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Heavy Quark Physics in $N_f = 2$ QCD*

CP-PACS Collaboration:

S. Aoki[a], R. Burkhalter[a,b], S. Ejiri[b], M. Fukugita[c], S. Hashimoto[d], Y. Iwasaki[a,b], K. Kanaya[a,b], T. Kaneko[b], Y. Kuramashi[d], K. Nagai[b], M. Okawa[d], H. P. Shanahan[b], A. Ukawa[a,b] and T. Yoshié[a,b]

[a]Institute of Physics, University of Tsukuba, Tsukuba 305-8571, Japan

[b]Center for Computational Physics, University of Tsukuba, Tsukuba 305-8577, Japan

[c]Institute for Cosmic Ray Research, University of Tokyo, Tanashi 188-8502, Japan

[d]High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan

We present a preliminary analysis of the heavy-heavy spectrum and heavy-light decay constants in full QCD, using a tadpole-improved SW quark action and an RG-improved gauge action on a $16^3 \times 32$ lattice with four sea quark masses corresponding to $m_\pi/m_\rho \approx 0.8, 0.75, 0.7, 0.6$ and $a^{-1} \approx 1.3\,\mathrm{GeV}$. We focus particularly on the effect of sea quarks on these observables.

1. Introduction

Despite the difficulties that heavy quarks present for study on the lattice, in two areas at least, they provide an excellent laboratory for examining effects of sea quarks, namely the hyperfine splitting of heavy-onia and heavy-light decay constants.

The calculation of the hyperfine splitting has been extensively pursued in quenched QCD[1]. In the charm sector, one can compare results with the experimental value $M_{J/\psi} - M_{\eta_c} = 118(2)\mathrm{MeV}$. Relativistic actions underestimate this splitting, giving a result of 70-80 MeV. Nonrelativistic actions yield similar values. This difference has been argued to arise from quenching, due to a smaller value of the strong coupling constant at short distances in quenched QCD[2]. Since the strong coupling constant, as estimated from the Coulomb term of the static potential, has been seen to increase by about 10% by the introduction of sea quarks[3,4], one may hope to observe an effect also in the hyperfine splitting.

A similar reasoning suggests that heavy-light decay constants are underestimated without sea quarks. Recent results from the MILC [5] and NRQCD [6] Collaborations do show that the decay constants increase with decreasing sea quark mass, although an accurate measurement still has to be carried out.

Table 1
Run parameters for this simulation with eventual final statistics in parentheses.

K_{sea}	m_{PS}/m_V	a_σ^{-1}[GeV]	N_{cfg} (HH,HL)
0.1375	0.8048(9)	0.9653(65)	179, 322 (700)
0.1390	0.751(1)	1.0205(80)	215, 311 (700)
0.1400	0.688(1)	1.0889(72)	270, 229 (700)
0.1410	0.586(3)	1.1612(87)	169, 224 (500)

In this report we present preliminary heavy quark results calculated on two-flavor full QCD configurations being generated by the CP-PACS Collaboration[7], with emphasis on search for sea quark effects.

2. Computational Details

Our analysis is carried out on a $16^3 \times 32$ lattice for four sea quark masses corresponding to $m_{PS}/m_V \approx$ 0.8-0.6. Configurations are generated with an RG-improved gauge action at $\beta = 1.95$ and the SW quark action with the clover coefficient $c_{sw} = P^{-3/4} = 1.53$ where $P = 1 - 0.8412/\beta$ is the one-loop value of plaquette. The lattice spacing, set either by string tension or m_ρ, takes the value $a^{-1} \approx 1.3\,\mathrm{GeV}$. Parameters relevant for the present study are listed

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*talk presented by H.P. Shanahan

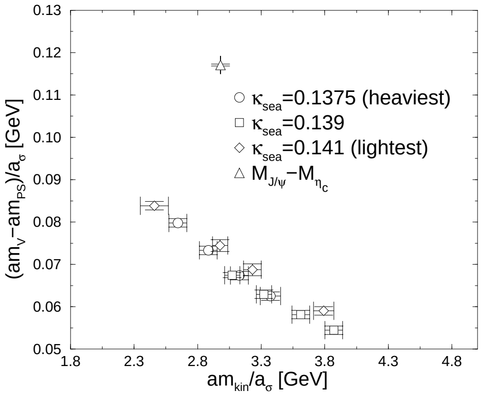

Figure 1. Heavy hyperfine splitting using kinetic mass definition. Scale is set by string tension measured for each sea quark mass.

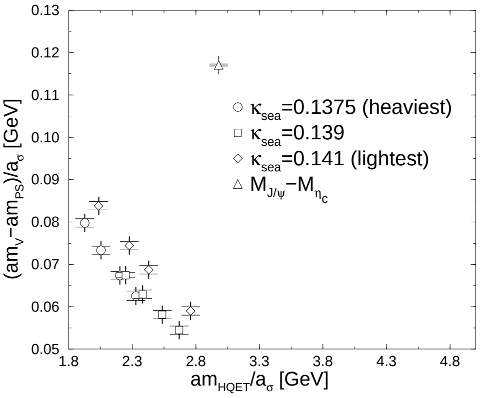

Figure 2. Heavy hyperfine splitting using HQET mass definition.

in Table 1.

