University of Colorado Boulder

Finite Temperature Study of a 4+6 Mass-Split System

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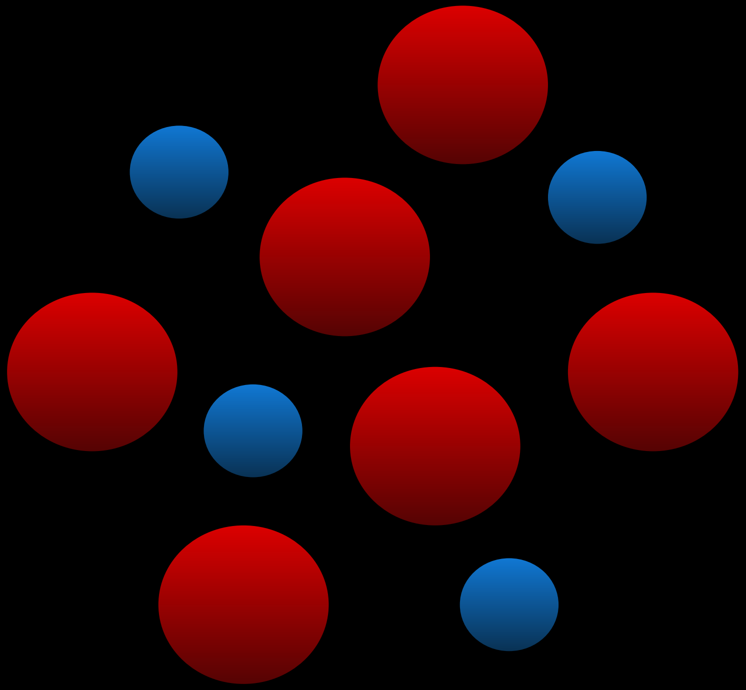
Composite Higgs assumes the Higgs boson to be bound state of a new, strongly-interacting sector.

This new strong sector has to be chirally broken and hence should experience a finite-temperature phase transition.

The observation of a first-order finite-temperature transition would have implications for the early universe, such as the production of primordial gravitational waves.



4+6 Mass-Split System

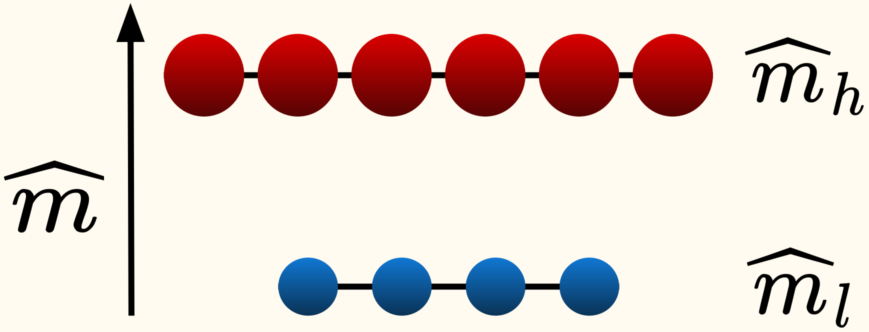
The 4+6 mass-split system provides a framework to explore the composite Higgs scenario.

The system is an SU(3) gauge theory composed of $N_l = 4$ light flavors and $N_h = 6$ heavy flavors of fermions with masses $\widehat{m}_l$, $\widehat{m}_h$, respectively.

N_l is chosen so that the light system is chirally broken.

N_h is chosen so that the mass-degenerate limit is conformal.

In this system, the gauge coupling is irrelevant and the scale is set by heavy mass $\widehat{m}_h$.



The continuum limit is tuned to

$\widehat{m}_h \to 0$ with $\widehat{m}_l/\widehat{m}_h$ fixed.

The chiral limit is tuned to

$\widehat{m}_l/\widehat{m}_h \to 0.$

The gauge coupling is held fixed.

