# Effective SU(2) Polyakov Loop Theories for the Deconfinement Transition

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## Motivation

- understand the phase diagram of QCD-matter under extreme conditions in temperature and density
- develop reliable methods for finite baryon density where fermion sign problem prevents direct lattice Monte-Carlo simulations
- functional methods applied to e.g. Polyakov-Quark-Meson model, Polyakov–Nambu–Jona-Lasinio model, important input: effective Polyakov loop potential
- use effective Polyakov loop theories on the lattice to extract the Polyakov loop potential
- test effective theory by comparing to full two-color QCD simulations (no sign problem)

## Effective Polyakov Loop Theories

- 3d SU(N) spin models sharing universal behavior at deconfinement transition with underlying gauge theory
- can be derived from combined strong coupling and hopping expansion
- less computational cost, especially with dynamical fermions
- finite density $\longrightarrow$ Worm algorithm, complex Langevin algorithm
- effective action:

most general form [1]:

$$S = \sum_{ij} L_i K^{(2)}(i,j) L_j + \sum_{ijkl} L_i L_j K^{(4)}(i,j,k,l) L_k L_l + \ldots - \sum_i h L_i + \ldots$$

can also contain loops in adjoint or higher representations. Truncate Series: e.g. nearest neighbor interactions, LO fermion contribution

$$S = -\lambda \sum_{\langle ij \rangle} L_i L_j - 4N_f \sum_i h L_i$$

more involved method, motivated by combined strong coupling and hopping expansion: resum generalized Polyakov loops [2]:

$$S = -\sum_{\langle ij \rangle} \log(1 + \lambda L_i L_j) - 4N_f \sum_i \log(1 + h L_i + h^2)$$

- compare different models to each other and use two-color QCD simulations as benchmark:
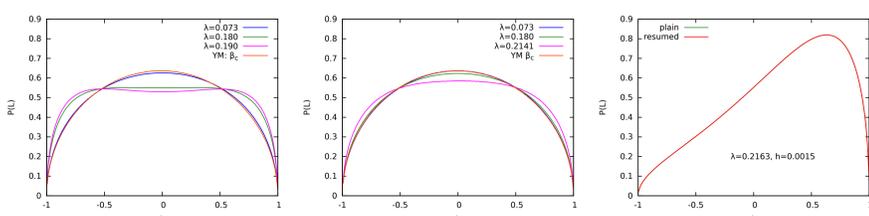


**left:** Polyakov loop distributions from the LO effective theory (pure gauge) in comparison with two-color Yang-Mills results from [3]. **center:** Distributions from the resummed effective theory (pure gauge). **right:** Comparison of the unquenched effective theory with and without resummation of the fermion action.
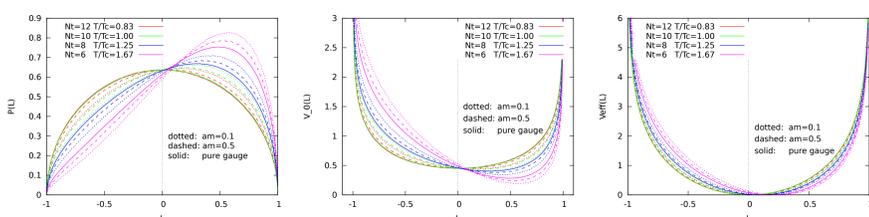
## Two-Color QCD Simulations and Effective Polyakov Loop Potential

- generate Polyakov loop distributions by two-color QCD simulations with two flavors of staggered quarks
- use fixed scale approach to set temperature scale
- obtain local effective Polyakov loop potential from Polyakov loop distributions:

$$V_0(L) = -\log P(L)$$
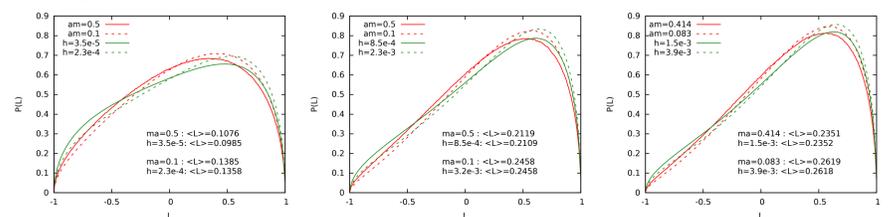$$W(h) = \log \int dL \exp[-V_0(L) + hL]$$
$$V_{\text{eff}}(\hat{L}) = \sup_h (\hat{L}h - W(h))$$



Polyakov loop distributions, constrained potential and effective potentials from two-color QCD simulations [4].
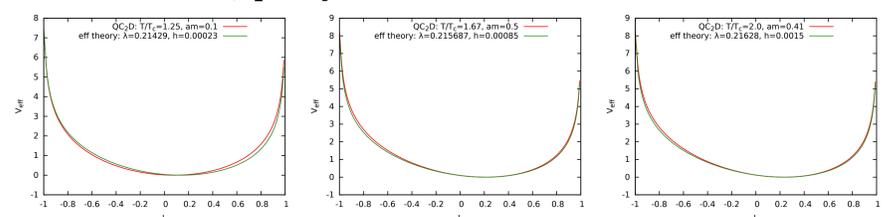
## Polyakov Loop Potentials from the Effective Theory

- generate Polyakov loop distributions by effective theory simulations
- tune couplings $\lambda$ and $h$ to reproduce the correct values of $\langle L \rangle$



Polyakov loop distributions from the effective theory compared to two-color QCD simulations. **left:** $T/T_c = 1.25$, $\lambda = 0.2142$ **center:** $T/T_c = 1.67$, $\lambda = 0.2156$ **right:** $T/T_c = 2.0$, $\lambda = 0.2163$.
- general form of distribution and dependence of temperature and fermion mass is reproduced
- small deviations from QC$_2$D shape



Effective Polyakov loop potential from the effective theory compared to two-color QCD simulations [4].
- good agreement between effective theory and two-color QCD

## Further Results

- non-local observables in the effective theory: Polyakov loop correlators
- $\lambda \gtrsim 0.073$: long range interaction become important $\longrightarrow$ possible reason for deviations in Polyakov loop distributions
- loops in higher representations, e.g. adjoint loops: strong fluctuations around $\lambda_c$, not important at $\lambda \neq \lambda_c$
- ergodicity problems around $\lambda_c \longrightarrow$ solved by thermalizing 'over and over'
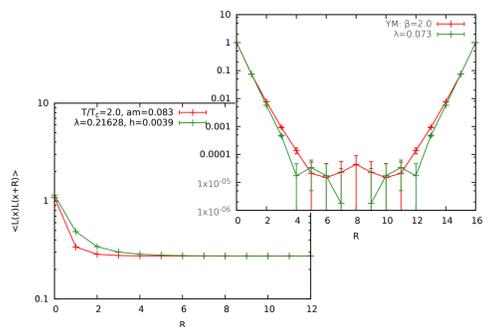


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Simulations for the effective theory were performed on NVIDIA GTX 780 and GTX Titan GPUs. Parts of the two-color QCD simulations were also done on the NVIDIA Tesla K20X GPUs from the Lichtenberg-Cluster at TU Darmstadt.

## Outlook

- effective Polyakov loop potentials: go to smaller quark masses $\longrightarrow$ scale adjustment
- attempt to include long range interactions, see [5]
- simulations of effective theory and full QC$_2$D at finite density
- main goal: effective Polyakov loop potentials at finite density
- other applications of effective theory: cold nuclear matter [6]

## References

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