Effects of non-perturbatively improved dynamical fermions in UKQCD simulations

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We present results for QCD with 2 degenerate flavours of quark using a non-perturbatively improved action on a lattice volume of $16^3 \times 32$ where the bare gauge coupling and bare dynamical quark mass have been chosen to maintain a fixed physical lattice spacing and volume (1.71 fm). By comparing measurements from these matched ensembles, including quenched ones, we find evidence of dynamical quark effects on the short distance static potential, the scalar glueball mass and the topological susceptibility. There is little evidence of effects on the light hadron spectrum over the range of quark masses studied ($m_\pi/m_\rho \geq 0.60$).

1. SIMULATION STRATEGY

The first generation of full QCD simulations has confirmed that, for many purposes, the quenched approximation is indeed very good and is hard to improve upon with finite computational resources. For recent reviews see [1,2]. Following an exploratory series of simulations using non-perturbatively improved Wilson fermions [3], the UKQCD collaboration has now completed the first phase of a sequence of *matched simulations* in which some attempt has been made to adjust the bare simulation parameters so that physically relevant quantities remain approximately constant [4]. In particular, we have generated ensembles in which the Sommer scale parameter r_0, expressed in lattice units, is matched as closely as is practical.

Table 1 contains a summary of the simulation parameters and ensemble statistics. This strategy is motivated partly by pragmatism and partly by theoretical considerations. With access to limited computational resources, it was clear that the Collaboration would be unable to address immediately all the limits required to recover a fully physical system: chiral, continuum and infinite volume limits. We have therefore adopted a *partially unquenched* approach in which, at finite lattice spacing, the dynamical quark mass (two degenerate flavours) is treated as an independently tunable parameter. Rather than hold the bare coupling fixed, we have chosen to hold r_0/a fixed with the expectation that the discretisation and finite size effects which are inevitably present should be better under control. The choice of r_0 to set the scale removes the need to perform the chiral extrapolation in valence quark mass which use of a non-gluonic observable would entail. Of course an overall uncertainty in the phenomenological value of r_0 remains ($\sim 2\%$), but the use of r_0 provides a standard which is well-defined both theoretically and computationally. Here we use $r_0 = 0.49$ fm.

In the second phase, we are attempting to vary the lattice spacing while holding the ratio of pseu-

Table 1
Simulation parameters and statistics. Configurations are separated by 40 trajectories.

β	$c_{\rm sw}$	$\kappa^{\rm sea}$	Cfg.	a [fm]	m_π/m_ρ
5.93	1.82	Quen.	624	.1040(03)	-
5.29	1.92	.1340	101	.1018(10)	.830(07)
5.26	1.95	.1345	101	.1041(12)	.791(08)
5.20	2.02	.1350	150	.1031(09)	.688(10)
Lightest $\kappa^{\rm sea}$ simulations.					
5.2	2.02	.13550	208	.0973(8)	.600(20)
5.2	2.02	.13565	60	.0941(8)	.567(50)
QCDSF					
5.29	1.92	.13500		.0932(5)	.755(6)
5.29	1.92	.13550		.0889(13)	.694(9)

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doscalar to vector meson mass fixed. Using fully non-perturbatively improved fermions [5], we expect that the discretisation errors are $\mathcal{O}(a^2)$. The fact that the improvement coefficient function $c_{\rm SW}(\beta)$ is only well-determined for $\beta \geq 5.2$ limits the accessible lattice spacing from above. The spacing is limited from below by the need to have an acceptably large physical volume.

We have begun a cooperative programme of simulations with the QCDSF collaboration (see talks by Pleiter and Stüben [6,7]). It is planned that simulations on larger volumes and at complementary values of the bare parameters will be obtained. Some initial simulations from QCDSF are also summarised in Table 1. Simulation points are indicated in Figure 1 which has, superimposed on it, curves of constant r_0/a and $\xi \equiv m_\pi/m_\rho$. These curves show a simple polynomial interpolation which gives a very approximate description of the data obtained so far and provides guidance on the choice of future simulations points.

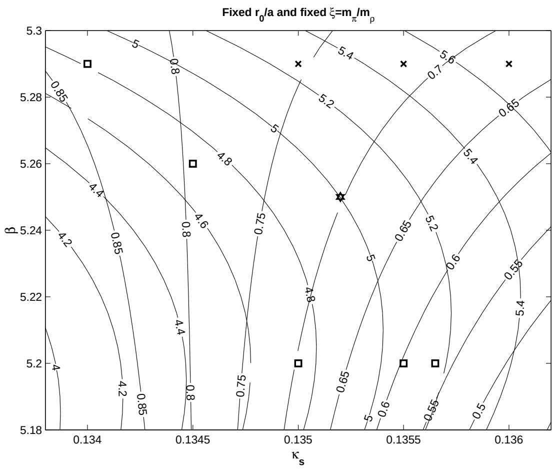

Figure 1. Curves of constant r_0/a (4, 4.2, ...) and ξ (0.5,0.55,...). The squares (star) indicate completed (ongoing) UKQCD runs. Crosses show ongoing and planned QCDSF runs.