LSD, arXiv:2007.01810

First-Order Transitions and Gravitational Waves

Caprini et al., arXiv:1512.06239
LSD, arXiv:2006.16429

A first-order phase transition occurs when multiple local minima of the free energy exist for a finite range of temperatures.

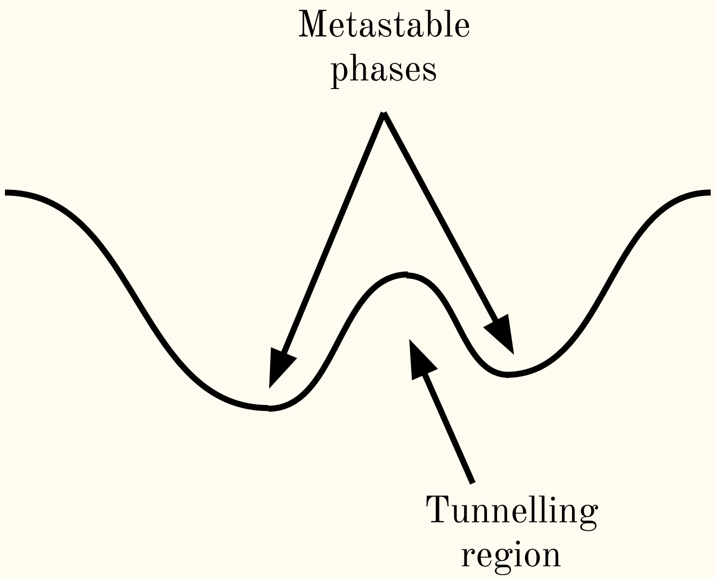
Scalar fields are allowed to tunnel or thermally fluctuate between the local minima.

"Bubbles" of metastable states that grow as one approaches either side of the phase boundary.

The first source of gravitational waves (GW) is the collision of the bubble walls of the emerging phase.

The second source of GW's are produced after bubble wall collisions.

Spectrum calculated from latent heat, the phase transition duration, and bubble wall velocity.



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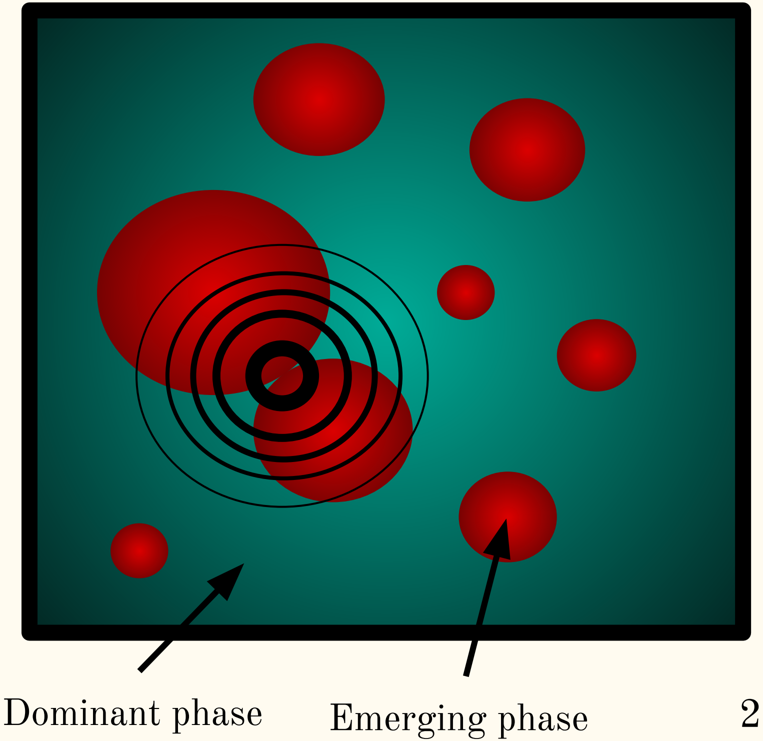


Simulation Details

In our system, finite-temperature phase transition separates a confined phase from a deconfined phase.

