Polyakov loop fluctuations and deconfinement in the limit of heavy quarks

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Introduction

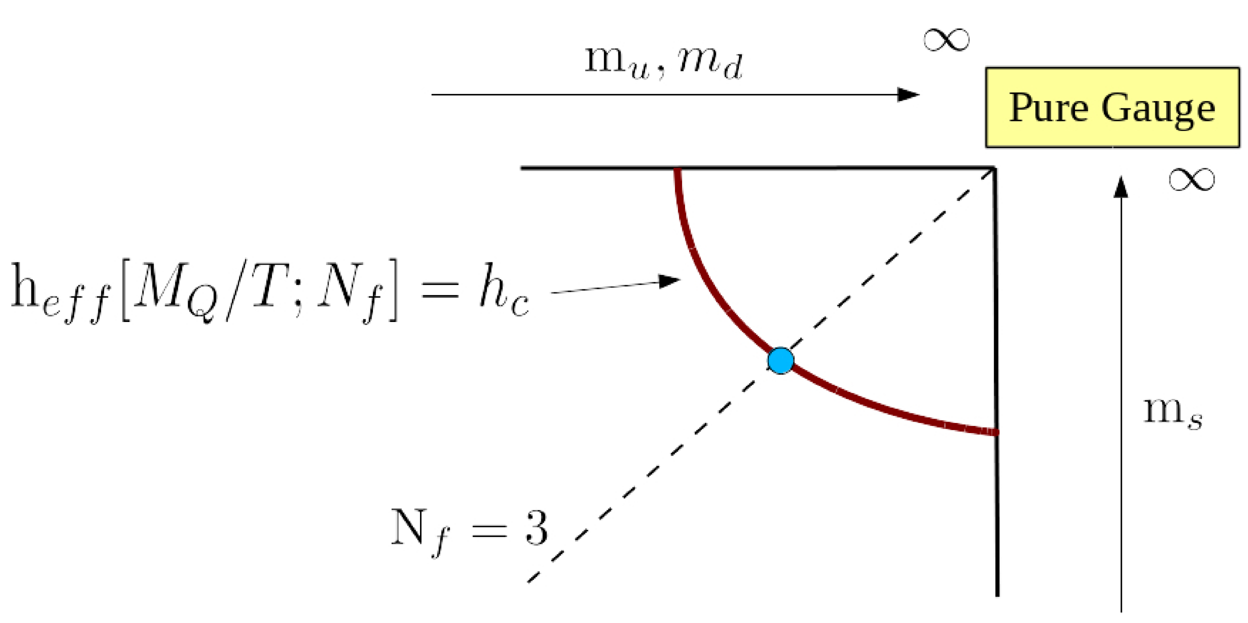

Figure 1: The shape of pure gauge potential above T_c.

1.) Deconfinement in the pure gauge limit

- described by spontaneous Z(3) symmetry breaking $\rightarrow$ 1st order.
- stable against small explicit symmetry breaking.

2.) Dynamical quarks break the symmetry explicitly

- strength increases as quark mass decreases.
- 1st order $\rightarrow$ 2nd order (deconfining CEP) $\rightarrow$ continuous

The effective potential of the Polyakov loop

1.) Pure gauge part: phenomenological model

$$\begin{aligned} U_G = &-\frac{1}{2}A(T)\bar{L}L + B(T)\ln M_H \\ &+\frac{1}{2}C(T)(L^3+\bar{L}^3) + D(T)(\bar{L}L)^2. \end{aligned} \quad (1)$$

- includes the effects of SU(3) Haar measure M_H.
- model parameters tuned to match the pure gauge lattice data on P, L, χ_L, χ_T

2.) Quark contribution:

- determinant of fermionic matrix $\hat{Q}_F$ under gluon background field A_4
- one loop result:

$$\begin{aligned} \hat{Q}_F &= (-\partial_\tau + \mu - igA_4)\gamma^0 + i\vec{\gamma}\cdot\nabla - m \\ U_Q &= -2N_f\beta^4 \int \frac{d^3k}{(2\pi)^3}[g^+ + g^-] \\ g^+ &= T\ln(1 + 3Le^{-\beta E^+} + 3\bar{L}e^{-2\beta E^+} + e^{-3\beta E^+}) \end{aligned} \quad (2)$$

- $g^{\pm}$ describes the coupling of quarks (anti-quarks) to the Polyakov loops, with $E^{\pm} = E(k) \mp \mu$.

