Quark Loop Effects in Semileptonic Form Factors for Heavy-Light Mesons

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We present preliminary results of a determination of the semileptonic form factor for the decay of pseudoscalar heavy-light mesons to pseudoscalar light-light mesons in full QCD. In this preliminary study we focus on the effects of dynamical quark loops. Accordingly, we compare results of simulations with matched quenched and Asqtad dynamical gauge configurations. The latter include three flavors of light quarks. Our simulation uses clover Wilson valence quarks, treated in the Fermilab formalism. Preliminary results, as yet uncorrected by continuum matching factors, suggest a measurable enhancement in the form factor due to dynamical quark loops over the accessible range of q^2.

1. INTRODUCTION

Recent improvements in lattice determinations of f_K and f_π [1] encourage us to hope that lattice values for semileptonic form factors for heavy-light decays will achieve an accuracy of a few percent in the near future. Previous form factor calculations have been done in the quenched approximation (except for a preliminary study [2]), using light quarks with masses of the order of the strange quark [3,4,5,6]. Here we report a preliminary investigation of quenching effects by comparing results from matched quenched and dynamical quark-loop gauge ensembles [7,8]. The 409 $20^3 \times 64$ quenched lattices were generated with a one-loop Symanzik-improved gauge action, and the 489 $20^3 \times 64$ dynamical lattices were generated with 2+1 flavors of Asqtad staggered quarks with bare quark masses $am_{u,d} = 0.02$ and $am_s = 0.05$, the latter, approximately 1.2 times the physical strange quark mass. The lattice scale a was based on the Υ 1S-1P mass splitting [9], giving $a = 0.125$ fm for the quenched lattices and $a = 0.122$ fm for the dynamical lattices.

Form factors were measured using clover-improved, propagating Wilson light and heavy quarks. Three light and five heavy quark masses were used for each ensemble. The mass of the lightest quark was approximately equal to the strange quark mass, thus avoiding problems with exceptional configurations. Quark masses were tuned only approximately between the two ensembles, so a comparison of results requires some interpolation. We included three heavy-light "B" meson three-momenta and 21 three-momentum transfers to the recoiling light-light "π" meson.

2. METHOD

We measure the three point function in the usual way with a light-light (or heavy-light) "π"

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interpolating operator $\mathcal{O}_{\pi,G}$ at $t = 0$, a heavy-light "B" interpolating operator $\mathcal{O}_{B,G}$ at $t_f = 16$ and a weak vector current operator acting over the range $t \in [0, 16]$:

$$F_\mu(\mathbf{kqp}, t) = \langle 0|O_{\pi,G}(\mathbf{k}, 0)V_\mu(\mathbf{q}, t)O^\dagger_{B,E}(\mathbf{p}, t_f)|0\rangle$$

The quark-antiquark wavefunction G for the π meson was a product of two independent Gaussians of width $1.4a$ centered at the origin. The quark-antiquark wavefunction E for the B meson was a plane wave of c.m. momentum $\mathbf{p}$ and a decaying exponential in the relative coordinate. The current vertex was projected onto three-momentum $\mathbf{q}$, thus selecting a recoil three-momentum $\mathbf{k} = \mathbf{p} - \mathbf{q}$. Heavy-light and light-light two-point functions were also measured over the same range of three-momenta $\mathbf{k}$ and with source/sink combinations G and E:

$$\begin{aligned} C_{X,GG}(\mathbf{k}, t) &= \langle 0|O_{X,G}(\mathbf{k}, 0)O^\dagger_{X,G}(\mathbf{k}, t)|0\rangle \\ &\to Z_{X,G}(\mathbf{k})Z_{X,G}(\mathbf{k})e^{-E_\pi(\mathbf{k})t} \\ C_{B,GE}(\mathbf{p}, t) &= \langle 0|O_{B,G}(\mathbf{p}, 0)O^\dagger_{B,E}(\mathbf{p}, t)|0\rangle \\ &\to Z_{B,G}(\mathbf{p})Z_{B,E}(\mathbf{p})e^{-E_B(\mathbf{p})t} \end{aligned}$$

for $X = \pi, B$. The form factor was extracted using the conventional ratio method

$$R_\mu(t) = \frac{F_\mu(\mathbf{k}, \mathbf{q}, \mathbf{p}, t)}{C_{\pi,GG}(\mathbf{k}, t)C_{B,GE}(\mathbf{p}, t_f - t)}$$

$$\langle \pi(\mathbf{k})|V_\mu(\mathbf{q})|B(\mathbf{p})\rangle = N Z_{\pi,G}(\mathbf{k})Z_{B,G}(\mathbf{p})R_\mu,$$

where $Z_{\pi,G}(\mathbf{k})$ and $Z_{B,G}(\mathbf{p})$ are hadron overlap coefficients, R_μ is the plateau value of $R_\mu(t)$ and

$$N = N_{u,d}N_b = \sqrt{1 - \frac{3\kappa_{u,d}}{4\kappa_{\rm cr}}}\sqrt{1 - \frac{3\kappa_b}{4\kappa_{\rm cr}}}$$

is the Fermilab normalization [10]. Additional vertex operators were measured to implement the tadpole improved rotation for the quark wave functions in the vector current:

$$q_I(x) = N_q\left[1 + ad\vec{\gamma}\cdot\vec{D}\right]q(x).$$

For each quark mass combination the two-point functions were fit simultaneously for all momenta to a ground plus first excited state expression parameterized by a smooth function of momentum. The resulting ground state energies were then fixed when fitting the three-point functions, and the resulting hadronic overlap coefficients were used to complete the three-point function.