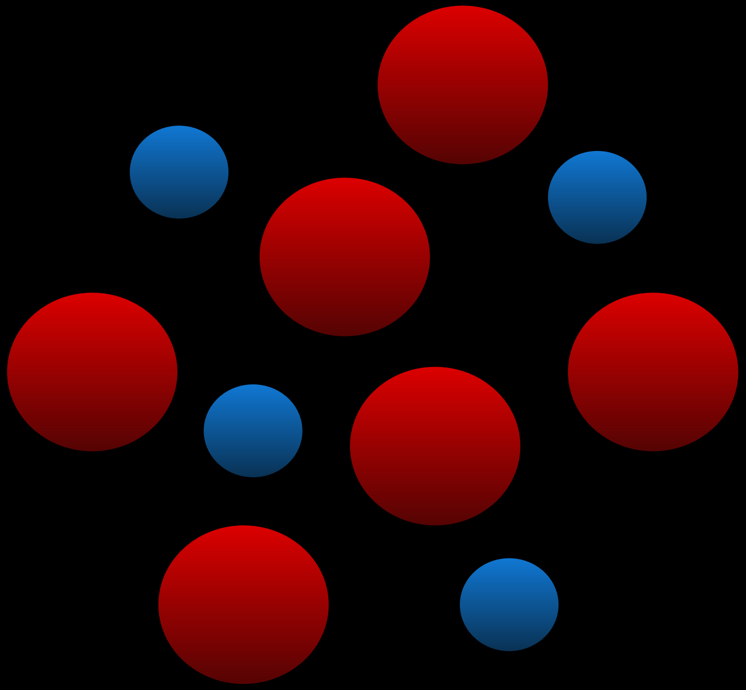
The average plaquette and gradient-flowed Polyakov loop, though not true order parameters, indicate a finite-temperature phase transition.

We scan in $\widehat{m}_h$ for various fixed values of $\widehat{m}_l/\widehat{m}_h$ to obtain the full finite-temperature phase diagram.

Our simulations use dynamical stout-smeared Mobius domain wall fermions with Symanzik gauge action.

The results that follow are obtained on 8^4 and $16^3 \times 8$ lattices. We take $L = 2N_T$.

Our results are preliminary.



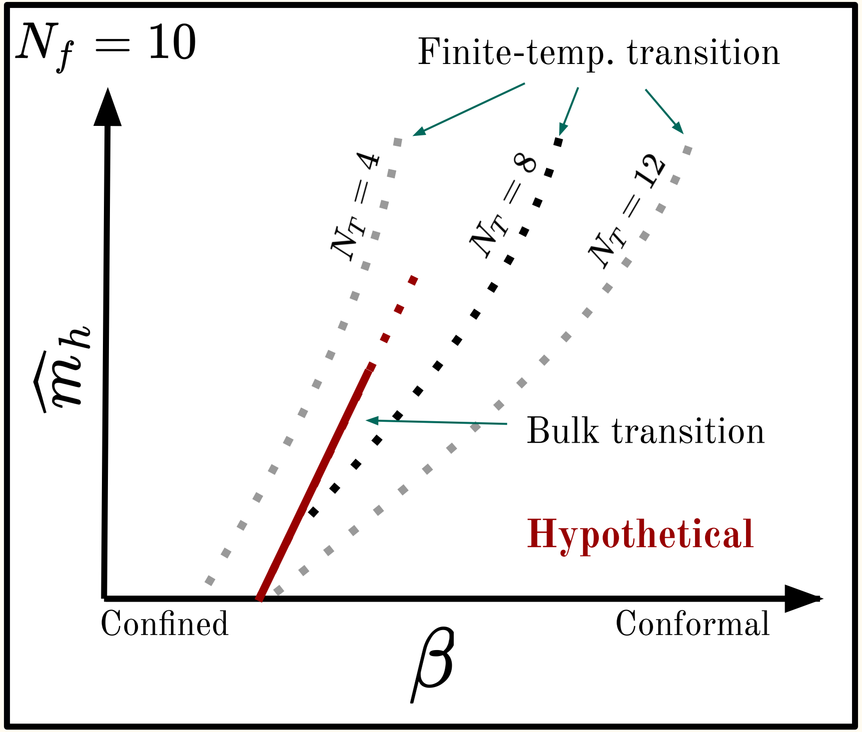
Finite-Temperature Study of the $N_f = 10$ Mass-Degenerate System

