EFI-92-60
Fermilab Library
0 1160 0019203 3

3

EFI 92-60
November 1992

SEMILEPTONIC DECAYS OF D MESONS AND THE HEAVY QUARK EFFECTIVE THEORY†

JAMES F. AMUNDSON and JONATHAN L. ROSNER
University of Chicago and Enrico Fermi Institute, 5640 S. Ellis Ave.
Chicago, Illinois 60637 USA

ABSTRACT

We consider the application of heavy quark symmetry to the strange quark in semileptonic decays of D mesons. We find that consistency with experimental data requires substantial ($\simeq 30\%$) corrections due to both perturbative QCD and finite-mass effects. Nonetheless, these corrections are consistent with *a priori* expectations and provide insight into the symmetry-breaking effects in B decays.

The Heavy Quark Effective Theory (HQET) is a useful tool for studying the decays of b quarks to c quarks, as in the decay $B \to D^{(*)}l\nu$. The reason we believe this is true is that corrections to the leading-order HQET are of order $\overline{\Lambda}/2m_Q$. Here m_Q denotes the mass of the heavy quark, while $\overline{\Lambda}$ is a constant of order $\Lambda_{\rm QCD}$. The quark model predicts that $\overline{\Lambda} \simeq 300$ MeV, while sum rule calculations[1] suggest a larger value, $\overline{\Lambda} \simeq 500$ MeV. Either way, the dominant corrections to $B \to D^{(*)}l\nu$ decay, which are of order $\overline{\Lambda}/2m_c$, should be fairly small.

If we we want to apply HQET to $D \to K^{(*)}l\nu$ decays, the situation is less clear. An expansion in $\overline{\Lambda}/2m_s$ might not make any sense at all. If however, we take the quark model prediction for $\overline{\Lambda}$ and a constituent strange quark mass $m_s \simeq 500$ MeV, $\overline{\Lambda}/2m_s$ is "only" about 30% and we can attempt to apply the HQET to the strange quark. Ideally, we want the strange quark to act as a sort of magnifying glass for subleading effects in the HQET. In recent work,[2] which we describe here, we have applied the HQET to semileptonic decays of D mesons in this manner.

In the heavy quark limit, all of the form factors for the decay of a heavy meson H to another heavy meson $h^{(*)}$ are given in terms of the Isgur-Wise function $\xi(w)$, where $w \equiv v \cdot v' = (m_H^2 + m_{h^{(*)}}^2 - q^2)/(2m_H m_{h^{(*)}})$ and v (v') is the four-velocity of the meson H ($h^{(*)}$). The Isgur-Wise function is not calculable in perturbation theory. We choose to describe it by a single parameter, ρ, with the functional form

$$\xi(w) = \exp\left[-\rho^2(w-1)\right]. \tag{1}$$

The heavy quark symmetry is broken by both perturbative QCD and finite-mass corrections. The perturbative QCD corrections are calculable, but the finite-mass corrections introduce four new unknown functions and one new unknown constant, $\overline{\Lambda}$.

†Presented by James F. Amundson at DPF 92 Meeting, Fermilab, November, 1992.

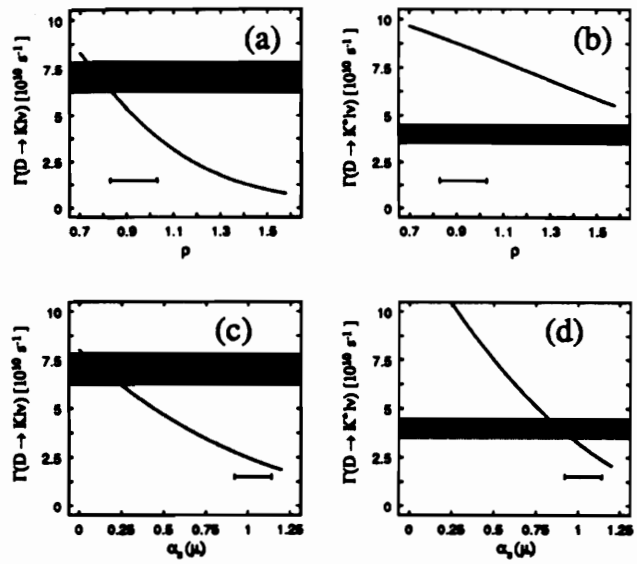

Figure 1: Predictions of heavy-quark symmetry for decay rates of $D \to \overline{K}e^+\nu_e$ (a,c) and $D \to \overline{K}^* e^+\nu_e$ (b,d). Predictions without QCD corrections are shown in (a,b). The ranges of ρ allowed by the fits to B decays are shown by the horizontal error bar. Predictions with QCD corrections are shown in (c,d), where the bars indicate the range of $\alpha_s(\mu)$ obtained in Ref. 2.

In the limit of vanishing lepton mass, there are four measurable form factors in $H \to h^{(*)}l\nu$ decay: f in $H \to hl\nu$ decay and V, A_1, and A_2 in $H \to h^*l\nu$ decay.

