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THERMODYNAMICS OF LATTICE QCD WITH 2 LIGHT DYNAMICAL (STAGGERED) QUARK FLAVOURS ON A $16^3 \times 8$ LATTICE ⋆

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Lattice QCD with 2 light staggered quark flavours is being simulated on a $16^3 \times 8$ lattice to study the transition from hadronic matter to a quark gluon plasma. We have completed runs at $m_q = 0.0125$ and are extending this to $m_q = 0.00625$. We also examine the addition of a non-dynamical "strange" quark. Thermodynamic order parameters are being measured across the transition and further into the plasma phase, as are various screening lengths. No evidence for a first order transition is seen, and we estimate the transition temperature to be $T_c = 143(7)MeV$.

The study of QCD at finite temperatures using lattice techniques enables us to examine the nature of the transition from hadronic matter to a quark-gluon plasma, and to determine the properties of the plasma. This yields information about QCD dynamics and helps us make predictions of relevance to RHIC and the early universe.

We simulate Lattice QCD with 2 light flavours of staggered quarks using the hybrid algorithm with noisy fermions on a $16^3 \times 8$ lattice. Runs have been performed with quark mass $m_q = 0.0125$ (lattice units) and this is now being extended to $m_q = 0.00625$. These simulations extend earlier work on smaller lattices [1]. We have simulated the neighbourhood of the transition, and well inside the plasma phase, to determine its properties. We have also included a non-dynamical (quenched) "strange" quark with mass 20 times that of the dynamical "u and d" quarks.

At $m_q = 0.0125$ we have run for 1000 time units at β of 5.45, 5.55, 5.6, 6.0, and 7.0 and for 2000 time units at β of 5.5 and 5.525. A further run at $\beta = 5.55$ starting from the other side of the transition is in progress. At $m_q = 0.00625$ we have run for 1000 time units at $\beta = 5.55$ and a run at $\beta = 5.525$ is underway. Fig. 1 shows the β dependence of the Wilson/Polyakov line and $\langle\bar{\psi}\psi\rangle$. From this and the time evolution of these quantities, we estimate that the transition occurs at $\beta_c = 5.5375(250)$. No sign of a first order transition has been seen. Fluctuations with long time constants, suggestive of a nearby critical point are observed near the transition. Combining this value of β_c with zero temperature spectrum data (ρ mass) yields a rough estimate of the transi-

⋆ presented by D.K.Sinclair

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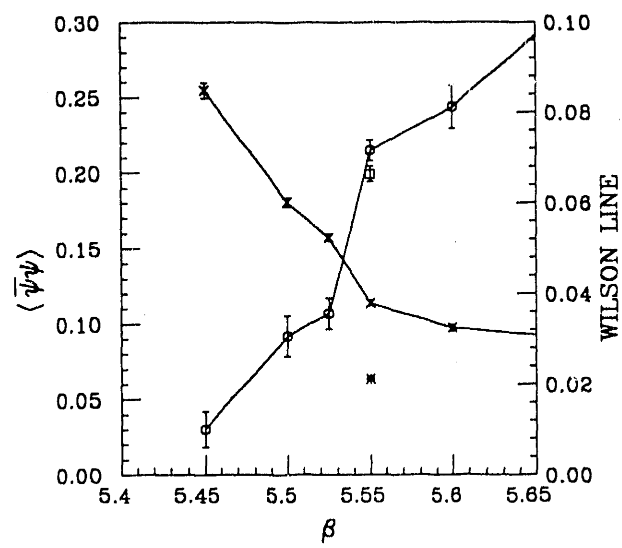

Fig. 1. Wilson Line o and $\langle\bar\psi\psi\rangle$ × at $m_q = 0.0125$. (□ and * are the same quantities at $m_q = 0.0625$.)

tion temperature, $T_c = 143(7) MeV$, where the quoted error is purely statistical.

We have measured the entropy densities for the glue, the (u,d) doublet and the strange quarks, including one loop corrections. The gluon and fermion contributions are [2]

$$\frac{s_g}{T^3} = \frac{4}{3T^4}(1 - \frac{1.022}{\beta})\beta(P_{st} - P_{ss}) \qquad (1a)$$

$$\frac{s_f}{T^3} = \frac{4}{3T^4}(1 - \frac{1.279}{\beta})\frac{n_f}{4}(\langle\bar\psi \not{D}_0 \psi\rangle - \frac{3}{4} + \frac{1}{4}m_q\langle\bar\psi\psi\rangle) \qquad (1b)$$

where P_{st} and P_{ss} are the average space-space, respectively space-time plaquettes. These quantities, divided by the ratios of lattice to continuum values for free fields to attempt to compensate for finite volume effects, are given in Table 1 [3].

