NORDITA-1999/50 HE

Interactions of heavy-light mesons*

UKQCD Collaboration: P. Pennanen[a], C. Michael[b†] and A.M. Green[c†]

[a]Nordita, Blegdamsvej 17, 2100 Copenhagen Ø, Denmark

[b]Theoretical Physics Division, Dept. of Math. Sciences, University of Liverpool, Liverpool, UK

[c]Dept. of Phys. and Helsinki Inst. of Phys., P.O. Box 9, FIN-00014 University of Helsinki, Finland

The potential between static-light mesons forming a meson-meson or a meson-antimeson system is calculated in quenched and unquenched SU(3) gauge theory. We use the Sheikholeslami-Wohlert action and statistical estimators of light quark propagators with maximal variance reduction. The dependence of the potentials on the light quark spin and isospin and the effect of meson exchange is investigated. Our main motivation is exploration of bound states of two mesons and string breaking. The latter also involves the two-quark potential and the correlation between two-quark and two-meson states.

We have been working on lattice calculations of multiquark systems in order to understand their properties from first principles. Here “multi” means that the system can be decomposed into more than one colour singlet, the simplest case being four quarks. Previously, we have studied four quarks in the static approximation in SU(2), getting energies for a general set of geometries which have been reproduced by a model based on two-body potentials and multiquark interaction terms [1]. We have also looked at the flux distribution corresponding to the binding energy [2]. These results for the static case are discussed in last year’s proceedings.

In the current work only two of the quarks are static and SU(3) is used, also unquenched. The binding of this system of two heavy-light mesons is studied as a function of the heavy quark separation. Different cases of spin and isospin of the light quarks are measured and the effect from meson exchange is extracted from the potentials. The model for energies of static quarks is extended for this more dynamic system as discussed in Ref. [3] and by A.M. Green in these proceedings. The meson-antimeson case with light quark isospin $I_q = 0$ is relevant to string breaking.

In the future we plan to explore breaking of an excited string, which is interesting from the point of view of hybrid meson phenomenlogy.

*Presented by P. Pennanen, `petrus@hip.fi`

†e-mails: `cmi@liv.ac.uk, anthony.green@helsinki.fi`

1. TWO HEAVY-LIGHT MESONS

Experimental candidates for bound states of four quarks (of which two are antiquarks) lie close to meson-antimeson thresholds. In our case e.g. a heavy Υ particle could be a $B^*\bar{B}^*$ system. Systems with heavy quarks should be more easily bound as the repulsive kinetic energy is smaller with the attractive potential being flavour independent. The binding of four-quark systems has been studied e.g. in bag, string-flip and deuson models, states with two b quarks being stable in most models.

In the lattice calculation we measure two diagrams for both meson-meson and meson-antimeson cases – see Fig. 1. One of them is the unconnected one without light quark interchange and the other connected, where the light quarks hop from one meson to another. The light quark mass we use is approximately that of s. Because of the static approximation for the heavy quarks their spin and isospin decouples making the pseudoscalar B and the vector B^* degenerate, while physically they have a 46 MeV (1%) separation. We call this degenerate set $\mathcal{B}$. For the two-meson system combinations of B and B^* do have different energies in our case. We measure wavefunctions symmetric under interchange of the mesons with the light quark spin and isospin being singlet or triplet; these then couple to B, B^* combinations [4].

We obtain estimates of light quark propaga-

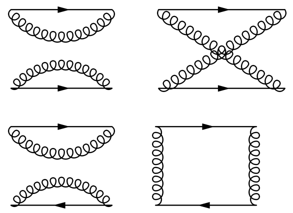

Figure 1. Diagrams for $\mathcal{BB}$ and $\mathcal{B}\bar{\mathcal{B}}$ systems.

tors using maximally variance reduced pseudofermionic ensembles [6], 24 of which are generated for each gauge configuration. A second nested Monte Carlo calculation is then performed for the pseudofermions of each gauge configuration. The variance reduction requires "halving" of the lattice into two separate regions with the propagators going from one region to the other. Thus the connected diagram for $\mathcal{B}\bar{\mathcal{B}}$ and the cross correlator between $Q\bar{Q}$ and $\mathcal{B}\bar{\mathcal{B}}$ need to have one of the normally spatial axes as the temporal axis, introducing considerable technical complications. The parameters of our calculation are $\beta = 5.2$, $C_{SW} = 1.76$, $a \approx 0.14$ fm, $M_{PS}/M_V = 0.72$ for unquenched [5] and $\beta = 5.7$, $C_{SW} = 1.57$, $a \approx 0.17$ fm, $M_{PS}/M_V = 0.65$ for the quenched case with a $16^3 \times 24$ lattice being used for both. We have 20 and 54 gauge configurations for quenched and unquenched respectively; with pseudofermionic fields these take some 60 GB of diskspace. A variational basis of local and fuzzed mesonic operators is used, diagonalization of which maximizes overlap with the ground state of the system.