To start off, we simulate the $N_f = 10$ mass-degenerate system.

We find that we run into a "bulk" phase transition for the choice of $N_T = 8$ and $\beta = 4.03$.

This bulk phase transition is merely a lattice artifact and we move away from it as N_T increases.

This sketch is inspired by Schaich et al., arXiv:1207.7164.



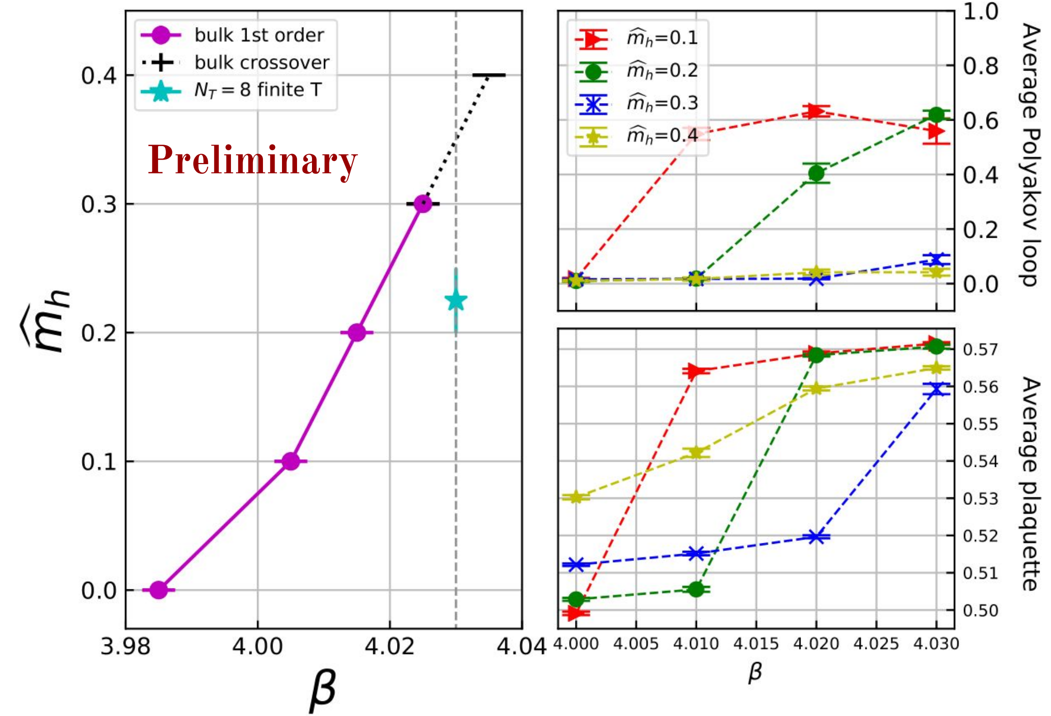
Finite-Temperature Study of the $N_f = 10$ Mass-Degenerate System

To get a better idea of the bulk phase transition, we focus on 8^4 lattices.

Both the average Polyakov loop and average plaquette signal the existence of the bulk phase transition.

The order of the bulk phase transition seems to go from first-order to crossover.