The lightest quark mass simulation which we have so far been able to achieve with useful statistics was at $(\beta,\kappa) = (5.20, 0.1355)$ (see Table 1). We are currently generating configurations which are expected to match the lattice spacing of this ensemble and the value of ξ for the ensemble at $(5.20, 0.1350)$. An attempt to simulate at $(5.20, 0.13565)$ where $\xi \approx 0.56$ (Table 1) was halted since the performance of the HMC algorithm was found to be unacceptably slow. For all ensembles studied, the measured integrated autocorrelation time for the plaquette (typically less $\lesssim$20 HMC trajectories) showed no increase with decreasing quark mass. The same was true for measurements of the topological charge and glueball correlators where the integrated autocorrelation time was of the order of $25 - 30$.

2. STATIC POTENTIAL

The static potential was extracted using an optimised variational method [8]. Within the range $0.35 \lesssim |\mathbf{r}| \lesssim 1.25$ fm, all matched data including quenched are well described by a simple bosonic string model ($e = \pi/12$).

$$[V(r) - V(r_0)]r_0 = (1.65 - e)\Big(\frac{r}{r_0} - 1\Big) - e\Big(\frac{r_0}{r} - 1\Big)$$

when expressed in units of r_0. Figure 2 shows the deviations from this model. For $r \lesssim 3a$ there is clear evidence for (a) strong discretisation effects and (b) a systematic depression of the potential with decreasing dynamical quark mass. Parametric fits show that the effect corresponds to an increase in the effective strong coupling of $18 \pm 10\%$ with respect to the quenched value. The simplest perturbation theory estimate of the effect of two light flavours is also 18%.

The values of r_0/a used to obtain the effective lattice spacing shown in Table 1 were extracted from parametric fits to the potential (including off-axis measurements) but over a restricted range of $|\mathbf{r}|$. In fact the values of r_0/a are rather stable with respect to the range used.

3. MESONS and GLUEBALLS

Figure 3 shows the valence quark mass dependence ($\sim m^2_{\rm PS}$) of the vector meson mass in comparison with physical mesons having strange quark content. New matched quenched data un-

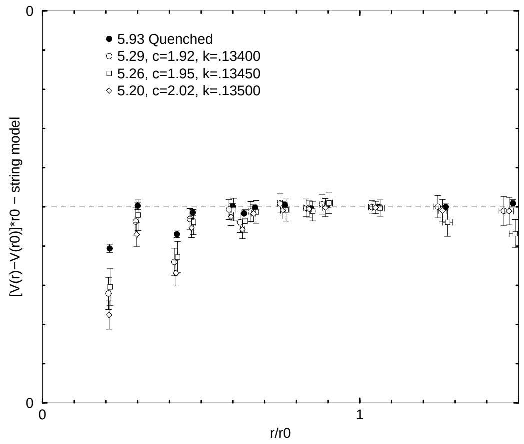

Figure 2. Difference of the lattice potential from the continuum bosonic string model.

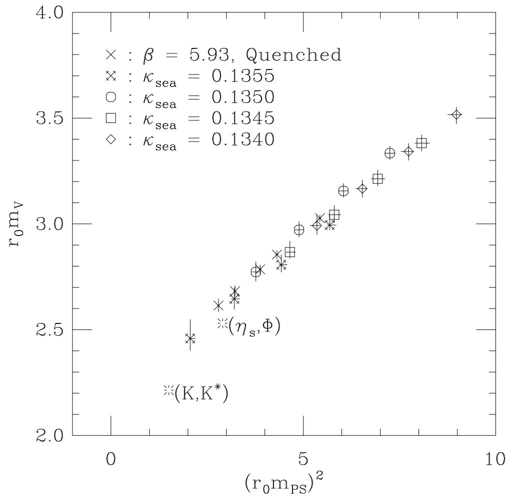

Figure 3. Valence quark mass dependence of the vector mass for different sea quark masses.

derline the conclusion that the lattice data are not far from the physical data even at finite lattice spacing and that there is little further improvement to be seen at the lightest sea quark masses reached (corresponding to $m_\pi/m_\rho \approx 0.6$).

Results for baryons and for quark masses will be presented elsewhere [9].

