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 $\Sigma^+_b$ and $\Pi_u$ 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 $\Pi_u$ excitations leading to exotic $QQg$ 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 $\Sigma^+_b$ 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...
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 $V_{fit}(r_0) = 0$. The lattice spacing is matched using $r_0$. The inset expands the area shown by the box.

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 $\Sigma_g^+$ and excited state $\Sigma_g^{g'}$ potentials. For the $\Pi_u$ 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 $(Rx)$ by paths of the form $(2a\bar{y}, Rx, -2a\bar{y})$ minus its reflection in the $xz$ plane [9].

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

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

$$W(R, T) = C_{\Sigma_g^+}(R)e^{-V_{\Sigma_g^+}(R)T}$$

$$+ C_{\Sigma_g^{g'}}(R)e^{-V_{\Sigma_g^{g'}}(R)T}. \tag{1}$$

For the $\Pi_u$ 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 $\Pi_u^-$ 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.

 differerent 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 $\Sigma_g^+$ 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 $\Sigma_g^+$ is slightly steeper than that of quenched QCD.

 In Fig. 3 we plot the $\Pi_u^-$ 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 $\Sigma_g^{++}$ excited state potential slightly steeper and the $\Pi_u^-$ 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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REFERENCES