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Orbitally Excited Heavy-Light Mesons Revisited

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Abstract

We refine heavy-quark-symmetry estimates of masses and widths of orbitally excited B, B_s, and D_s mesons given in [1]. We present additional details of the predictions for d-wave states.

Incisive study of particle-antiparticle mixing and CP-violation for neutral B mesons requires that the quantum numbers of the meson be identified at the time of production. That identification can be made by observing the decay of a B^0 or $\bar{B}^0$ produced in association with a particle of opposite b-number whose decay signals the flavor of the neutral B of interest. The efficiency of flavor identification might be dramatically enhanced if the neutral B under study were self-tagging [2].

Charmed mesons have been observed as (strong) decay products of orbitally excited $(c\bar{q})$ states, through the decays $D^{**} \rightarrow \pi D$ and $D^{**} \rightarrow \pi D^*$ [3]. The charge of the pion emitted in the strong decay signals the flavor content of the charmed meson. If significant numbers of B mesons are produced through one or more narrow excited $(\bar{b}q)$ states, the strong decay $B^{**\pm} \rightarrow B^{(*)0}\pi^\pm$ tags the neutral meson as $(\bar{b}d)$ or $(b\bar{d})$, respectively.

The ultimate application of B^{**}-tagging would be in the search for the expected large CP-violating asymmetry in $(B^0$ or $\bar{B}^0) \rightarrow J/\psi K_S$ decay [4]. The study of time-dependent B^0-$\bar{B}^0$ oscillations would also benefit from efficient tagging. B^{**}-tagging may also resolve

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kinematical ambiguities in semileptonic decays of charged and neutral $\bar{B}$ mesons by choosing between two solutions for the momentum of an undetected neutrino. In hadron colliders and Z^0-factories, kinematic tagging may make practical high-statistics determinations of the form factors in semileptonic weak decay, and enable precise measurements of V_{cb} and V_{ub} [5,6]. The study of B_s-$\bar{B}_s$ mixing would be made easier if the kaon charge in the decay $B^{***} \to K^{\pm}(B_s \text{ or } \bar{B}_s)$ served as a flavor tag. Overall, efficient B^{**}-tagging would dramatically enhance the prospects for studying CP-violation and B_s-$\bar{B}_s$ mixing.

In Ref. [1], we estimated 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. Our results showed that one requirement for the utility of B^{**}-tagging, narrow resonances, is likely to be met by the B_2^* and B_1'. Experiment must rule on the strength of these lines and the ratio of signal to background.

For hadrons containing a heavy quark Q, quantum chromodynamics displays additional symmetries in the limit as the heavy-quark mass m_Q becomes large compared with a typical QCD scale [7]. These heavy-quark symmetries are powerful aids to understanding the spectrum and decays of heavy-light $(Q\bar{q})$ mesons. Because $m_b \gg \Lambda_{\text{QCD}}$, heavy-quark symmetry should provide an excellent description of the B and B_s mesons. It is plausible that properties of D mesons, and even K mesons, should also reflect approximate heavy-quark symmetry.

One 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 [8]. Accordingly, 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 the 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 $j_q = L \pm \frac{1}{2}$.

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

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

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. In the heavy-quark limit, the excitation energy $E(n\mathrm{L}(j_q))$ is independent of the heavy-quark mass [9].

Let us focus first upon the $j_q = \frac{3}{2}$ states observed as narrow $D\pi$ or $D^*\pi$ resonances. We will show below that 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. The charmed mesons alone would suffice to predict the 2^+-1^+ splitting. Further information, involving a different heavy quark, is needed to estimate the 2P excitation energy. Since no excited B or B_s levels are yet known, we provisionally use the strange resonances. According to Eq. (1), the masses of the strange and charmed mesons with $j_q = \frac{3}{2}$ are given by

