Probing deconfinement with Polyakov loop susceptibilities *

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Deconfinement can be described by the spontaneous breaking of Z(3) center symmetry. The relevant quantities to study are the Polyakov loop and its susceptibilities. The Polyakov loop reflects the free energy of a static quark immersed in a hot gluonic medium. At low temperatures its thermal expectation value vanishes, signaling color confinement, while at high temperatures it is nonzero, resulting in a finite energy of a static quark and consequently the deconfinement of color. It is thus an order parameter for the deconfining phase transition.

The Polyakov loop susceptibility, on the other hand, represents fluctuations of the order parameter. It exhibits a peak at the transition temperature, and a width that signals the temperature window in which the phase transition takes place. While the basic thermodynamic functions of the SU(3) pure gauge theory, such as pressure and entropy, are well established within the lattice approach, the temperature dependence of the renormalized Polyakov loop and its susceptibilities are less clear. A careful study of these quantities will improve our understanding of the QCD phases.

In SU(3) gauge theory, the Polyakov loop is a complex-valued operator. One can therefore explore the fluctuations of the order parameter along the longitudinal (real) and transverse (imaginary) directions. However, the proper renormalization for these composite gluonic correlators remains ambiguous. One way to circumvent this problem is to consider the ratios of susceptibilities [1].

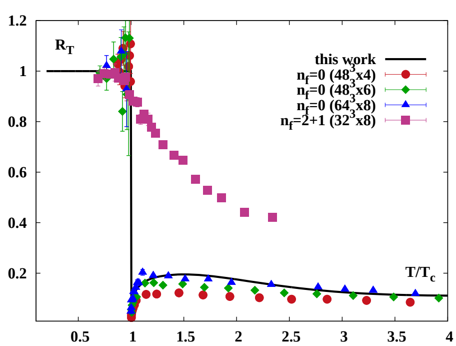

Figure 1: The ratio of Polyakov loop susceptibilities, $R_T = \chi_T/\chi_L$, in pure gauge system and in (2+1)-flavor QCD. The temperature is normalized to the (pseudo)critical value in each system. The lines show the results of the Polyakov loop model [2].

Fig. 1 shows the temperature dependence of the ratio of the transverse and longitudinal Polyakov loop susceptibilities, obtained in SU(3) gauge theory and in (2+1)-flavor QCD [2]. In the pure gauge limit ($N_f = 0$), the ratio R_T is discontinuous at T_c, and change only weakly with temperature on either side of the transition. This feature makes the ratio ideal for probing deconfinement. At high temperatures, the Z(3) symmetry is spontaneously broken. The pure gauge result indicates a small value for this ratio. In terms of an effective potential, this finding suggests that, around the global minimum associated with the symmetry-broken vacuum, the curvature in the transverse direction is much steeper than that in the longitudinal direction.

In the presence of light quarks, the Polyakov loop is no longer a true order parameter for deconfinement owing to the explicit breaking of the Z(3) symmetry. The ratio is smoothened and vary continuously across the pseudocritical temperature. One expects that the width of the crossover transition depends on the number of flavors and the values of quark masses. The value of R_T at high temperatures is found to deviate substantially from the pure gauge limit. An interpretation of this feature is still lacking.

We conclude that the ratio of Polyakov loop susceptibilities provides an excellent signal for the deconfinement phase transition. One immediate application of this work is to constrain the parameters used in effective models, thus providing a more realistic description of the QCD phase structure [2]. Further, more detailed lattice calculations are needed in order to obtain robust results for the gluonic correlation functions, as well as a better understanding of the systematic uncertainties.

References

[1] P. M. Lo, B. Friman, O. Kaczmarek, K. Redlich, and C. Sasaki, Phys. Rev. D **88** (2013) 014506.

[2] P. M. Lo, B. Friman, O. Kaczmarek, K. Redlich, and C. Sasaki, Phys. Rev. D **88** (2013) 074502.

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