The form factor predictions of heavy quark symmetry, including the leading-order perturbative QCD and finite-mass corrections, can be summarized as follows:

$$F_i(w) = k_i(w)\left\{b_i(w,\alpha_s)\xi(w) + \frac{\overline{\Lambda}}{2m_q}\left[c_i(w)\xi(w) + \Psi_i(w)\right]\right\}, \tag{2}$$

where $k_i(w)$ and $c_i(w)$ are simple kinematic factors, $b_i(w,\alpha_s)$ contains the corrections from perturbative QCD and $\Psi_i(w)$ contains the corrections due to the new unknown functions due to finite mass effects. They obey the condition[3]

$$\Psi_{A_1}(w) = \Psi_V(w)\ ;\ \Psi_{A_1}(w=1) = \Psi_V(w=1) = 0. \tag{3}$$

In Figure 1 we show the comparison of the leading-order theory with the measured rates. First we ignore all symmetry breaking corrections, varying only ρ, the parameter governing the shape of the Isgur-Wise function. The $D \to K^*$ data cannot be fit for any value of ρ. Next we take $\rho = 0.93$ from fits to B decays and try to see if we can fit the data by including perturbative QCD corrections. Although the situation for $D \to K^*$ is improved for large values of $\alpha_s(\mu)$, there is no value of $\alpha_s(\mu)$ which simultaneously fits both the $D \to K$ and $D \to K^*$ widths.

The preferred value of $\alpha_s(\mu)$ shown in the plot was determined by a procedure similar to that used to extract V_{cb} using heavy quark theory. We obtain $\alpha_s(\mu) = 1.03 \pm 0.11$, which is very large, but not inconsistent with our *a priori* expectations. The actual corrections are of order $\alpha_s(\mu)/\pi \simeq 33\%$.

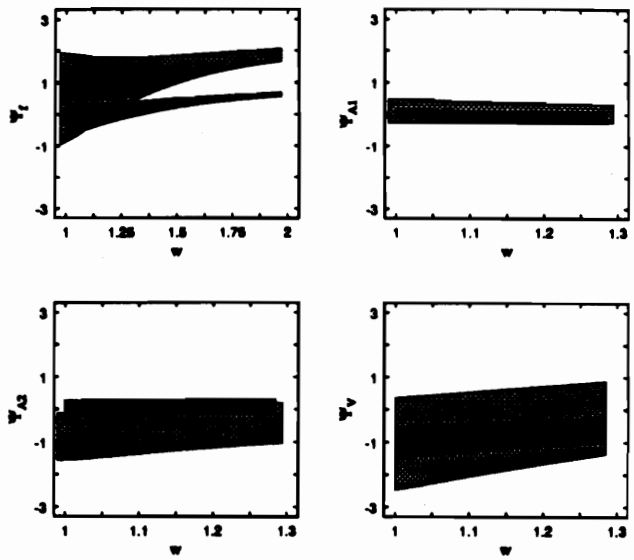

Figure 2: Values of form factors associated with subleading operators obtained from experiment. The light and dark regions correspond to taking $\overline{\Lambda} = 200$ and 400 MeV, respectively. The light regions have been extended horizontally for clarity in some cases.

All of the form factors in $D \to K^{(*)}$ decay have been measured.[4] The only unknown quantity in the form factor $V(w=1)$ is $\overline{\Lambda}$. Comparison with the measured form factor gives $\overline{\Lambda}/2m_s = -0.05 \pm 0.24$, and $\overline{\Lambda} = -44 \pm 297$ MeV. Unfortunately, the error on this value is too large to be truly useful.

In Figure 2 we have extracted the subleading effects from the data by subtracting the leading-order and perturbative QCD predictions from the measured form factors and plotting the remainder. Since this process depends on $\overline{\Lambda}$, an essentially unknown quantity, we have used two representative values of $\overline{\Lambda}$. We can see that Ψ_f is clearly non-zero for large values of w. This is what is required to simultaneously explain the $D \to K$ and $D \to K^*$ rates. We also see that the conditions in Eq. (3) are better satisfied for the smaller value of $\overline{\Lambda}$.

This work was supported in part by United States Department of Energy under Grant No. DE AC02 90ER40560.

1. M. Neubert, SLAC Report No. SLAC-PUB-5826, June, 1992, to be published in Phys. Rev. D.
2. J. F. Amundson and J. L. Rosner, Enrico Fermi Institute preprint EFI-92-38-Rev, submitted to Phys. Rev. D.
3. M. Luke, Phys. Lett. B **252**, 447 (1990).
4. S. Stone, Syracuse University Report No. HEPSY-1-92, to be published in *Heavy Flavors*, edited by A. J. Buras and H. Lindner, World Scientific, Singapore (1992); E691 Collaboration, J. C. Anjos *et al.*, Phys. Rev. Lett. **67**, 1507 (1991); E653 Collaboration, K. Kodama *et al.*, Phys. Lett. B **286**, 187 (1992).