The High-Temperature Phase of Landau Gauge Yang-Mills Theory

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The high-temperature phase of QCD is an enigma. Although its equation of state is close to that of an ideal gas, perturbation theory fails in describing it. Indeed, the problems encountered are similar to those in the vacuum, like infrared divergences. A possible way towards understanding the origin of this discrepancy is presented here.

In a first step only Yang-Mills theory is treated, i.e. QCD without quarks, to reduce the complexity of the problem. For many technical reasons it is advantageous to choose Landau gauge. In equilibrium the theory is then governed by the Euclidean Lagrangian [1]

$$\begin{aligned} \mathcal{L} &= \frac{1}{4}F^a_{\mu\nu}F^a_{\mu\nu} + \bar{c}^a\partial_\mu D^{ab}_\mu c^b \qquad (1)\\ F^a_{\mu\nu} &= \partial_\mu A^a_\nu - \partial_\nu A^a_\mu - gf^{abc}A^b_\mu A^c_\nu \\ D^{ab}_\mu &= \delta^{ab}\partial_\mu + gf^{abc}A^c_\mu \ . \end{aligned}$$

Herein A denotes the gluon field and c and $\bar{c}$ the Faddeev-Popov ghost and anti-ghost fields. The latter are a convenient way to describe the quantum fluctuations of the gluon field and additionally ensure the correct number of degrees of freedom.

From (1), the corresponding Dyson-Schwinger equations have been derived and solved in an approximation scheme for the propagators at temperatures above the phase transition [2, 3]. The propagators are described by three independent scalar functions as

$$\begin{aligned} D_G(q) &= -\frac{G(q_0^2,q_3^2)}{q^2} \ , \\ D_{\mu\nu}(q) &= P^T_{\mu\nu}(q)\frac{Z(q_0^2,q_3^2)}{q^2} + P^L_{\mu\nu}(q)\frac{H(q_0^2,q_3^2)}{q^2} \ . \end{aligned}$$

Here G denotes the ghost dressing function, and Z and H the ones for gluons transverse or longitudinal w.r.t. the heat bath. $q=(q_0,q_3)$ is the four-momentum with q_0 the Matsubara frequency $q_0 = 2\pi nT$ with n integer.

The infrared properties of the propagators can be directly linked to confinement and the presence of long-range forces. Especially a ghost dressing function G which diverges at $q^2=0$ indicates the presence of long-range forces and signals confinement according to the Kugo-Ojima and Gribov-Zwanziger scenarios. Furthermore, if a propagator vanishes at $q^2=0$, the corresponding particle is confined. This is clear for a massless particle, as this is just the statement that the on-shell propagator vanishes (for a brief introduction to confinement in covariant gauges see [4]).

As visible from figure 1, displaying the soft modes $q_0=0$, G diverges. Furthermore, Z vanishes, in accordance with lattice results. Thus at least gluons transverse to the heat bath are confined. Propagators for gluons longitudinal w.r.t. the heat-bath are not shown. They exhibit screening, although they are not entirely trivial [2]. This behavior is not changed even in the infinite temperature limit. Therefore the high-temperature phase is microscopically never purely perturbative and at least a residual confinement is present. Investigations of the thermodynamic potential, however, indicate that the potential is dominated by the hard modes. The latter are not not shown, but are essentially tree-level like, up to perturbative corrections [3]. Therefore the equation of state is nearly that of an ideal gas. This indicates how the discrepancy mentioned in the beginning could be resolved, but it has to be studied in more detail before a firm conclusion can be drawn.

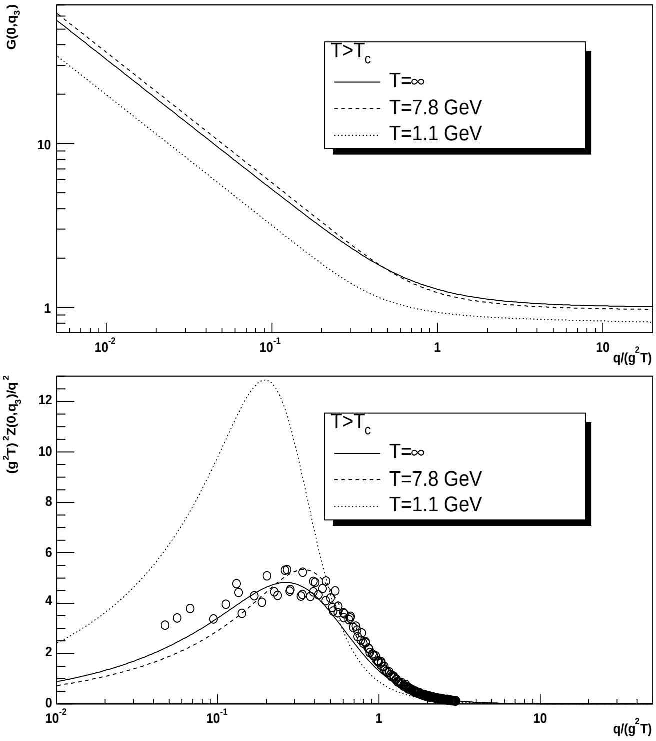

Figure 1: The dressing function of the ghost and the propagator of the gluon transverse w.r.t. the heat-bath are displayed from top to bottom for soft modes. The infinite temperature lattice data in the lower panel are from [5].

References

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