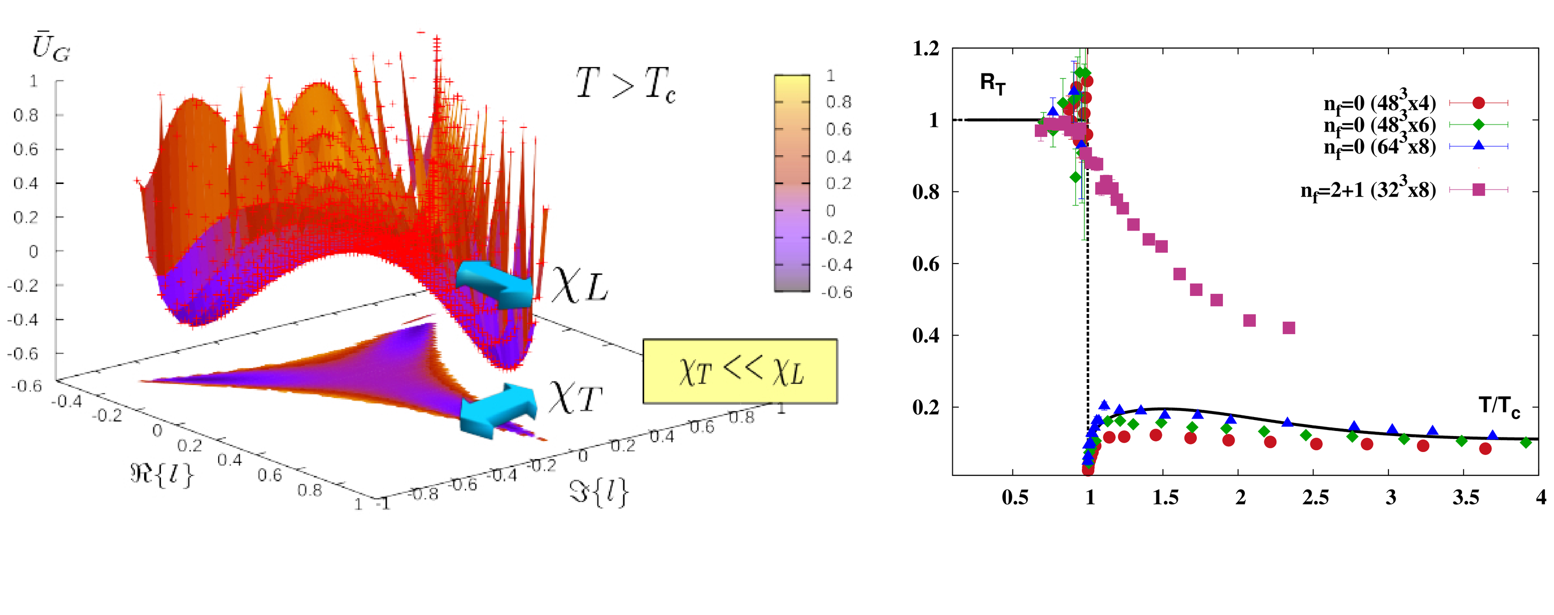

Figure 2: Left: the shape of pure gauge potential U_G above T_c. Right: the ratio of Polyakov loop susceptibilities, $R_T = \chi_T/\chi_L$, in pure gauge system and in (2+1)-flavor QCD. The temperature is normalized to the (pseudo)critical value in each system. The lines show the results of the Polyakov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

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: $\chi_{L,T} = \frac{1}{2}V(\langle L\bar{L}\rangle_c \pm \langle LL\rangle_c)$.