Bulk Phase Transition using 8^4 Lattices

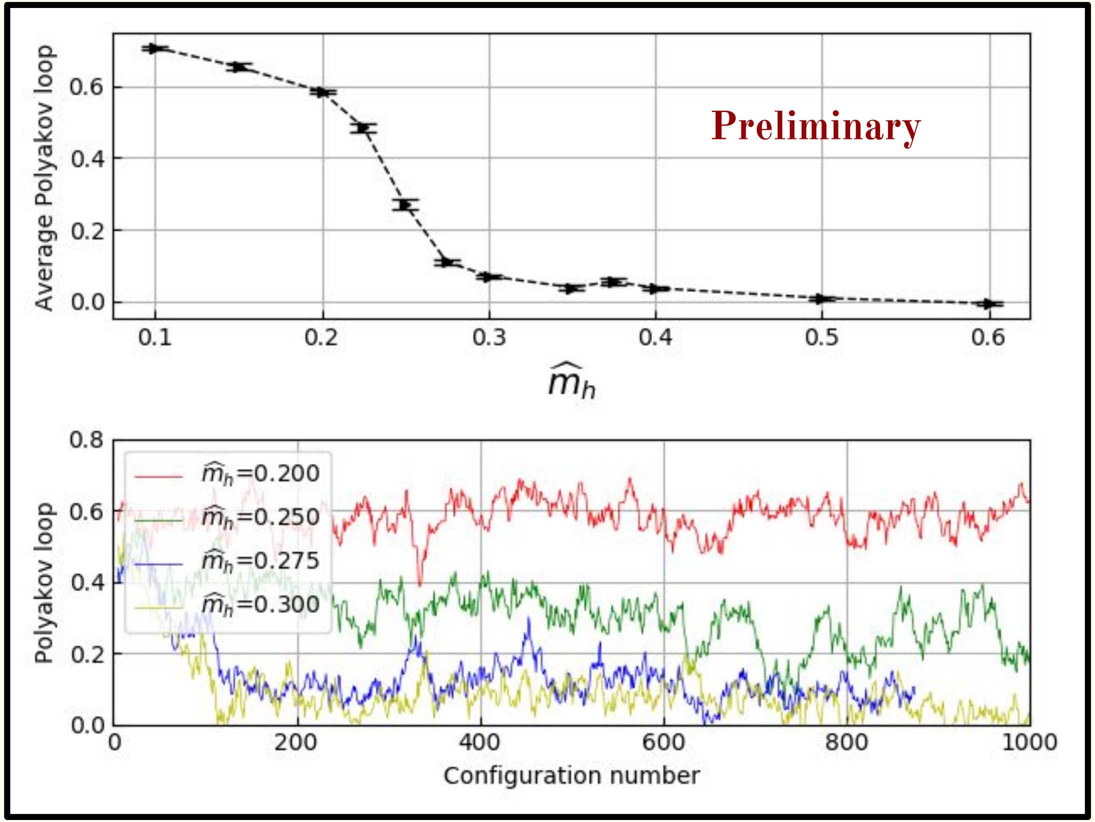


Finite-Temperature Study of the $N_f = 10$ Mass-Degenerate System

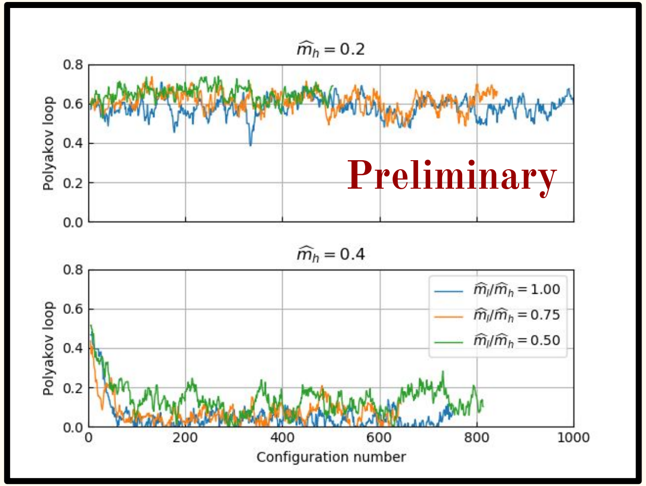
We scan in $\widehat{m}_h$ and fix $N_T = 8, L = 16, \beta = 4.03$.

