Figs. 1 and 2). In particular the coincidence of chiral and deconfinement crossover transitions seen in both lattice QCD and in the PNJL model (see Fig. 3) is a feature that needs to be better understood.

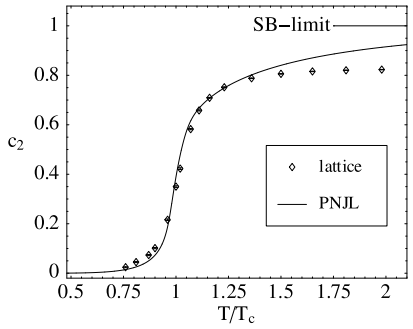

Fig. 1: A comparison of the second moment of the normalized pressure evaluated on the lattice [4] and in the PNJL model. (From Ref. [3])

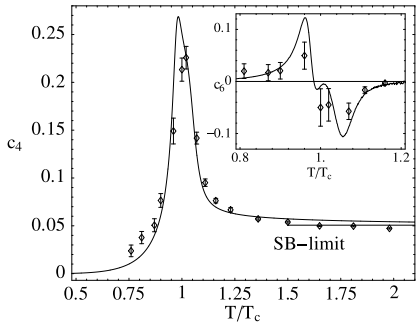

Fig. 2: Same as Fig. 1 of fourth and sixth moment of the normalized pressure.

In Ref. [3] we have presented a way to calculate corrections beyond mean field, resolving issues related to the complex fermion determinant in the PNJL model. This is achieved by means of a perturbative approach establishing a systematically ordered series of correction terms. We define the unperturbed model by the Taylor expansion up to second order in the fields of the real part of the bosonized effective action of the NJL model[1] plus the effective Polyakov loop potential[2]. The first term in such a Taylor expansion defines the mean field limit. Higher orders (beyond mean field) are treated using perturbative techniques. In the present PNJL model the perturbative corrections are small compared to mean field effects in Hartree Fock approximation indicating fast convergence of the established perturbative series. However for some quantities the mean field expectation values cancel. As a prominent example the thermal expectation values of the Polyakov loop $\langle\Phi\rangle$ and its conjugate $\langle\Phi^*\rangle$ are investigated here. Due to corrections beyond mean field the quantity $\langle\Phi\rangle - \langle\Phi^*\rangle$ assumes non-vanishing values once the quark chemical potential is non-zero. The up-down quark number susceptibility $\chi_{ud} = -\partial^2\Omega/(\partial\mu_{\rm u}\partial\mu_{\rm d})$ vanishes in mean field approximation as well, whereas the Polyakov loop induced corrections are non-zero.

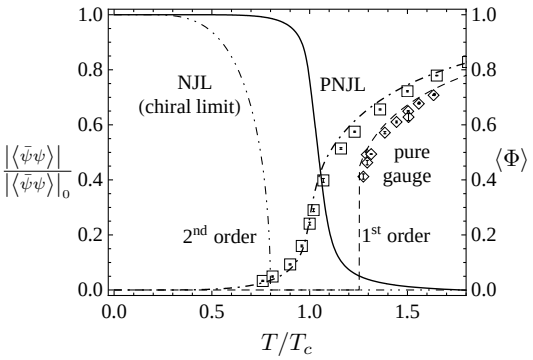

Fig. 3: Combining aspects of confinement (Polyakov loop Φ) and spontaneous chiral symmetry breaking (condensate $\langle\bar\psi\psi\rangle$) result in a joint crossover in the PNJL model [1,2,3]. The lattice results [5] shown here also show this feature. (From Ref. [3])

Further important corrections to mean field theory are those generated by collective quark-antiquark excitations. Such collective modes model the effects of light mesons in this framework. In the 2-flavour NJL-model these excitations correspond to the pion and the σ-boson. Due to the small mass of the pion as a pseudo Goldstone mode the resulting corrections of the effective potential are typically larger than corrections related to Polyakov loop induced confinement. In comparison with the mean field (Hartree) pressure such corrections are small. Pionic contributions to the pressure are important, however, below $T_{\rm c}$.

In the context of isospin asymmetric matter these pressure contributions also affect the quark-number susceptibilities χ_{uu} and χ_{ud}. Such susceptibilities are of special interestest in the experimental search for the critical endpoint in the QCD phase diagram.

References

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[1] The NJL parameters, current quark mass m_0, 4-quark coupling G and 3-momentum cutoff Λ are adjusted such that this part of the model reproduces physical pion properties.

[2] The Polyakov loop potential is parametrised such that is fulfils constraints imposed by the $SU(3)_{\rm c}$ gauge symmetry of QCD. Its parameters are fixed such that pure glue lattice QCD results are reproduced.