$$\begin{aligned}
M(2\mathrm{P}_2)_K - M(1\mathrm{S})_K &= E(2\mathrm{P}) + \frac{C(2\mathrm{P}_2)}{m_s} \quad , \\
M(2\mathrm{P}_1)_K - M(1\mathrm{S})_K &= E(2\mathrm{P}) + \frac{C(2\mathrm{P}_1)}{m_s} \quad ; \\
M(2\mathrm{P}_2)_D - M(1\mathrm{S})_D &= E(2\mathrm{P}) + \frac{C(2\mathrm{P}_2)}{m_c} \quad , \\
M(2\mathrm{P}_1)_D - M(1\mathrm{S})_D &= E(2\mathrm{P}) + \frac{C(2\mathrm{P}_1)}{m_c} \quad ,
\end{aligned} \tag{2}$$

where we have suppressed the j_q label for brevity. We are left with four linear equations in the five unknowns $E(2\mathrm{P})$, $C(2\mathrm{P}_2)$, $C(2\mathrm{P}_1)$, m_s^{-1}, and m_c^{-1}.

The K- and D-meson masses we use as experimental inputs are displayed in Table I. There is no ambiguity about the $2^+(\frac{3}{2})$ levels. We identify $D_1(2424)$ as a $j_q = \frac{3}{2}$ level because it is narrow, as predicted [12,13] by heavy-quark symmetry. We follow Ito et al. [14] in identifying $K_1(1270)$ as the $1^+(\frac{3}{2})$ level, because that assignment gives a consistent picture of masses and widths.

To proceed, we choose a value for the charmed-quark mass, m_c. After solving Eqs. (2), we verify the reasonableness of m_s and predict the $j_q = \frac{3}{2}$ masses for the B, D_s, and B_s families. We consider two sets of parameters inspired by J/ψ and Υ spectroscopy: $m_c = 1.48$ GeV/c^2, $m_b = 4.8$ GeV/c^2 [15]; and $m_c = 1.84$ GeV/c^2, $m_b = 5.18$ GeV/c^2 [16]. Both solutions [$C(2\mathrm{P}_2) = (0.0629, 0.0783)$ (GeV/c^2)^2, $C(2\mathrm{P}_1) = (0.0105, 0.0132)$ (GeV/c^2)^2, $E(2\mathrm{P}) = (0.4437, 0.4437)$ GeV/c^2, $m_s = (0.3295, 0.4097)$ GeV/c^2] yield reasonable values for the strange-quark mass. Their implications for the B, D_s, and B_s levels are consistent within 2 MeV. The average values are presented in Table I.

The heavy-quark-symmetry prediction for the 1^+ D_s meson lies 10 MeV below the level observed [10,17] at 2536.5 ± 0.8 MeV/c^2. The prediction for the 2^+ D_{s2}^* meson lies 12 MeV below the level observed [18] at 2573.2 ± 1.9 MeV/c^2. We take the discrepancy between calculated and observed masses as a measure of the limitations of our method.

The $2P(\frac{1}{2})$ D mesons have not yet been observed, so we cannot predict the masses of other heavy-light states by this technique. Splitting within the multiplet can be estimated using Eq. (1) from the kaon spectrum alone. The small splitting between $K_0^*(1429)$ and $K_1(1402)$ implies that the $1^+(\frac{1}{2})$ and $0^+(\frac{1}{2})$ levels should be nearly degenerate in all the heavy-light systems. Chiral symmetry and heavy-quark symmetry combined suggest that, like their counterparts in the strange-meson spectrum, the heavy-light $j_q = \frac{1}{2}$ p-wave states should have large widths for pionic decay to the ground states [19]. This will make the discovery and study of these states challenging, and will limit their utility for B^{**}-tagging.

