Static hybrid quarkonium potential with improved staggered quarks

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We are studying the effects of light dynamical quarks on the excitation energies of a flux tube between a static quark and antiquark. We report preliminary results of an analysis of the ground state potential and the $\Sigma_g^{\prime +}$ and Π_u potentials. We have measured these potentials on closely matched ensembles of gauge configurations, generated in the quenched approximation and with 2+1 flavors of Asqtad improved staggered quarks.

1. INTRODUCTION

Simulations with dynamical quarks have found that light quarks modify the heavy quark-antiquark potential in a number of ways [1–3]. At large distances they decrease the string tension in units of the Sommer r_0 and r_1 parameters (defined by $r^2 F(r) = 1.65$ and 1.00, respectively) and lead eventually to string-breaking. At shorter distances they modify the running of the coupling constant, deepening the Coulomb well and increasing the ratio r_0/r_1. In this work, we extend these studies to some of the potentials with excited flux tubes. Of particular interest to quarkonium spectroscopy are the Π_u excitations leading to exotic $Q\bar{Q}g$ hybrids [4].

We report results of a study in which our sources and sinks are optimized to create and annihilate a flux-tube state. In the presence of dynamical quarks, string breaking is expected. It is known that in the conventional Σ_g^+ channel, transitions to the open two-meson channel are exceedingly weak, qualitatively consistent with the small widths of quarkonium states above the heavy-light meson thresholds [5,3]. Since at present we do not include the open two-meson channel we do not expect to observe string breaking here.

2. MEASUREMENTS

We have measured the heavy quark potential on an ensemble of $28^3 \times 96$ ($a \approx 0.09$ fm) gauge configurations generated in the presence of $2+1$ flavors of Asqtad dynamical quarks of varying masses and a one-loop Symanzik gauge action[6]. The strange quark mass is set approximately to its physical value. Here we compare results from our 358-configuration quenched ensemble with our 495-configuration dynamical quark ensemble for which $(m_\pi r_0)^2 \approx 1.3$.

The configurations are first smoothed using a single hypercubic (HYP) blocking pass [7], a technique that improves significantly the signal-to-noise ratio [8]. The blocking procedure involves replacing all gauge links (timelike as well as spacelike) with an SU(3)-projected average over paths confined to adjacent hypercubes. Thus distortions in the result are local and expected to be

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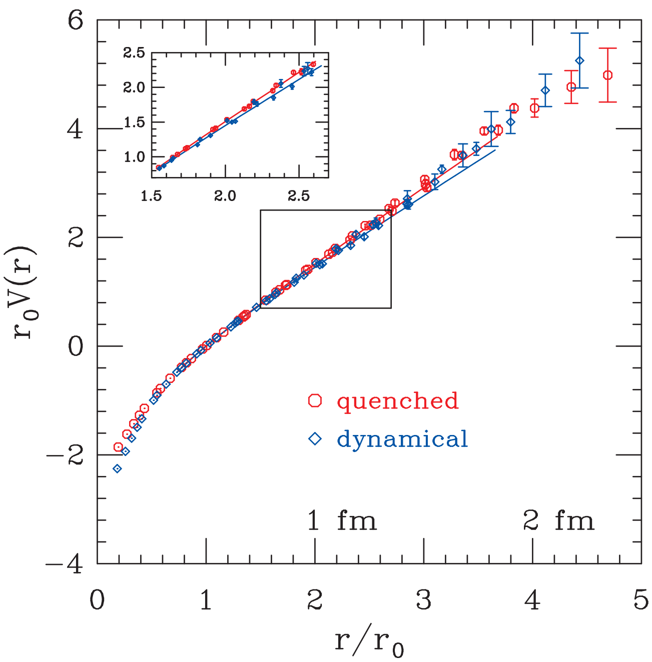

Figure 1. The ground state static quark potential for quenched (octagons) and 2+1 flavor (diamonds) QCD, in units of r_0. The solid lines are fits to the Coulomb plus constant plus linear form, fixing $V_{\rm fit}(r_0) = 0$. The lattice spacing is matched using r_0. The inset expands the area shown by the box.

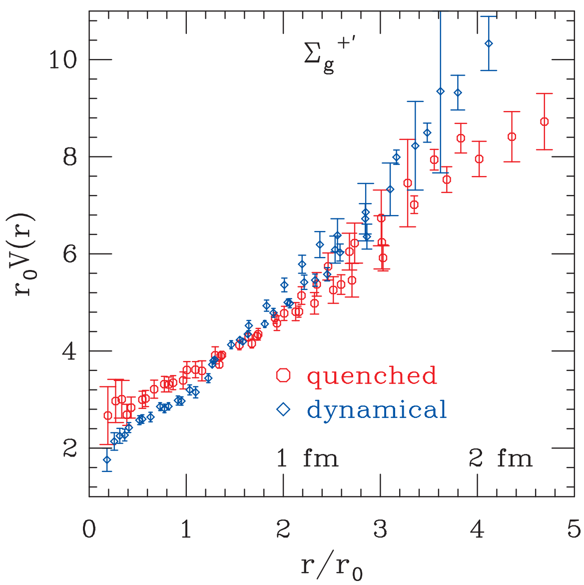

Figure 2. The excited Σ_g' potential for quenched (octagons) and 2+1 flavor (diamonds) QCD, in units of r_0. The lattice spacing was matched using r_0.

confined to distances smaller than about $2a$ [8]. After HYP blocking the spacelike links are further smoothed via five cycles of APE smearing with SU(3) projection.