In Figure 4 we show preliminary data for the mass of the scalar glueball (A_1^{++} lattice state) obtained using optimised variational techniques. The basis made use of 7 operators and 6 levels of fuzzing. Another important ingredient was the use of non-zero momentum operators $|\mathbf{p}|^2 \leq 2a^2$) to obtain effective energies from which effective masses could also be extracted. For these momenta, good plateaux were again obtained.

The figure shows the zero-momentum effective masses. Data for the lightest quark ensemble ($\kappa^{\rm sea} = 0.1355$) are compared with a 'world average' of quenched scalar masses interpolated to the relevant lattice scale. This provides reasonably convincing evidence of a decrease in the mass of order 10% for the scalar glueball at fixed lattice spacing.

One possible source of (finite size) error could be mixing with a scalar 'torelon' which has an additional decay mode in the presence of fundamental charges. Direct measurements of the energy and vacuum expectation values of such states [9] show that the mixing is expected to be small on these lattices.

Measurements of the tensor glueball have also been made but larger statistical errors make the corresponding comparison with quenched results less fruitful.

4. TOPOLOGICAL SUSCEPTIBILITY

The matched ensembles have also been used to look for evidence of suppression of instanton effects by light quark modes [10]. In Figure 5 we show the suitably scaled topological susceptibility obtained by standard cooling techniques applied to the gauge configurations after every tenth trajectory. Interestingly, the measured decorrelation rate of the topological charge was little slower than for the plaquette. The data show a clear suppression with dynamical quark mass. Since

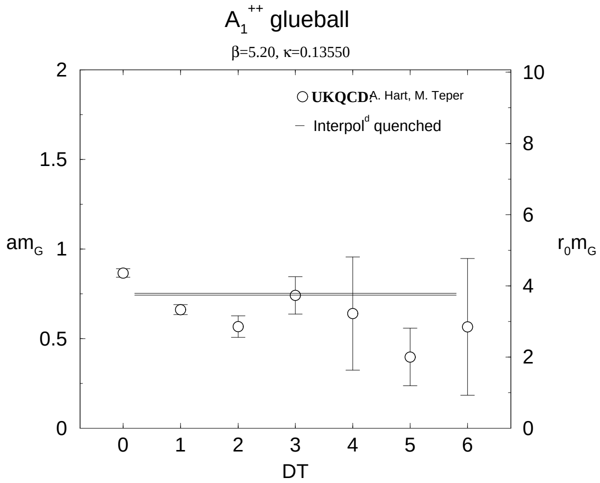

Figure 4. Effective mass for the scalar glueball.

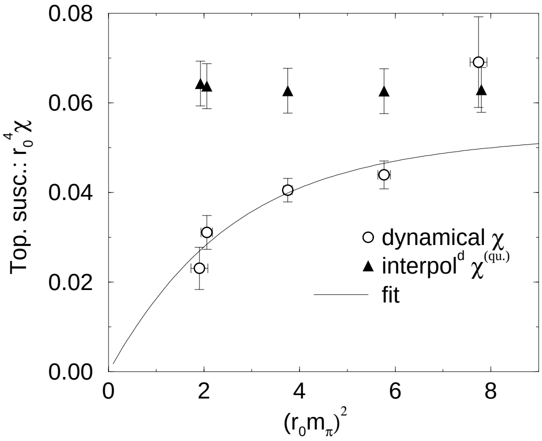

Figure 5. Scaled topological susceptibility versus effective quark mass.

the leading chiral behaviour is expected to be

$$\frac{r_0^2 \chi}{m_\pi^2} = (r_0 f_\pi)^2/8 + c_1 (r_0 m_\pi)^2 ,$$

one may use models to interpolate this data and hence extract an estimate of the pion decay constant f_π. Note that, in contrast to methods based on matrix elements, no non-perturbative renormalisation factors are required to obtain the value of f_π. Using $r_0 = .49$ fm to set the scale and ignoring finite-a corrections, one estimates $f_\pi = 148 \pm 7^{+25}_{-14}$ MeV in comparison with 132 MeV from experiment.

The use of matched data in this analysis is critical to its success in that, otherwise, the underlying suppression can easily be masked by the strong (r_0^{-4}) change in scale expected when changing $\kappa^{\rm sea}$ at fixed β.

5. SUMMARY and CONCLUSIONS

The use of matched ensembles of dynamical fermion configurations has allowed a preliminary study of possible unquenching effects prior to a full analysis of the continuum and chiral limits. Evidence is presented for a lowering of the scalar glueball mass, charge screening at short distances and of the suppression of instanton effects at light quark masses. For the quark masses studied ($m_\pi/m_\rho \gtrsim 0.6$) there is little evidence of dynamical quark effects in the light hadron spectrum. Further simulations exploring the lattice spacing dependence and quark mass dependence are underway.

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