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Chiral behaviour and screening masses close to the chiral phase transition

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We investigate the temperature dependence of the chiral sector and of hadronic screening masses in quenched lattice QCD below the critical temperature.

1. INTRODUCTION

The behaviour of meson masses and decay constants in the vicinity of T_c is receiving increasing attention in heavy ion phenomenology [1]. Knowledge of this behaviour is needed for the interpretation of experimental data. Investigations of the temperature dependence have been made within various approaches to QCD, above all in chiral perturbation theory and by exploiting sum rules. All of these approaches, however, have to make certain assumptions on various hadronic parameters. Some of them are open only to weak experimental tests. In contrast, lattice calculations provide first principle tests of such temperature dependencies. Thus any result on the temperature dependence of the hadron parameters in the vicinity of T_c is of crucial importance, irrespective of whether one sees a change or not.

2. PRESENT RESULTS

At present, we have analyzed quenched configurations at $\beta = 5.90(0.75T_c)$ and $5.95(0.85T_c)$. The lattices have sizes $8 \times 24^2 \times 32$ and 8×32^3 respectively. Utilizing staggered fermions, we inverted fermion matrices at each β value and at quark masses $ma = 0.05, 0.035, 0.025$ and 0.01 at $\beta = 5.90$ and $ma = 0.05, 0.025$ and 0.01 at 5.95. We constructed the Goldstone pion (π) and the vector meson (ρ) propagators for each set of parameters. We used point sources in order to exploit certain Ward identities relating variables in the chiral sector. The chiral condensate can be obtained from the trace of the inverse fermion matrix, $D+m$, or the integral of the pseudoscalar correlation function H_{PS},

$$\langle\overline{\psi}\psi\rangle = \mathrm{Tr}(D+m)^{-1} = m\sum_z H_{PS}(z)\ . \qquad (1)$$

We checked the quality of our data by means of this identity. Very good agreement was found. The leading m contribution to the chiral condensate in quenched QCD can be removed by calculating the so-called intercept,

$$(1 - m\frac{\partial}{\partial m})\langle\overline{\psi}\psi\rangle = m\sum_z \{H_{PS}(z) - H_S(z)\} \qquad (2)$$

where H_S is the scalar meson propagator. The pion decay constant is obtained from the (lattice transcription of the) matrix element

$$f_\pi m_\pi^2 \sim \langle 0|\overline{u}\gamma_5 d|\pi\rangle\ . \qquad (3)$$

This allows us to check, in the limit of vanishing quark mass, the Gell-Mann, Oakes, Renner formula at finite temperature,

$$f_\pi^2 m_\pi^2 = m\langle\overline{\psi}\psi\rangle\ . \qquad (4)$$

None of these quantities receive renormalizations when staggered fermions with point sources are used.

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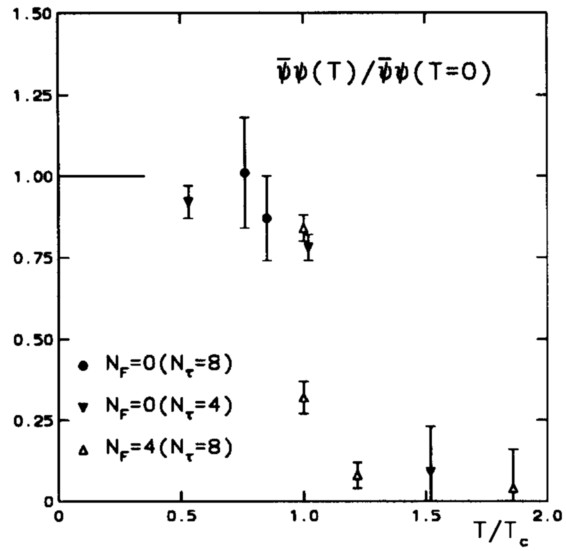

Figure 1. The chiral condensate at finite temperature in units of the zero temperature value [2,3]. The filled circles come from this calculation. The filled triangles are quenched data at $N_\tau = 4$, ref. [4], the open triangles are MT_c data for 4 flavours in full QCD.

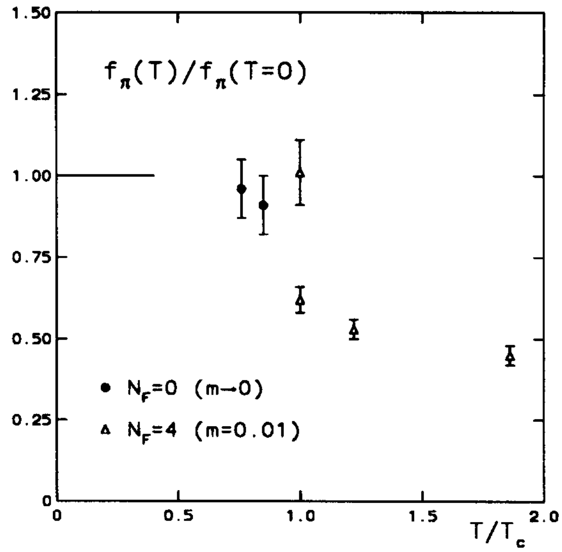

Figure 2. The pion decay constant f_π at finite temperature in units of the zero temperature value [3]. The filled circles come from this calculation and denote data extrapolated to the chiral limit. The open triangles are MT_c data for 4 flavours in full QCD at quark mass $ma = 0.01$.