On the thus smoothed lattices we measure the expectation value of the standard $R \times T$ Wilson loop on axis and along three different off-axis directions. These measurements yield the conventional ground state Σ_g^+ and excited state $\Sigma_g^{+\prime}$ potentials. For the Π_u excited state, we measured the expectation value of a bent loop formed by replacing the source and sink flux tubes of length R by a superposition of large "staples" of sides $(2a, R, 2a)$. For example one such loop replaces each on-axis spacelike flux path $(R\hat{x})$ by paths of the form $(2a\hat{y},\ R\hat{x},\ -2a\hat{y})$ minus its reflection in the xz plane [9].

For the standard Wilson loop we extracted the usual Σ_g^+ potential $V_{\Sigma g+}$ and its excited state $V'_{\Sigma g+}$ by doing a blocked, correlated, double-exponential fit to the Wilson loop data:

$$W(R,T) = C_{\Sigma g+}(R) e^{-V_{\Sigma g+}(R)T} \quad (1)$$

$$+ \ C'_{\Sigma g+}(R) e^{-V'_{\Sigma g+}(R)T}. \quad (2)$$

For the Π_u potential we did only a single-exponential fit.

In all cases we use the same fit ranges for both quenched and dynamical lattices to reduce possible systematic errors.

3. RESULTS

In Fig. 1 we compare the ground state potential on the quenched ensemble and the 2+1 flavor ensemble. Both the distance scale and the potential are plotted in units of r_0, and a constant has been subtracted from the potential so that it is zero at r_0. Since r_0 was determined from this potential, the fits are tangent at this point. Away from r_0, the potentials have dif-

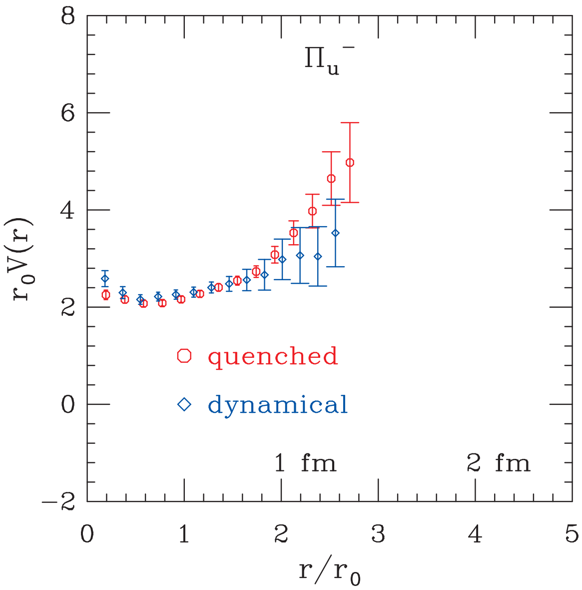

Figure 3. The Π_u^- potential for quenched (octagons) and 2+1 flavor (diamonds) QCD, in units of r_0. The potentials are plotted relative to the zero determined in the fit to the ground state potentials.

ferent shapes, namely, the Coulomb attraction is slightly stronger in the light quark ensemble and the string tension is slightly weaker in units of r_0, confirming earlier findings [1]. A softening of the Coulomb well is also evident. This is an expected consequence of HYP smoothing.

Similarly in Fig. 2 we show light quark effects in the Σ_g' excitation potential. The potentials are plotted relative to the zero determined in the fit to the ground state potentials. From Fig. 2 we see that the excited state potential Σ_g' is slightly steeper than that of quenched QCD.

In Fig. 3 we plot the Π_u^- potential. This hybrid potential is weakly repulsive at short range, as would be expected from the Coulomb interaction in a color octet quark-antiquark system. This effect is softened by HYP smoothing. At the level of our statistical errors there are no apparent differences at long range, but better statistics would certainly be of interest.

4. CONCLUSIONS

Our measurements at $a = 0.09$ fm confirm the shape changes in the ground-state potential, seen previously at $a = 0.13$ fm. In units of r_0 we find, further, that adding $2+1$ flavors of dynamical quarks makes the $\Sigma_g^{+\prime}$ excited state potential slightly steeper and the Π_u^- slightly more repulsive at short range. We find no clear evidence for a flattening of the potentials that would signal string breaking.

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