The subtracted temporal Wilson/Polyakov line correlation functions have been measured. These give us an estimate of the screening of the interquark potential [4]. To enhance the signal we have used blocked Wilson lines [5], and

β	s_g	s_{ud}	s_s
5.450	-0.7(4.0)	0.41(65)	-0.19(21)
5.500	1.8(2.4)	1.70(43)	0.27(16)
5.525	3.7(2.2)	1.58(38)	0.35(24)
5.550	6.9(3.9)	4.40(45)	0.48(24)
5.600	11.1(3.9)	3.54(44)	0.10(30)
6.000	10.0(2.9)	5.18(35)	1.02(30)
7.000	8.6(3.1)	5.67(29)	1.75(29)
∞	7.018385	9.211631	4.605815

Table 1
The entropy densities for the gluons, the u+d quarks and the s quark. The values given for $\beta = \infty$ are the Stefan-Boltzmann predictions.

measured the zero momentum correlation functions which should show a simple exponential asymptotic behaviour. We find clear evidence for screening in the plasma phase, and some evidence for it in the hadronic matter phase. These screening masses are given in Fig. 2. If the Debye screening masses are indeed half these values as in perturbation theory [4] and our estimate of T_c is accurate, the ψ/J will still be produced as one passes through the transition but this production will be suppressed if one goes much above T_c.

In order to understand the nature of excitations of the quark gluon plasma compared with those of hadronic matter, we have also measured the spatial correlations of operators with the quantum numbers of low mass hadrons [6,7] (π, σ, ρ, A_1, N and N'). In order to enhance these measurements of hadronic screening lengths, we use an extended (wall) source, analogous to that used by the HEMCGC [8] collaboration at $T = 0$. These screening masses are shown in Fig. 3.

In the hadronic matter phase, these masses exhibit the spontaneously broken chiral symmetry of the $T = 0$ theory, with a light π and heavier σ. The ρ mass is less than that of the A_1 and the N mass less than that of the N'. In the plasma phase we see evidence that chiral symmetry is

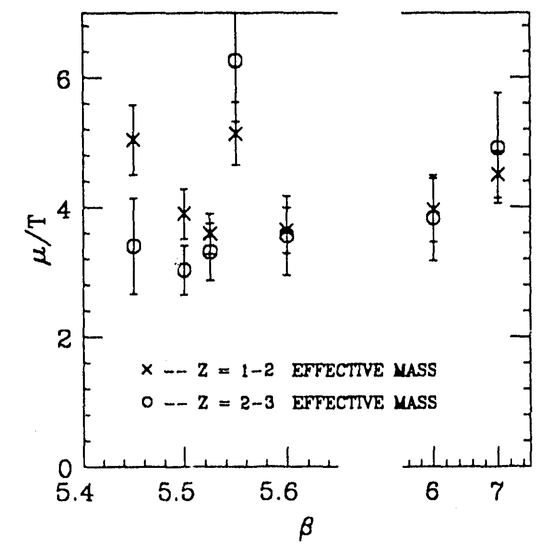

Fig. 2. Estimates of the screening masses μ for the colour averaged potential.

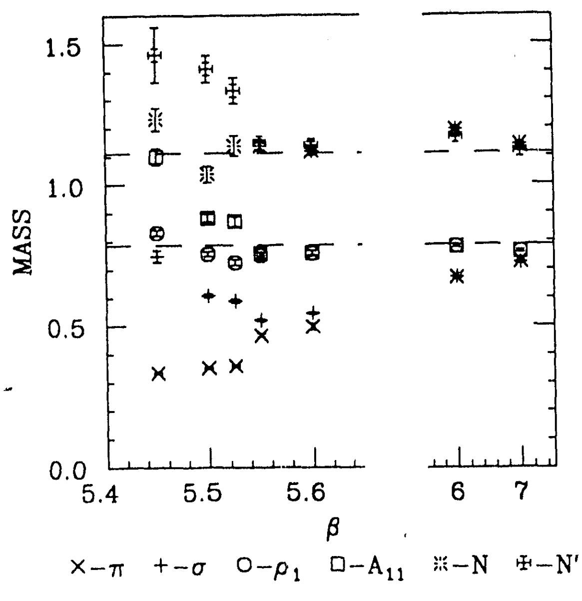

Fig. 3. Hadronic screening masses. The dashed lines are at $mass = 2\pi/N_t$ and $mass = \sqrt{8}\pi/N_t$.

restored. The π is now heavy and close in mass to the σ. The ρ and A_1 are approximately degenerate, as are the N and N'. On closer inspection we notice that the "masses" of the ρ and A_1 are close to $2\pi/N_t$ while those of the N and N' are close to $\sqrt{8}\pi/N_t$. This suggests that these states are collections of unbound quarks of the lowest allowed Matsubara frequency (π/N_t), while the (π, σ) multiplet remains bound [9]. Hadronic wave function measurements by the MILC collaboration [7] and the area law we observe for spatial Wilson line correlations cast doubt on this simple picture.

Finally, we have measured the topological susceptibility by the cooling method, [10] and find good agreement with the anomalous Ward identity [11].

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