The change in the average gradient-flowed Polyakov loop and the average plaquette indicate that the mass-degenerate system experiences a finite-temperature phase transition.

Some ensembles may still have long thermalization times; hence, more time is needed to fully determine the nature of the transitions.



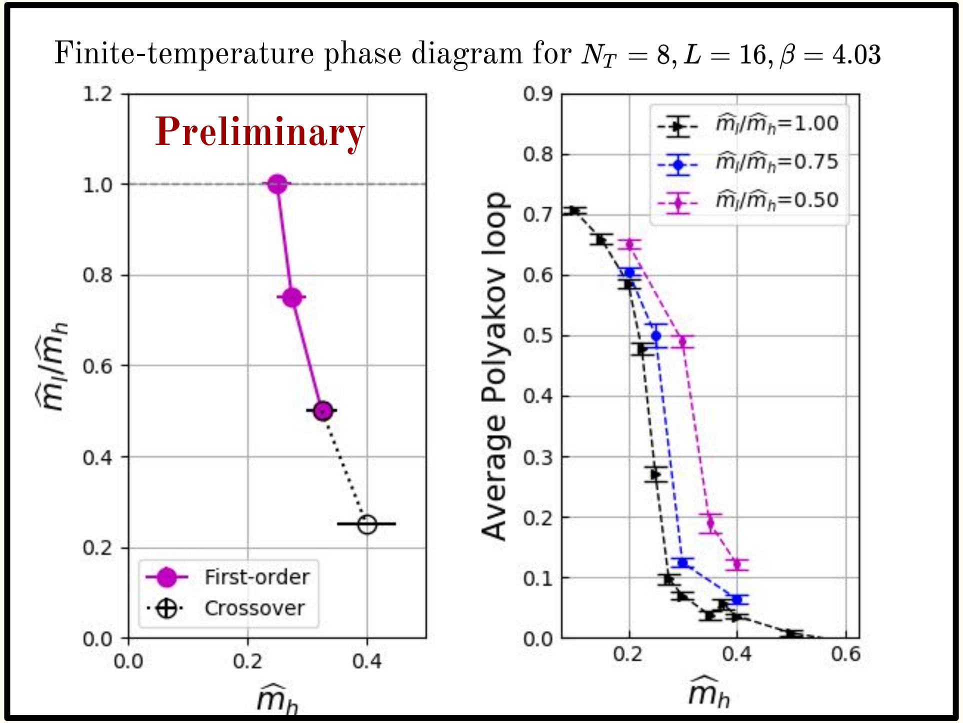
Finite-Temperature Transition in the 4+6 Mass-Split System



We probe different $\widehat{m}_l/\widehat{m}_h$ values for $N_T = 8, L = 16, \beta = 4.03$.

We suspect that $\widehat{m}_l/\widehat{m}_h = 1.0, 0.75, 0.5$ may be first-order and ratios below $\widehat{m}_l/\widehat{m}_h = .5$ may turn into a crossover.

We need more statistics to better understand the nature of the phase transition.



Outlook

Summary

We have presented preliminary results on a finite-temperature study of a 4+6 mass-split system. We found that our initial choice of $N_T = 8$ runs into a bulk phase transition. Our simulations indicate that there could be a first-order phase transition for $N_T = 8$.

The Future

Accumulate more statistics.

Look at different observables (such as susceptibilities).

Simulate at different gauge couplings, $\widehat{m}_l/\widehat{m}_h$, spatial volumes, and temperatures.

Establish order of finite-temperature phase transition.

Understand better how to convert lattice results into gravitational wave spectra.

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