The results for chiral parameters are compared to data at zero temperature [2,3] in Figs. 1 and 2. The quality of our results for these quantities is very good so that the error bars in the plotted ratios are dominated by the zero temperature data. Uncertainties in the temperature assignment are neglected.

In Fig. 1 we show the quark condensate. In the quenched case, at both zero and non-zero temperature, we have extrapolated to the chiral limit. The value at $m \to 0$ agrees very well with the intercept at the finite quark mass value $ma = 0.01$. (At larger quark masses sub-leading mass terms are seen.) This allows to compare with full QCD data obtained at $ma = 0.01$, not extrapolated to $m = 0$. Note the remarkable similarity between 0 and 4 flavour QCD. Fig. 2 summarizes the results for the pion decay constant as obtained from Eq.3. Again, in the quenched case we extrapolate to $m = 0$ but compare with full QCD results at $ma = 0.01$, leading to the apparent tail in particular above T_c.

As for the temperature dependence, for both observables the data seem to indicate a slight trend downwards when T_c is approached. However, the error bars of the zero temperature data are too large to suggest a definitive conclusion. The trend appears simultaneously in the chiral condensate and in f_π, in line with the Gell-Mann, Oakes, Renner formula, Eq.4.

We then proceeded to calculate the pion and the ρ meson mass utilizing the same quark propagators as used in the analysis of the chiral sector, i.e. from point sources. Hadron masses from quenched simulations at $\beta = 5.95$ with staggered fermions for $T = 0$ are available [5] for $m_q = 0.025$ and 0.01. These facilitate a direct comparison. At $\beta = 5.90$ we compare with interpolated data.

For the pion we obtain very clean signals. At $\beta = 5.95$, the pion masses obtained from our simulations are equal within errors to those measured at zero temperature at the same quark mass. Thus, as at zero temperature, the pion mass extrapolates to the zero quark mass limit like $m_\pi^2 = A_\pi m_q$. Moreover, the value of A_π is the same as that in the zero temperature measurements. The same behaviour is found at $\beta = 5.90$.

In the rho channel, at the smaller quark masses, we observe long ranging contributions of excited states. Thus, it is difficult to clearly isolate the lightest contribution to the correlation function, despite the size of the sample and the large extent of the lattice in the spatial directions. In Fig. 3 we compare our estimates for the ρ meson mass at $\beta = 5.95$ directly with the zero temperature data [5]. Our error bars have been obtained by jackknifing blocked samples. Neglecting the errors, there could be temperature effect, lowering the ρ mass, especially in the extrapolation to vanishing quark mass. One might also hope that our numbers represent an upper limit to the mass. Still, improved estimates are absolutely needed to clarify this situation.

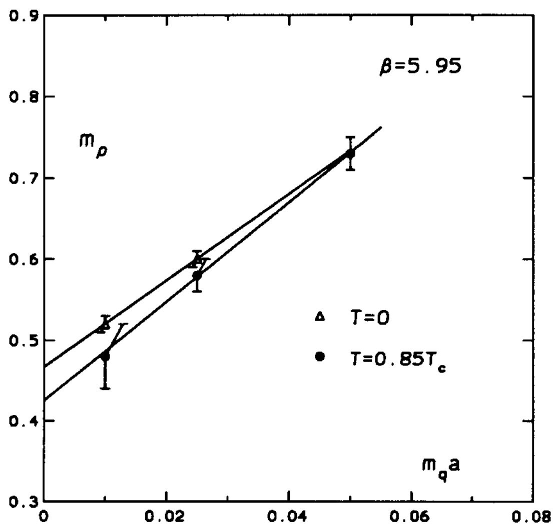

Figure 3. The ρ meson mass as function of the quark mass, at $T = 0$ [5] and at $T = 0.85T_c$.

3. CONCLUSION

We have presented first results of an investigation of the temperature dependence of chiral parameters and hadronic screening lengths close to and below the deconfinement phase transition. The chiral condensate as well as the pion decay constant appear to show a rather weak temperature dependence. Higher accuracy in the zero temperature data would, though, be desirable. The behaviour of the pion mass agrees with the observations at zero temperature. For the mass of the ρ meson, the results are not yet conclusive and we are currently performing an analysis with wall sources to improve on this.

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