Heavy-light decay constants with three dynamical flavors

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We present preliminary results for the heavy-light leptonic decay constants in the presence of three light dynamical flavors. We generate dynamical configurations with improved staggered and gauge actions and analyze them for heavy-light physics with tadpole improved clover valence quarks. When the scale is set by m_ρ, we find an increase of $\approx$23% in f_B with three dynamical flavors over the quenched case. Discretization errors appear to be small ($\lesssim$3%) in the quenched case but have not yet been measured in the dynamical case.

The computation of leptonic decay constants for heavy-light mesons plays a key role in the extraction of CKM matrix elements from experiment and has been a focus of lattice QCD calculations for many years. Here, we report on the first attempt to compute such decay constants in the presence of $N_F = 3$ light sea quarks (u, d, s). For the generation of the dynamical lattices, we use the "Asqtad" action [1], which consists of order $\alpha_s a^2, a^4$ improved staggered quarks and order $\alpha_s^2 a^2, a^4$ Symanzik improved glue [2,3]. This action has small discretization errors for many quantities [4,5]. For the valence quarks, we employ a tadpole-improved (Landau link) clover action and the Fermilab formalism [6]. The analysis is done in a "partially quenched" manner: the valence quark masses are extrapolated to their physical values with the sea quark masses held fixed. The chiral extrapolation of the sea quark masses (at fixed lattice spacing) is performed afterwards.

Table 1 shows the parameters of our lattices and the current state of this project. As we decrease the dynamical quark masses from large values in the three-flavor case, we keep the three masses degenerate until the physical strange quark mass is reached. We then keep the strange quark mass fixed as we further decrease $m_{u,d}$.

Configurations with varying dynamical quark mass (including quenched and two-flavor configurations) have been matched in lattice spacing using the quantity r_1 [5], which is defined from the static quark potential at shorter distance than r_0 [7]. From the value $r_0 \approx 0.5$ fm we have found $r_1 \approx 0.35$ fm [8] in full QCD. Note that the errors in these phenomenological values may be as large as 10% [7]; we therefore prefer to use m_ρ in setting the absolute scale. Details of the lattice generation and light quark results are in Ref. [8]. Our analysis of heavy-light decay constants follows Refs. [9,10]; we describe only the important differences below.

On all lattice sets, we compute quark propaga-

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Table 1
Status of heavy-light running. We show the nominal value of a determined from $r_1 = 0.35$ fm. All 0.13 fm lattices are $20^3 \times 64$; all 0.09 fm lattices are $28^3 \times 96$. "# gen." is the number of configurations that have been generated; "# f_B" is the number on which f_B has been calculated.

dynamical $am_{u,d}/am_s$	β	a (fm)	# gen.	# f_B
∞/∞	8.00	0.13	408	290
$0.02/\infty$	7.20	0.13	536	411
0.40/0.40	7.35	0.13	332	–
0.20/0.20	7.15	0.13	341	341
0.10/0.10	6.96	0.13	339	–
0.05/0.05	6.85	0.13	425	425
0.04/0.05	6.83	0.13	351	–
0.03/0.05	6.81	0.13	564	193
0.02/0.05	6.79	0.13	486	486
0.01/0.05	6.76	0.13	407	399
∞/∞	8.40	0.09	417	200
0.031/0.031	7.18	0.09	162	40
0.0124/0.031	7.11	0.09	25	–

tors for 5 light and 5 heavy masses. This gives good control over both chiral and heavy quark interpolations/extrapolations. In Ref. [9], with 3 light quark masses, the chiral extrapolation was a major source of systematic error. Here, changing from linear to quadratic chiral fits of decay constants changes the results by $\lesssim$2%.

The (tadpole improved) perturbative renormalization of the heavy-light axial current, $Z_A^{\rm tad}$, has not yet been calculated. At present, we therefore proceed as follows at $a \approx 0.13$ fm:

(1) Define boosted coupling α_s^P from the plaquette following Refs. [3,11], and then define the 1-loop coefficient ζ_A by $Z_A^{\rm tad} = 1 + \alpha_s^P \zeta_A$.

(2) Fix the scale from m_ρ on each set, with valence quarks extrapolated to physical values.

(3) Fix ζ_A by demanding that $f_B^{\rm quench} = 169$ MeV (the MILC continuum-extrapolated result [12]). This gives $Z_A^{\rm tad}$ on all the 0.13 fm lattices, since ζ_A is independent of the number of dynamical flavors.

Note that ζ_A is dependent on the heavy quark mass through the dimensionless quantity am. To test scaling we first repeat the above procedure for f_D at 0.13 fm and then interpolate to the correct quark mass for f_B at 0.09 fm. There is a 2% change in ζ_A for f_B between the two lattice spacings. Because this change results in only a 0.3% effect on f_B, we believe that systematic effects in the procedure are negligible.

Note also that comparisons of f_B with $f_B^{\rm quench}$ or changes of f_B with a are only very weakly dependent on our assumption about the continuum value of $f_B^{\rm quench}$. Further, the ratio f_{B_s}/f_B is essentially independent of perturbation theory.

