QCD Phases and Thermodynamics of a Nonlocal PNJL Model ◇

T. Hell, S. Rößner, and W. Weise

For two almost massless quark flavours, the SU(2) chiral symmetry of the QCD-Lagrangian is known to be dynamically broken at low energies. Pions appear as the corresponding Goldstone bosons. A simple scheme including these properties is the Nambu–Jona-Lasinio (NJL) model in which the quark interaction is described by a local four-fermion coupling. Asymptotic freedom is implemented crudely through a regularizing cutoff at approximately 1 GeV. This limits the applicability of the NJL model to a momentum range below that cutoff.

In the present work we include asymptotic freedom in a more realistic way and avoid the UV-cutoff of the NJL model. We use a chirally invariant nonlocal Lagrangian based on the one-gluon exchange interaction in the limit of high momenta. This Lagrangian enables us to perform calculations within a Schwinger-Dyson like approach to full QCD, reproducing a momentum dependent dynamical quark mass (Fig. 1) which is also accessible in lattice-QCD simulations (cf. e. g. Ref. [3]). As a result we are able to match the non-perturbative region of QCD to its perturbative regime.

In the zero temperature case it is possible to investigate pion properties and to recover fundamental current algebra relations such as the Goldberger–Treiman- and the Gell-Mann–Oakes–Renner relations. This is an improvement beyond the standard NJL model where, owing to the UV-cutoff, the validity of current algebra relations is not guaranteed.

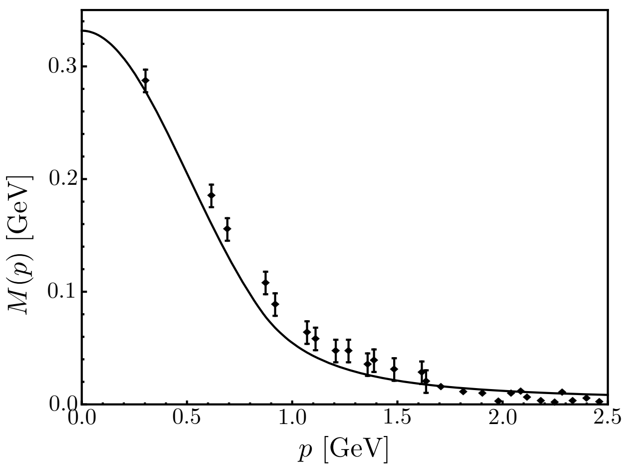

Fig. 1: Momentum dependence of the dynamical quark mass $M(p)$ compared to lattice data from Ref. [3].

As a second step we have applied this model to QCD thermodynamics, incorporating couplings to a gluonic background field in order to describe the confinement-deconfinement transition. The chiral condensate serves as an order parameter for the chiral phase transition while the confinement-deconfinement transition is controlled by the Polyakov loop. The resulting approach is a consistent nonlocal extension of the well-known PNJL model (Ref. [1,2]). One finds that the dynamical entanglement of the fermionic and the gluonic sector is of crucial importance in order to reproduce lattice results (Ref. [1]). While the transition temperatures for each individual sector differ significantly, the coupling of the fermions to the Polyakov loop intertwine these sectors so that chiral and confinement-deconfinement transitions coincide at a common transition temperature T_c close to 200 MeV.

Corrections of order $1/N_c$ beyond the mean field approximation have also been investigated, in particular those concerning mesonic quark-antiquark correlations. We found that mesonic corrections are important below the transition temperature T_c and decrease very rapidly above T_c. Furthermore, below T_c the mesonic contributions can be described roughly by those of an ideal gas of mesons (see Fig. 2).

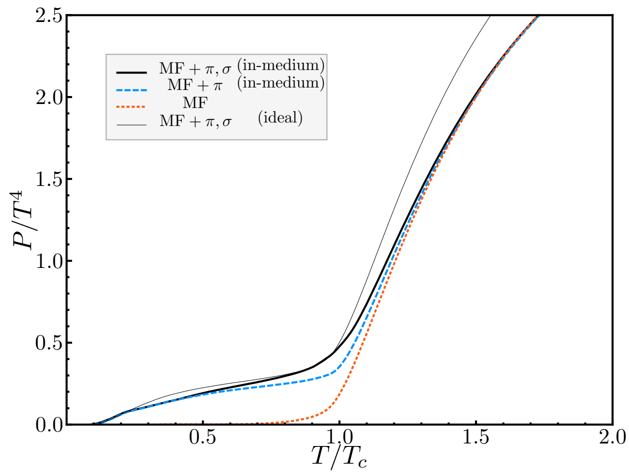

Fig. 2: Temperature dependence of the pressure: The dotted line shows the mean field contributions, the dashed line the mean field result in addition to the contributions of a pion; the full result including both sigma and pion corrections is shown by the solid line. As a comparison, the thin line displays the effects of a gas of ideal bosons together with the mean field result.

References

[1] S. Rößner, T. Hell, C. Ratti and W. Weise, arXiv:0712.3152 (2007)
[2] S. Rößner, C. Ratti and W. Weise, Phys. Rev. **D75** (2007) 034007
[3] P. O. Bowman *et al.*, Nucl. Phys. Proc. Suppl. **110** (2003) 323
[4] M. Cheng *et al.*, Phys. Rev. **D77** (2008) 014511

◇ Work supported in part by BMBF, GSI, and by the DFG Excellence Cluster "Origin and Structure of the Universe".