Fermi National Accelerator Laboratory

B^{**} PROPERTIES

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1. INTRODUCTION

If significant numbers of B mesons are produced through one or more narrow excited $(\bar{b}q)$ states, the strong decay $B^{**\pm} \rightarrow B^{(*)0}\pi^{\pm}$ will tag the neutral meson as $(\bar{b}d)$ or $(b\bar{d})$, respectively. This might be dramatically more efficient than using the pair-produced partner of the B as a flavor tag, and could advance the search for the expected large CP-violating asymmetry in (B^0 or $\bar{B}^0$) $\rightarrow J/\psi K_S$ decay. B^{**}-tagging might also resolve kinematical ambiguities in semileptonic decays of charged and neutral B mesons by choosing between two solutions for the momentum of the undetected neutrino.[1]

Estia Eichten, Chris Hill, and I have used heavy-quark symmetry to estimate the masses, widths, and branching fractions of orbitally excited B, D_s, and B_s states from the properties of corresponding K and D levels.[2] Our analysis show that one requirement for the utility of B^{**}-tagging—narrow resonances—is likely to be met by the B_2^* and B_1. Experiment will have to rule on the strength of these lines and the ratio of signal to background.

For our purposes, the essential idea of the heavy-quark limit is that the spin $\vec{s}_Q$ of the heavy quark and the total (spin + orbital) angular momentum $\vec{j}_q = \vec{s}_q + \vec{L}$ of the light degrees of freedom are separately conserved.[3] Each energy level in the excitation spectrum of $(Q\bar{q})$ mesons is composed of a degenerate pair of states characterized by j_q and total spin $\vec{J} = \vec{j}_q + \vec{s}_Q$, i.e., by $J = j_q \pm \frac{1}{2}$. The ground-state pseudoscalar and vector mesons, which are degenerate in the heavy-quark limit, correspond to $j_q = \frac{1}{2}$, with $J = 0$ and 1. Orbital excitations lead to two distinct doublets associated with $j_q = L \pm \frac{1}{2}$.

2. MASSES

The leading corrections to the spectrum prescribed by heavy-quark symmetry are inversely proportional to the heavy-quark mass. We may write the mass of a heavy-light meson as

$$M(n\mathrm{L}_J(j_q)) = M(1\mathrm{S}) + E(n\mathrm{L}(j_q)) + \frac{C(n\mathrm{L}_J(j_q))}{m_Q}, \tag{1}$$

where n is the principal quantum number and $M(1\mathrm{S}) = [3M(1\mathrm{S}_1) + M(1\mathrm{S}_0)]/4$ is the mass of the ground state. The excitation energy $E(n\mathrm{L}(j_q))$ has a weak dependence on the heavy-quark mass that we have evaluated in a potential model.[4]

We focus upon the $j_q = \frac{3}{2}$ states observed as narrow $D\pi$ or $D^*\pi$ resonances because their counterparts in other heavy-light systems should also be narrow. Our overall strategy is to use the observed properties of the K and D mesons to predict the properties of the orbitally excited B, D_s, and B_s mesons.

There is no ambiguity about the $2^+(\frac{3}{2})$ levels $K_2^*(1429)$ and $D_2^*(2459)$. We identify $D_1(2424)$ as a $j_q = \frac{3}{2}$ level because it is narrow, as predicted by heavy-quark symmetry. Following Ito et al.,[5] we identify $K_1(1270)$ as the $1^+(\frac{3}{2})$ level, because that assignment gives a consistent picture of masses and widths. For a given value of the charmed-quark mass, a fit to the strange and charmed resonances leads to predictions for other heavy-light masses. Our expectations are summarized in Table 1. The prediction for the 1^+ D_s meson lies 34 MeV below $D_{s1}(2536)$; that discrepancy is a measure of the limitations of our method.

3. DECAY WIDTHS

The decay of an excited heavy-light meson H to a heavy-light meson H' and a light hadron h is governed by heavy-quark symmetry. The two-body decay rate for an ℓ-wave transition may be written as

$$\Gamma(H \to H'h) = \mathcal{C}^2 p^{2\ell+1} F \exp(-p^2/\kappa^2), \tag{2}$$

where p is the three-momentum of the decay products in the rest frame of H, $\mathcal{C}$ is a normalized 6-j symbol, and F sets the strength of each independent decay amplitude. Once F is determined from the charmed or strange mesons, this dynamical quantity may be used to predict related decays, including those of orbitally excited B mesons. We determine the overall strength of the decay and the momentum scale κ of the form factor by fitting to existing data. We assume that κ is typical of hadronic processes ($\approx$ 1 GeV) and that it varies little with decay angular momentum ℓ.

