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THE QGP PHASE AND THE COUPLING

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1. The high temperature phase of QCD

On quite general grounds it is expected, that fundamental forces between quarks and gluons get modified at finite temperature. The long distance part of these forces which reflect the non-perturbative screening property of the quark gluon plasma (QGP) (*i.e.* $T > T_c$) plays a central role in our attempts to understand the bulk properties of the QCD plasma phase, *e.g.* the equation of state[1,2] or the order parameter[3,4,5] (Polyakov loop) and the apparent deviations from the ideal gas behavior found in these numerical calculations. For instance, in Fig. 1 we show the confinement deconfinement order parameter as function of temperature ranging from T_c up to temperatures about $25T_c$. At temperatures of this large extent deviations only about 10% from the ideal gas limit are present but the order parameter is expected to approach its ideal gas limit slowly with increasing temperature[6]. The deviations of these different thermodynamic quantities from their ideal gas behavior are often discussed in terms of strongly coupled Coulombic forces (see Ref. 7) at temperatures above deconfinement.

On the other hand, it is the short and intermediate distance regime which is important for the discussion of possible signals which are considered today as being suitable to gain information on the properties of hot and dense matter generated experimentally in heavy ion collisions. For instance, at short distances hard processes dominate the physics of the quark gluon plasma and the scale which controls the coupling appropriate for these distances will be given by the distance itself [10]. It is the interplay between short and large distance length scales which plays a crucial role for the quantitative understanding of hard as well as soft processes in dense matter and it is not immediately evident which scale, *i.e.* temperature and/or distance, will dominate the running of the QCD coupling. An analysis of this question becomes of particular interest in view of the recently suggested scenario for the existence of a large number of Coulombic bound states in the QCD plasma phase close to T_c[7,8,9]. A different view at temperatures close above deconfinement

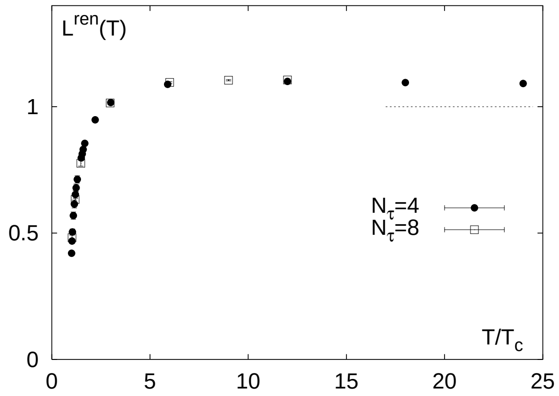

Fig. 1. The order parameter, L^{ren}, as function of temperature from pure gauge lattice studies (see Ref. 3). The dashed line indicates its free gas limit, $\lim_{T\to\infty} L^{ren} = 1$.

has recently been introduced by us by direct investigating the coupling with non-perturbative methods at those temperatures[10]. Our studies suggest that it might be misleading to quantify all the non-perturbative, still strong forces at temperatures which are only moderately larger than T_c in terms of 'strongly Coulombic forces' as remnants of the confinement forces still may in parts control the dynamics of the QCD plasma. Moreover, the values of the coupling strongly depend on the different physical observables used for its definition in the non-perturbative regime.

2. The running coupling at finite temperature

For the purpose of defining a running coupling at finite temperature the color singlet quark antiquark free energy (F_1) is most appropriate as it has at short and large distances a simple asymptotic behavior which is dominated by one gluon exchange (for the definition of F_1 and further references see Refs. 3, 10). In general, however, the definition of a running coupling in QCD is not unique beyond the validity range of 2-loop perturbation theory; aside from the scheme dependence of higher order coefficients in the QCD β-function, at large distances any perturbative motivated definition of a running coupling will also become sensitive to non-perturbative effects and may lead to quite different results. This is already apparent when defining the coupling in QCD either in terms of free energy (in the $T=0$-case: potential)

$$\alpha_V(r,T) = -\frac{3r}{4} \times F_1(r,T)\ , \qquad (1)$$

or its derivative (in the $T=0$-case: force)

$$\alpha_{qq}(r,T) = +\frac{3r^2}{4} \times \frac{dF_1(r,T)}{dr}\ . \qquad (2)$$

In fact, for a linear confining potential, *i.e.* $V(r) \simeq \sigma r$, α_V will become negative and drop quadratically while α_{qq} defined through Eq. (2) will rise quadratically at large

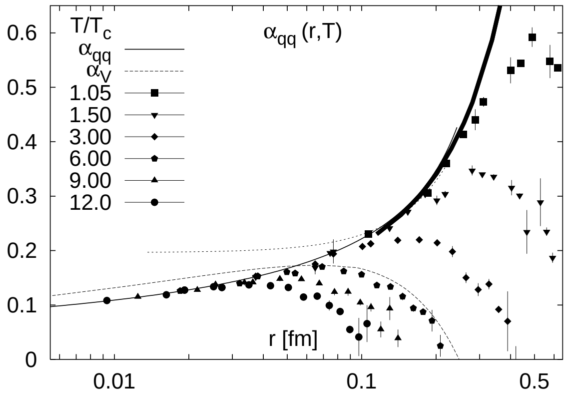

Fig. 2. The running coupling in the qq-scheme defined in Eq. (2) as function of distance at several temperatures. Also shown are the corresponding $T = 0$ quantities, $\alpha_V(r)$ (dashed line) and $\alpha_{qq}(r)$ (solid line) from Ref. 10. The thick (lattice data) and the upper dashed (string picture) lines show the T=0 confinement potentials in terms of α_{qq}.

distances. The latter allows for smoothly matching the increasing coupling in the perturbative regime to the non-perturbative increase. In Fig. 2 we show our results for $\alpha_{qq}(r,T)$ at several temperatures above T_c. It is quite evident from that figure that α_{qq} is controlled at small distances by the quark antiquark separation and shows no or only little temperature dependence. Moreover, at temperatures close to T_c the coupling mimics the linear rising of the zero temperature confinement potential. Remnants of the confining forces thus survive the deconfinement phase transition and play an important role in the quark antiquark interaction at intermediate distances. At larger distances, however, the free energy is clearly controlled by color screening and thus non-perturbative effects dominate α_{qq}. Subtracting the screening effects from the coupling at large distances can lead to different definitions for the coupling as function of temperature which show quite different values at temperatures close above T_c.

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