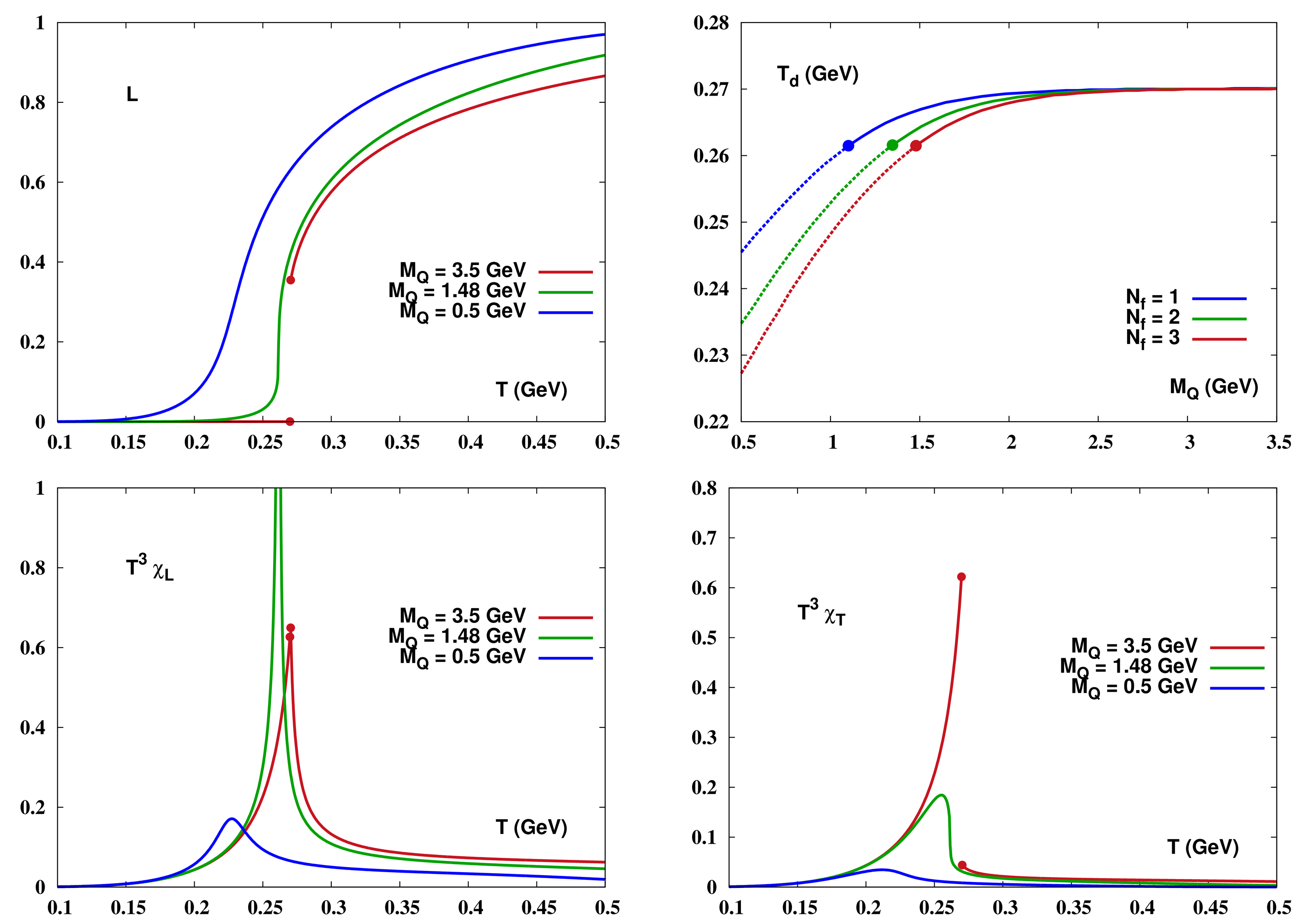

Figure 3: Temperature dependence of thermal observables for different quark masses at $N_f = 3$. Also shown is the quark mass dependence of the deconfining temperature, defined from the peak of χ_L, for different N_f. Full lines correspond to the first order phase transitions, while dashed lines represent the pseudocritical temperature of the crossover transition. The CEP for different N_f are indicated by the points.