The decays $2\mathrm{P}(\frac{3}{2}) \to 1\mathrm{S}(\frac{1}{2}) + \pi$ are governed by a single $\ell = 2$ amplitude. To evaluate the transition strength F, we fix $\Gamma(D_2^* \to D\pi) + \Gamma(D_2^* \to D^*\pi) = 25$ MeV, as suggested by recent experiments.[6] This determines all the pionic transitions between the $2\mathrm{P}(\frac{3}{2})$ and $1\mathrm{S}(\frac{1}{2})$ multiplets. The results are shown in Table 1, where we indicate the variation of the predicted rates as the momentum scale κ ranges from 0.8 to 1.2 GeV. The strengths of K and (negligible) η transitions are determined by $SU(3)$. The predictions agree well with what is known about the $L = 1$ D and D_s states.

Increasing the D_{s1} and D_{s2}^* masses by 34 MeV to match the observations of D_{s1} increases each of the partial widths for those states by 1 or 2 MeV. The narrow width observed for D_{s1} is close to the prediction from heavy-quark symmetry. This suggests that mixing of the narrow $2\mathrm{P}(\frac{3}{2})$ level with the broader $2\mathrm{P}(\frac{1}{2})$ state is insignificant. This pattern should hold for B and B_s as well.

Our estimates for the ρ transitions are also shown in Table 1. The dependence on the momentum scale κ in the form factor is much more pronounced than for the pseudoscalar transitions because of the wide variation in momentum over the ρ peak.

The results collected in Table 1 show that both the B_2^* and the B_1 states should be narrow (20 to 40 MeV), with large branching fractions to a ground-state B or B^* plus a pion. These states should also have significant two-pion transitions that we have modeled by the low-mass tail of the ρ resonance. The strange states, B_{s2}^* and B_{s1}, are very narrow ($\Gamma \lesssim 10$ MeV); their dominant decays are by kaon emission to the ground-state B and B^*.

Table 1. Masses and decay rates of the 2P($\frac{3}{2}$) heavy-light mesons.

	Width (MeV)			
Transition	Calculated	PDG 1992	CLEO 1993	E687 1993
$D_2^*(2459) \to D^*\pi$	9			
$D_2^*(2459) \to D\pi$	16			
$D_2^*(2459) \to D\rho$	5 to 13			
$D_2^*(2459) \to$ all	30 to 38	19 ± 7	28^{+8+6}_{-7-6}	$24 \pm 7 \pm 5$
$D_1(2424) \to D^*\pi$	11 to 13			
$D_1(2424) \to D\rho$	8 to 11			
$D_1(2424) \to$ all	19 to 23	20^{+9}_{-5}	20^{+6+3}_{-5-3}	$15 \pm 8 \pm 5$
$D_{s2}^*(2537) \to D^*K$	2 to 4			
$D_{s2}^*(2537) \to DK$	6 to 7			
$D_{s2}^*(2537) \to$ all	8 to 11			
$D_{s1}(2502) \to D^*K$	3 to 6	< 4.6	< 2.3	< 3.2
$B_2^*(5767) \to B^*\pi$	11			
$B_2^*(5767) \to B\pi$	10			
$B_2^*(5767) \to B^*\rho$	13 to 29			
$B_2^*(5767) \to B\rho$	4 to 13			
$B_2^*(5767) \to$ all	38 to 63			
$B_1(5755) \to B^*\pi$	14			
$B_1(5755) \to B^*\rho$	11 to 33			
$B_1(5755) \to B\rho$	6 to 8			
$B_1(5755) \to$ all	31 to 55			
$B_{s2}^*(5846) \to B^*K$	2 to 4			
$B_{s2}^*(5846) \to BK$	1 to 3			
$B_{s2}^*(5846) \to$ all	3 to 7			
$B_{s1}(5834) \to B^*K$	1 to 3			

4. ACKNOWLEDGEMENTS

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