We measure the different spin and isospin components as discussed in Ref. [4]. For the $\mathcal{B}\bar{\mathcal{B}}$ case $I_q = 1$ has only the unconnected diagram, whereas $I_q = 0$ has the connected one subtracted.

2. RESULTS

The raw correlators show that for the $\mathcal{BB}$ system the unconnected diagram is much noisier and does not contribute to the binding at $R > 1$. The connected diagram, on the other hand, gives a small binding for larger R and also contributes to the observables where the spin of the light quarks changes.

At $R = 0$ the heavy quarks are at the same point and the $\mathcal{BB}$ case looks like a baryon with an antitriplet string. We can compare to previously measured [6] energies of the Λ_b, Σ_b baryons for $I_q, S_q = (0,0)$ and $I_q, S_q = (1,1)$ respectively, finding excellent agreement [4]. States with a sextet string $(0,1;\ 1,0)$ lie higher. The $\mathcal{B}\bar{\mathcal{B}}$ singlet at $R = 0$ looks like a pion, and we find agreement with the energy of a pion with non-zero momentum.

The meson-meson potentials are shown in Fig. 2. The $I_q, S_q = (1,1)$ case is similar to $(0,0)$ but less bound; the level ordering observed at $R = 0$ is retained and the attraction disappears earlier. For the $(1,0)$ a remnant of the sextet string makes the small-R potential repulsive. The $(0,1)$ at $R = 0$ is attractive for unquenched and repulsive for quenched; this is the only qualitative ($\approx 2.5\sigma$) difference between the quenched and unquenched results visible in our data. Both $(0,1)$ and $(1,0)$ seem to have attraction at $r \approx 0.3$ fm, which is a meson exchange effect as opposed to the small distance behaviour governed by gluonic effects. From a crude two-body Schrödinger approach using these potentials we expect binding for all of these cases except perhaps $(1,0)$.

The meson-antimeson potential for $I_q, S_q = (1,0)$ is shown in Fig. 3, the $(1,1)$ case being similar. For both of these a $Q\bar{Q} + q\bar{q}$ state with the same quantum number is lighter for small R. For $(1,0); (1,1)$ the relevant energies are $V(R)+\pi$ and $V(R) + \rho$ respectively, where $V(R)$ is the static $Q\bar{Q}$ potential. An estimate of $V(R) + \pi$ is included in Fig. 3.

The contribution from meson exchange can be examined e.g. by looking at the crossed diagram measured in the quenched approximation at fixed T as a function of R. The $BB \to BB$ case should have a contribution from ρ exchange, and we indeed find agreement by using the previously measured m_ρ and normalizing by hand. For $BB^* \to B^*B$ we should have a contribution from π exchange. In this case we can use a recent determination of the $BB^*\pi$ coupling [7], the experimental decay constant and our m_π. In the one-π exchange formula everything is thus known, and we find excellent quantitative agreement for $R \geq 0.5$ fm. This is strong support for deuson models [8] in this distance range.