Hadron correlators are computed using local and exponentially smeared sources in Coulomb gauge. For study of the heavy-heavy spectrum we choose values of K corresponding to $am_Q = 0.68$, 0.75, 0.83 and 0.9 in the naive pole mass definition $am_Q = (1/K - 1/K_c)/2$. In conjunction with the above estimate for a^{-1}, our present study therefore explores the region of charm quark.

For the heavy-light decay constants a set of lighter heavy quark masses are chosen, determined from a plot of the kinetic mass of heavy-light meson against $1/K$. The light quark has a mass tuned to approximately the strange quark mass as estimated from $m^{PS}_{\bar{s}s}/m_\phi = 0.688$ according to the Gell-Mann-Okubo formula.

3. Results

3.1. Hyperfine splitting

We calculate the hyperfine splitting from the difference of pole masses. With the use of the SW action lattice discretization effects associated with large quark masses are expected to be small for this quantity. The pole mass itself, however, does suffer from large discretization effects, causing problems in calculating the ground state mass. Several possible schemes for measuring the ground state mass have been proposed. We compare two :

(i) the kinetic mass, derived from the dispersion relation,

(ii) an "HQET" mass, suggested by Bernard *et al.*[8], defined as

$$am^{PS}_{HQET} = am^{PS}_{pole} + N_Q(am^Q_{kin} - am^Q_{pole}), \quad (1)$$

with N_Q the number of heavy quarks. We use tree-level quark mass definitions tadpole-improved by a factor $u_0 = P^{1/4}$.

We show our results in Figs. 1 and 2. The scale is set by the string tension determined for each sea quark mass to absorb change of scale. As can be seen, the two definitions draw different conclusions for the hyperfine splitting. The kinetic mass gives results which indicate an almost negligible change between the heaviest sea quark mass ($\approx 3m_{strange}$) and the lightest ($\approx m_{strange}/2$). The values are roughly consistent with those obtained from quenched studies. Using the HQET mass definition there is a significant difference between the heaviest and lightest sea quark masses, but the pseudoscalar masses are now much smaller, indicating that at the charm quark mass, the hyperfine splitting is smaller, approximately 55 MeV.

3.2. Heavy-light decay constants

In Fig. 3 we plot $f_{PS}\sqrt{M_{PS}}$, using the KLM normalization for quark fields. The axial vector

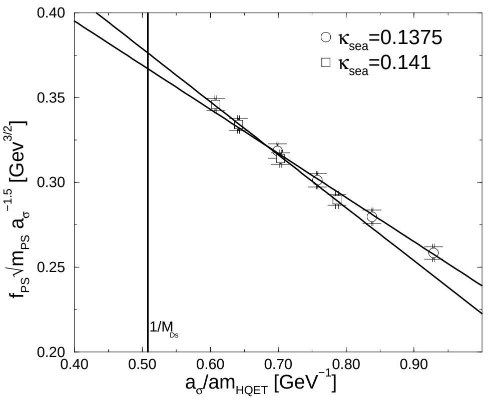

Figure 3. $f_{PS}\sqrt{m_{PS}}$ versus $1/m_{PS}$ with a valence strange quark. For clarity only the heaviest and lightest sea quark masses and their central fits are shown.

renormalization fatcor is taken from Ref. [9] calculated for massless quark at one-loop perturbation theory. As the heavy quark masses taken are smaller than those for the hyperfine splitting measurements, the difference between the two mass definitions is negligible. We adopt the HQET mass definition which has smaller statistical error. The scale is set by the string tension as before.

The results for the heaviest and lightest sea quark masses are quite similar in magnitude. There is a slight upward change in the slope, however, for lighter sea quark. An extrapolation to obtain f_{D_s}, for which we adopt an expansion linear in $1/m_{PS}$, yields a shift between the heaviest and lightest sea quark masses of 2–3 %.

4. Conclusions

At present the ambiguity that exists in the ground state meson mass precludes any quantitative statement about sea quark effects in the hyperfine splitting. We emphasize that this is not symptomatic of the dynamical configurations employed but is a general feature of coarse lattice spacings. This problem will be alleviated in the set of configurations with a finer lattice spacing $a^{-1} \sim 2.5$ GeV generated by CP-PACS, which we plan to analyze next. Another possible avenue of approach would be to reduce discretization effects through introduction of further terms in the SW action as suggested in Refs. [10,11].

The heavy-light decay constants around the charm mass region examined here show only a slight shift upwards as the sea quark mass is reduced. Quenched chiral perturbation theory[12,13] suggests, however, that the shift increases with the heavy quark mass, and may reach a sizable level in the region of the b quark. Studies with very heavy (or static) quarks may then provide the best region for understanding the systematic error due to quenching.

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