Polyakov loop fluctuations and deconfinement in the limit of heavy quarks

Pok Man Lo, 1 Bengt Friman, 1 and Krzysztof Redlich 1,2

1 GSI, Helmholtz Center for Heavy Ion Research
2 Institute of Theoretical Physics, University of Wroclaw
pmlo@gsi.de

Introduction

Deconfinement in the pure gauge limit
• described by spontaneous Z(3) symmetry breaking → 1st order
• stable against small explicit symmetry breaking.
2.) Dynamical quarks break the symmetry explicitly
• strength increases as quark mass decreases.
• 1st order → 2nd order (deconfining CEP) → continuous.

The effective potential of the Polyakov loop
1.) Pure gauge part: phenomenological model
\[ U_T = -\frac{1}{2}(kT)\partial L + B(T)\ln M_Q + \frac{1}{2}(kT)\partial (LL)^2. \]  

2.) Quark contribution:
• determinant of fermionic matrix \( Q_P \) under gluon background field \( A_t \)
• one loop result:
\[ Q_P = (\partial_\mu + i g A_\mu)\gamma^\mu \gamma^5 \gamma_5 \nabla - m \]
\[ U_Q = -2N_c\beta^3 \int \frac{d^4k}{(2\pi)^4} (g^\mu + g_\mu) \]
\[ g^\mu - T \nabla (1 + 3Le^{-3E}) + 3Le^{-3E} + e^{-3E} \]

• \( g^\mu \) describes the coupling of quarks (anti-quarks) to the Polyakov loops, with \( E^2 = E|k| \equiv m \).

Results on order parameter and its fluctuations
1.) Polyakov loop
• measures the free energy of static quark immersed in hot gluonic medium.
• defines an order parameter for deconfinement.
2.) Polyakov loop susceptibility
• features peak and width.
• has two components: \( \chi_{L,T} \equiv \frac{1}{2}(\langle LL \rangle + \langle TT \rangle) \).

Deconfining CEP at finite chemical potential

Mean-field analysis reveals:
\[ U_Q \approx -h(\beta m, \beta \mu, N_f)K_L \]
\[ h(\beta m, \beta \mu, N_f) \approx \frac{N_c}{2}(\beta m)^2K_3(\beta m) \cos h(\beta m), \]
\[ \mu_c = T \cosh^{-1}(h_c / (N_c/2(\beta m)^2K_f(\beta m))). \]

Conclusions
• \( \chi_c \) is strongly enhanced in the critical region → probe the location of the deconfining CEP.
• \( \chi_T \) is insensitive to the continuous phase transition → only monotonic behavior.
• Deconfining CEP: \( m_c \approx 1.48 \text{GeV} \) for \( N_f = 3, \mu = 0 \).
• Matrix model: \( m_c \approx 2.5 \text{GeV} \).
• Lattice estimate: \( m_c \approx 1 - 2.5 \text{GeV} \) (no continuum extrapolation yet).
• Deconfining temperature: \( T_c \approx 0.26 \text{GeV} \) at the CEP. 9 MeV lower than pure gauge result.
• \( m_c \) increases with \( \mu \) → first order region shrinks.
• Mandatory to take fluctuations into account in constructing the Polyakov loop potential.

Further research
• to study the nature of physical excitations associated with the longitudinal Polyakov loop
• to characterize the gluons in the QGP
• to determine the screening masses associated with the relevant multi-gluon and glueball states

References