THE FINITE TEMPERATURE BEHAVIOUR OF LATTICE QCD WITH MODERATE TO LARGE QUARK MASSES*

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Simulations of lattice QCD with 4 flavours of staggered quarks were performed using the Hybrid algorithm on a $12^3 \times 4$ lattice. For quark masses $\geq .1$ (lattice units) the finite temperature transition did not appear to be first order.

1. INTRODUCTION

There is general agreement from simulations on $8^3 \times 4$ and $10^3 \times 6$ lattices that the finite temperature transition for QCD with 4 light quark species is first order.¹ This transition is presumably driven by restoration of chiral symmetry.

For intermediate to large quark masses there is no consensus.^{1,2,3} However, recent simulations on lattices of sizes up to $8^3 \times 4$ have favoured a first order transition, while indicating that larger lattices are needed to decide this issue.³ Even the assumed first order transition for pure gauge theory, (which should govern the $m \rightarrow \infty$ limit) has recently been questioned.⁴

For $N^3 \times 4$ lattices the relevant quark mass range is $m > .05$. For these reasons we have run Hybrid simulations with 4 flavours of staggered quarks on a $12^3 \times 4$ lattice at quark masses $m = .1, .2, .4$ and $.8$, to attempt to clarify the situation.⁵

The work reported here was done in collaboration with J. B. Kogut.

2. HYBRID SIMULATIONS

We have performed hybrid simulations on a $12^3 \times 4$ lattice using the version of the algorithm described by Duane and Kogut⁶ with the modifications of Kogut, Kovacs and Sinclair.¹ The simulations were done on a $12^3 \times 4$ lattice with $m = .1, .2, .4$ and $.8$, time step $\delta\tau = .025$ and $\omega = 2$.

Long runs were performed at the transitions:

5000 time units at $m = .1, \beta = 5.115$ 2500 time units at $m = .2, \beta = 5.24$ 2000 time units at $m = .4, \beta = 5.40$ 2000 time units at $m = .8, \beta = 5.55$

with shorter runs at other $\beta = 6/g^2$ values. We made measurements of the Wilson line, $\langle \bar{\psi}\psi \rangle$, average plaquette, energy density, and Wilson line correlations. These runs were performed on the Argonne ST-100.

The large lattice should suppress tunneling and enhance first order signals. The base data were rebinned

FIGURE 1

Time evolution of the Wilson line at $m = .1, \beta = 5.115$ on $12^3 \times 4$ lattice.

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over a time interval $\Delta\tau = 10$ to enhance any long time structure by reducing short time-scale fluctuations.

Figure 1 shows the time evolution of the Wilson line at $m = .1$ $\beta = 5.115$.

Figure 2 exhibits the histogram of this data along with that for adjacent β values $\beta = 5.125$ (3000 time units) and $\beta = 5.100$ (2000 time units). What one notices is a weak 2-state signal which, however, we

FIGURE 2

Histogram of time evolution of Wilson line at $m = .1$, $\beta = 5.100, 5.115, 5.125$ on $12^3 \times 4$ lattice.

shall argue is probably not a signal for a first order transition.

Similar behaviour is exhibited by $\langle \bar{\psi}\psi \rangle$ and the average plaquette.

Figure 3 gives a histogram of the Wilson line time evolution for $m = .2$ at the transition. Here, no sign of any 2-state structure can be seen.

FIGURE 3

Histogram of the time evolution of the Wilson line for $m = .2$, $\beta = 5.24$ on a $12^3 \times 4$ lattice.

For $m = .4$ and $.8$, no 2-state signal has been observed.⁵

3. INTERPRETATION

At $m = .1$, some 2 state structure is observed, but this is on top of a large background. The peaks of the histogram have moved considerably closer together than for the $8^3 \times 4$ lattice (consistent with a $1/\text{volume}$ separation).

If we had a strong first order transition we would expect the peak separation to approach a constant, and the dip between peaks to become more pronounced as the lattice size is increased. Thus this signal appears to be a finite size effect, not a first order signal.

For $m > .1$ no evidence for a first order transition is seen.

4. CONCLUSIONS

For 4 flavours of dynamical quarks, no signal for a first order transition has been seen for $m \geq .1$ on a $12^3 \times 4$ lattice.

The persistence of large scale fluctuations suggests that even larger lattices are needed. Good measurements of correlation lengths are needed to look for higher order transitions.

The chiral region $m < .05$ should be studied on these larger lattices. (We are currently doing this.)

Very long runs are needed because of the long time constant fluctuations in the system.

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