Deconfining CEP at finite chemical potential

Mean-field analysis reveals:

$$\begin{aligned} U_Q &\simeq -h(\beta\mu, \beta m, N_f)L_L, \\ h(\beta m, \beta\mu, N_f) &\simeq \frac{6N_f}{\pi^2}(\beta m)^2 K_2(\beta m)\cosh(\beta\mu), \\ \mu_c &= T\cosh^{-1}(h_c/(\frac{6N_f}{\pi^2}(\beta m)^2 K_2(\beta m))). \end{aligned} \quad (3)$$

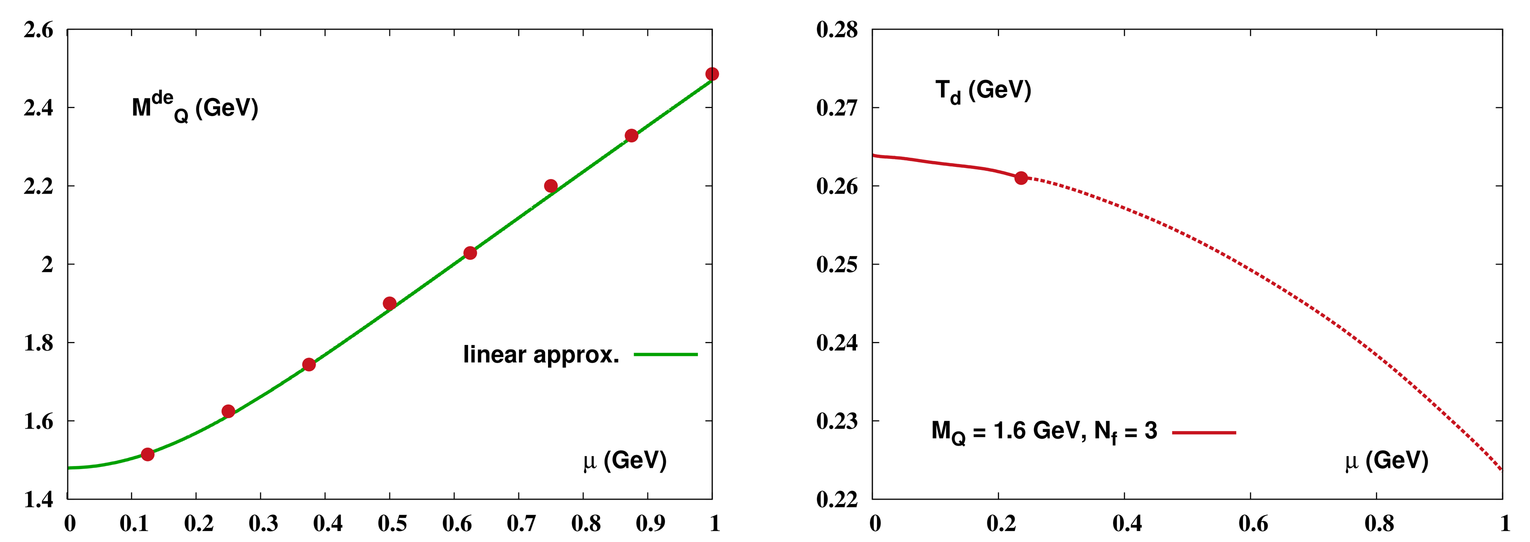

Figure 4: The critical quark mass and temperature for different quark chemical potential at the CEP for $N_f = 3$. Solid points represent results obtained from the global maximum of χ_L. The line is the solution of the Eqn. (6)

Conclusions

- χ_L is strongly enhanced in the critical region $\rightarrow$ probe the location of the deconfining CEP.
- χ_T is insensitive to the continuous phase transition $\rightarrow$ shows only monotonic behavior.
- Deconfining CEP: $m_c = 1.48\,\text{GeV}$ for ($N_f = 3, \mu = 0$).
  - matrix model: $m_c \approx 2.5\,\text{GeV}$.
  - lattice estimate: $m_c \approx 1 - 1.5\,\text{GeV}$ (no continuum extrapolation yet).
  - $T_c = 0.261\,\text{GeV}$ at the CEP, $9\,\text{MeV}$ lower than pure gauge result.
- m_c increases with $\mu \rightarrow$ 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

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