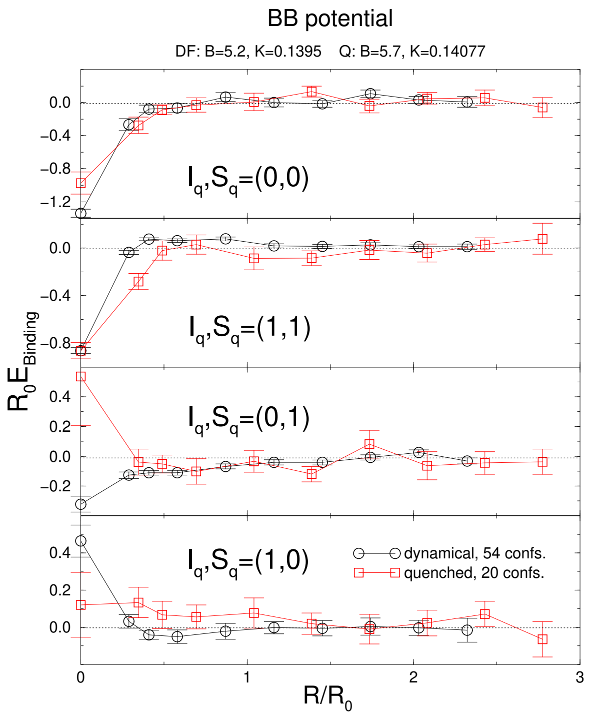

Figure 2. $\mathcal{BB}$ potentials. Here $2M_BR_0 = 4.98(1),\ 5.83(3)$ for quenched, unquenched respectively and $aR_0 = 0.49$ fm.

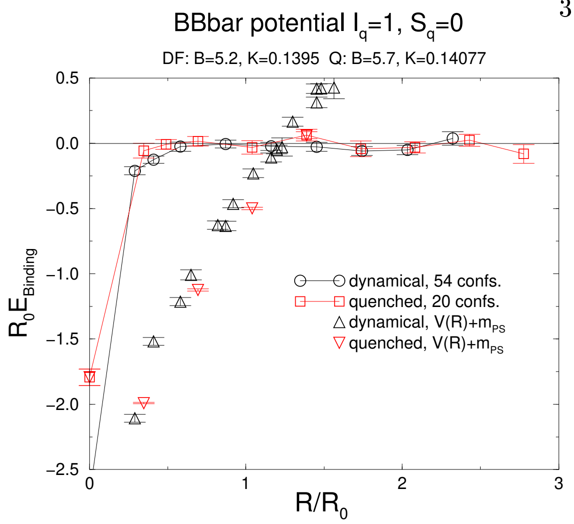

Figure 3. $\mathcal{B}\bar{\mathcal{B}}$ potentials. For small R a state with a $Q\bar{Q}$ and a pion should be lighter.

3. STRING BREAKING

In our quenched and unquenched calculations the ground state $\mathcal{B}\bar{\mathcal{B}}$ and $Q\bar{Q}$ potentials cross at $r \approx 1.2$ fm. We are investigating the breaking of the $Q\bar{Q}$ string by using a variational approach similar to that used in Higgs models by several groups. The cross correlator between two-meson and two-quark states allows us to study their mixing also in the quenched theory – in the unquenched case additional fermion bubbles induce corrections. The quenched mixing matrix element can then be used to estimate the splitting of energy levels at the string breaking point, even though no actual splitting occurs with quenching. With an unquenched calculation the energy splitting can be studied directly using the full variational approach.

One might think that an excited string would break at a smaller distance than the ground state. This is not necessarily the case, as e.g. the first excited state has $J_z = 1$ with quark separation along z and only breaks into mesons $\mathcal{B}_L\bar{\mathcal{B}}_{L'}$ with $L + L' > 0$. In general it is an open question if a state with particular quantum numbers has the lowest energy at a particular heavy quark separation as a) a hybrid $Q\bar{Q}$ meson with excited glue, b) a ground state $Q\bar{Q}$ meson and a $q\bar{q}$ meson or c) two heavy-light mesons. These energy levels and their mixing can be studied on the lattice with our techniques.

REFERENCES

1. A. M. Green and P. Pennanen, Phys. Rev. **C57**, 3384 (1998), `hep-lat/9804003`.
2. P. Pennanen, A. M. Green and C. Michael, Phys. Rev. **D59**, 14504 (1999), `hep-lat/9804004`.
3. A. M. Green, J. Koponen and P. Pennanen, `hep-ph/9902249`.
4. **UKQCD** Collaboration, C. Michael and P. Pennanen, Phys. Rev. **D60**, 54012 (1999), `hep-lat/9901007`.
5. **UKQCD** Collaboration, C. R. Allton *et al.*, Phys. Rev. **D60**, 34507 (1999), `hep-lat/9808016`.
6. **UKQCD** Collaboration, C. Michael and J. Peisa, Phys. Rev. **D58**, 34506 (1998), `hep-lat/9802015`.
7. **UKQCD** Collaboration, G. M. de Divitiis *et. al.*, JHEP **10**, 010 (1998), `hep-lat/9807032`.
8. N. A. Törnqvist, Z. Phys. **C61**, 525–537 (1994), `hep-ph/9310247`.