The Lorentz invariant form factors $f^+(q^2)$ and $f^-(q^2)$ were extracted using kinematic factors based on physical hadron masses determined from the two-point dispersion relations. To compare quenched and dynamical results, we required an interpolation in only the heavy quark mass, since a light quark mass in each ensemble was already matched to the strange quark mass, as determined from the unmixed $s\bar{s}$ pseudoscalar meson. To this end the form factors were fit to a parameterization of Bećirević and Kaidalov (BK) [11]:

$$\begin{aligned} f^+ &= \frac{c_H(1-\alpha_H)}{(1-\tilde{q}^2)(1-\alpha_H\tilde{q}^2)} \\ f^0 &= \frac{c_H(1-\alpha_H)}{(1-\tilde{q}^2/\beta_H)} \end{aligned}$$

($\tilde{q}^2 = q^2/m^2_{B^*}$), which incorporates constraints from heavy quark scaling, the B^* meson pole, and QCD sum rules. The resulting BK coefficients were then interpolated to the various dynamical-ensemble physical heavy-light meson masses through a fit to scaling forms as a function of the heavy-light meson mass, as shown in Fig. 1. A sample result is shown in Fig. 2. The quenched prediction is about 10% low. At this heavy-light mass the effect is greater than 2σ. We find a similar underestimate for the entire range of heavy-light meson masses in this study, from approximately m_{D_s} to m_{B_s} with light spectator and recoil quarks at the strange quark mass.

3. CONCLUSION

We have measured the semileptonic form factor for decays of a heavy-light pseudoscalar meson to a light-light pseudoscalar meson using improved Wilson valence quarks. We chose carefully matched quenched and Asqtad $2 + 1$ flavor staggered fermion ensembles to look for the effects of virtual quarks. Fixing all light quarks at the strange quark mass, we required only a single heavy-quark interpolation to make the comparison. For heavy-light masses of the order of the B_s mass, we found that virtual quark loops tend to

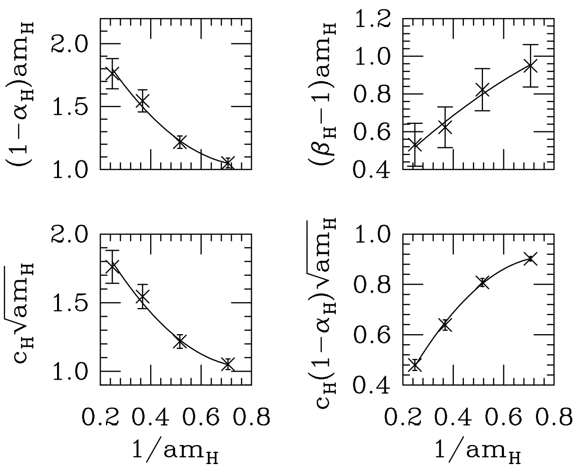

Figure 1. Quadratic heavy-quark scaling fits to the BK parameters for the quenched form factors with a strange spectator and recoil quark.

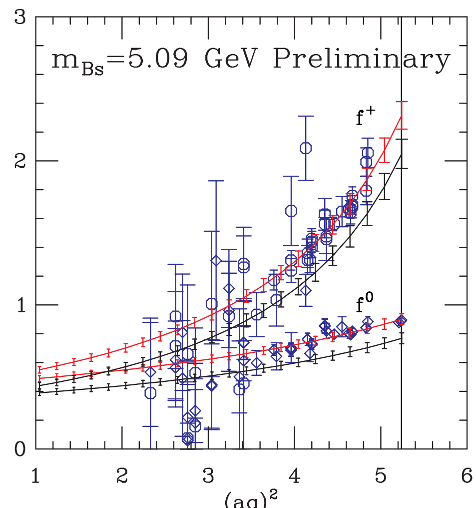

Figure 2. The f^0 and f^+ form factors in the presence of dynamical quark loops. Here the spectator quark and recoil quark have a mass equal to the strange quark. The mass of the heavy-light meson is approximately 5.09 GeV. For each form factor the upper curve with error bars is a fit to the simulation points and the lower curve is predicted from the quenched ensemble. The prediction falls short by about 10%.

increase the form factors by approximately 10%, a $> 2\sigma$ effect. Note however that our preliminary analysis neglects lattice/continuum matching (lattice renormalization) of the heavy-light current. Since the coupling constant is larger on the dynamical lattices, including the renormalization may compensate for at least some of the difference found between quenched and dynamical simulations.

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