In the plots below, we show two sets of errors. The smaller ones represent the statistical errors from the fits, computed by jackknife. We use the same fitting ranges in time for all lattices with the same spacing. The larger error bars take into account variations caused by changing the fitting ranges while keeping confidence levels and statistical errors reasonable.

Preliminary data for f_B with the scale set by m_ρ is shown in Fig. 1. There is clear evidence for an increase in f_B as the dynamical quark mass is decreased. There is also an increase in the $N_F = 3$ results over those with $N_F = 2$. Note that the quenched results at the two lattice spacings are consistent; they differ by $\lesssim$3%.

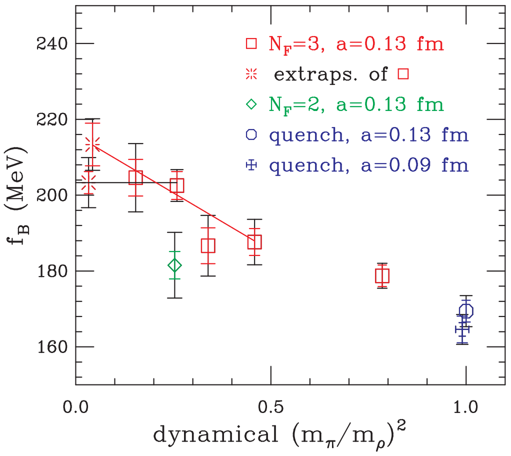

Figure 1. f_B versus $(m_\pi/m_\rho)^2$ of the dynamical light quarks. The scale is set by m_ρ, with valence quarks extrapolated to the physical point.

Figure 2 shows f_B with the scale set by $r_1 = 0.35$ fm (the phenomenological error in this value of r_1 is not included). There is now little if any dependence on the dynamical quark mass: Holding r_1 fixed forces the short distance potentials to match quite closely, which in turn keeps f_B, the "wave function at the origin," more or less fixed. In the physical case (three dynamical quarks extrapolated to physical masses) the values of f_B in Figs. 1 and 2 are consistent.

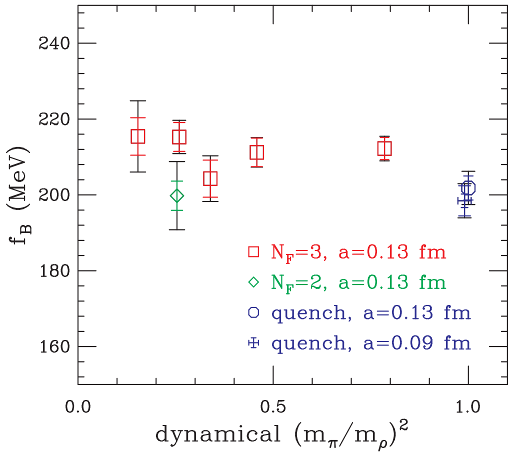

Figure 2. Same as Fig. 1, but with scale set by $r_1 = 0.35$ fm.

The ratio f_{B_s}/f_B is shown in Fig. 3. No obvious dependence on the number or masses of dynamical quarks is apparent. We therefore fit all the data to a constant.

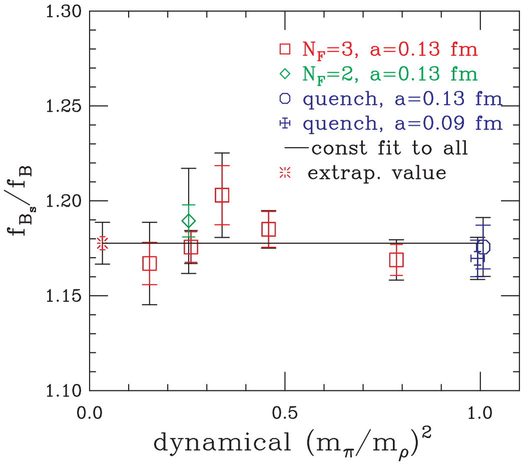

Figure 3. Same as Fig. 1, but for f_{B_s}/f_B.

For the moment, we assume that the scaling errors in f_B or f_{B_s}/f_B are no larger than the difference in our quenched results at 0.13 fm and 0.09 fm. With this assumption (which will be tested in the coming year) we arrive at the following *preliminary* results: $f_B/f_B^{\rm quench} = 1.23(4)(6)$ and $f_{B_s}/f_B = 1.18(1)(^{+4}_{-1})$, where the first error is statistical and the second is systematic, including discretization and chiral extrapolation (valence and dynamical) errors, the uncertainties in κ_s (for f_{B_s}/f_B), and a rough estimate of perturbative errors. A direct determination of f_B itself with three dynamical flavors must await the calculation of the renormalization factors.

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12. Ref. [10] quotes $f_B^{\rm quench} = 173(6)(16)$ MeV, where f_π sets the scale for the central value. With an m_ρ scale, this becomes 169 MeV.