Quasiparticle Description of Hot QCD at Finite Quark Chemical Potential

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It is possible to describe the EOS of hot QCD at vanishing quark chemical potential μ to good approximation by the EOS of a gas of quasiparticles with thermally generated masses, incorporating confinement effectively by a temperature-dependent, reduced number of thermodynamically active degrees of freedom [1]. Lattice thermodynamical quantities such as the pressure, the energy density and the entropy density are accurately reproduced in the temperature range $T_c < T \lesssim 4T_c$. This model is extended to finite quark chemical potential in a thermodynamically self-consistent way [2].

The pressure of an ideal gas of quark and gluon quasiparticles with effective masses depending on temperature and quark chemical potential, is given by

$$p(T,\mu) = -B(T,\mu) + \frac{\nu_g}{6\pi^2}\int_0^\infty dk C(T,\mu) f_B(E_k^g)\frac{k^4}{E_k^g}$$
$$+\frac{N_c}{3\pi^2}\sum_{q=1}^{N_f}\int_0^\infty dk C(T,\mu)[f_D^+(E_k^q) + f_D^-(E_k^q)]\frac{k}{E_k^q}.$$

$E_k^i = \sqrt{k^2 + m_i^2(T,\mu;G(T,\mu))}$ is the quasiparticle energy, $G(T,\mu)$ is the effective coupling strength and $C(T,\mu)$ parametrizes the reduction of thermally active degrees of freedom due to the onset of confinement close to T_c. $B(T,\mu)$ acts as a background field and is necessary to maintain thermodynamic consistency. The expressions for the effective coupling $G(T,\mu=0)$ and the confinement factor $C(T,\mu=0)$ from Ref. [1] are generalized to finite quark chemical potential using Maxwell relations. The characteristic curves of constant confinement $C(T,\mu)$ =const. are shown in Fig.1.

In our quasiparticle model, the sudden decrease of the pressure, the energy density, the quark number density and the entropy density when T_c is approached from above, is parametrized by the confinement factor $C(T,\mu)$. Consequently, it is natural to relate the critical line to the characteristic curve of the confinement factor through $T_c(\mu)$. The lattice phase boundary line and our result is shown in Fig.1.

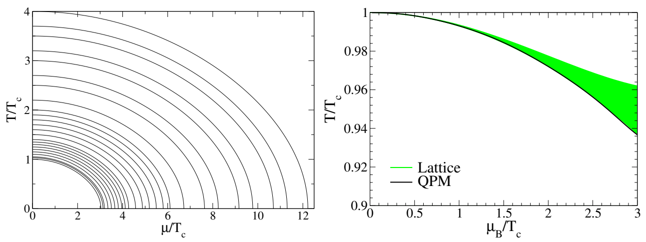

Fig. 1: Left figure: characteristic curves of constant confinement factor $C(T,\mu)$ =const. Right figure: The phase boundary line $T_c(\mu)$ calculated with the quasiparticle model for $N_f = 3$. The shaded band shows the $1-\sigma$ error band obtained in lattice calculations in ref Ref. [3].

Thermodynamical quantities have been calculated in recent lattice computations using a p4-improved staggered action on a $16^3 \times 4$ lattice [4]. There, the N_τ dependence is known to be small, in contrast to standard staggered fermion actions which show substantially larger cut-off effects. Our quasiparticle model accurately reproduces the pressure discrepancy $\Delta p(T,\mu) = [p(T,\mu) - p(T,0)]/T^4$ and the quark number density $n_q = \partial p(T,\mu)/\partial\mu$. Results are shown in Figs.2 and 3.

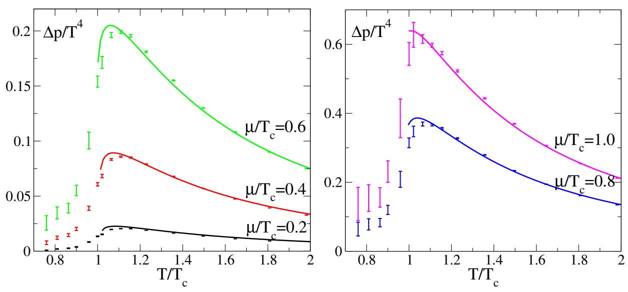

Fig. 2: The normalized pressure difference $\Delta p(T,\mu)/T^4$ as a function of temperature compared to lattice results from Ref. [4] (symbols).

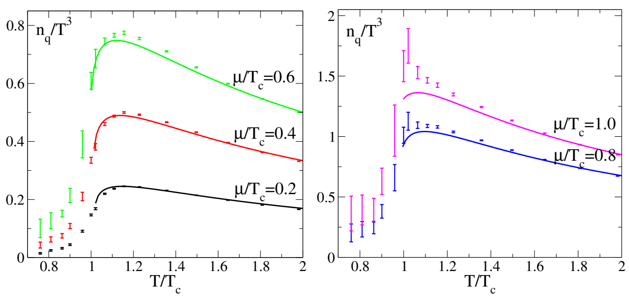

Fig. 3: The normalized quark number density $n_q(T,\mu)/T^3$ as a function of temperature compared to Ref. [4] (symbols).

We have developed a quasiparticle description of the QCD EoS at finite temperature and quark chemical potential and calculate the phase boundary line $T_c(\mu)$, the normalized pressure difference $\Delta p(T,\mu)$ and the normalized quark number density $n_q(T,\mu)/T^3$. Our results are in remarkably good agreement with recent lattice calculations even for large quark chemical potentials $\mu \sim T_c$.

References

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