Decay widths. Consider the decay of an excited heavy-light meson H, characterized by $L_J(j_q)$, to a heavy-light meson $H'(L'_{J'}(j'_q))$, and a light hadron h with spin s_h. The amplitude for the emission of h with orbital angular momentum ℓ relative to H' satisfies certain symmetry relations because the decay dynamics become independent of the heavy-quark spin in the $m_Q \to \infty$ limit of QCD [12]. The decay amplitude can be factored [13] into a reduced amplitude $\mathcal{A}_R$ times a normalized 6-j symbol,

$$\mathcal{A}(H \to H'h) = (-1)^{s_Q + j_h + J' + j_q} \mathcal{C}^{s_Q, j'_q, J'}_{j_h, J, j_q} \mathcal{A}_R(j_h, \ell, j_q, j'_q),$$

where $\mathcal{C}^{s_Q, j'_q, J'}_{j_h, J, j_q} = \sqrt{(2J'+1)(2j_q+1)} \begin{Bmatrix} s_Q & j'_q & J' \\ j_h & J & j_q \end{Bmatrix}$ and $\vec{j}_h \equiv \vec{s}_h + \vec{\ell}$. The coefficients $\mathcal{C}$ depend only upon the total angular momentum j_h of the light hadron, and not separately on its spin s_h and the orbital angular momentum wave ℓ of the decay. The two-body decay rate may be written as

$$\Gamma^{H \to H'h}_{j_h, \ell} = (\mathcal{C}^{s_Q, j'_q, J'}_{j_h, J, j_q})^2 p^{2\ell+1} F^{j_q, j'_q}_{j_h, \ell}(p^2), \tag{3}$$

where p is the three-momentum of the decay products in the rest frame of H. Heavy-quark symmetry does not predict the reduced amplitude $\mathcal{A}_R$ or the related $F^{j_q, j'_q}_{j_h, \ell}(p^2)$ for a particular decay. Once determined from the charmed or strange mesons, these dynamical quantities may be used to predict related decays, including those of orbitally excited B mesons. For each independent decay process, we assume a modified Gaussian form

$$F^{j_q,j_q'}_{j_h,\ell}(p^2) = F^{j_q,j_q'}_{j_h,\ell}(0)\exp(-p^2/\kappa^2)\left[\frac{M_\rho^2}{M_\rho^2+p^2}\right]^{\ell}, \tag{4}$$

and determine the overall strength of the decay and the momentum scale κ by fitting existing data. The final factor moderates the p^ℓ threshold behavior of the decay amplitude at high momenta [20]. Our ability to predict decay rates depends on the quality of the information used to set these parameters.

In writing (3) we have ignored $1/m_Q$ corrections to heavy-quark symmetry predictions for decay rates, except as they modify the momentum p of the decay products. We assume that the momentum scale κ of the form factor in (4) is typical of hadronic processes (≈ 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 $F^{\frac{3}{2},\frac{1}{2}}_{2,2}(0)$, we fix $\Gamma(D_2^* \to D\pi) + \Gamma(D_2^* \to D^*\pi) = 25$ MeV, as suggested by recent experiments [3]. This determines all pionic transitions between the $2\mathrm{P}(\frac{3}{2})$ and $1\mathrm{S}(\frac{1}{2})$ multiplets. The results are shown in Table II, where we have used experimentally observed masses of the D, D_s, and K levels and our calculated masses for the B and B_s states. The predicted rates are stable as the momentum scale κ ranges from 0.8 to 1.2 GeV. $SU(3)$ determines the strengths of K and η transitions [21]. The predictions agree well with what is known about the $L = 1$ D and D_s states [22]. The ratio $\Gamma(D_2^* \to D\pi)/\Gamma(D_2^* \to D^*\pi) = 1.8$ is consistent with the 1992 Particle Data Group average, 2.4 ± 0.7 [10], and with a recent CLEO measurement, $2.1 \pm 0.6 \pm 0.6$ [23].

The narrow width observed for D_{s1} is consistent with 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 [12,13] is negligible [24]. This pattern should hold for B and B_s as well. We have also applied heavy-quark dynamics to the decays of the $2\mathrm{P}(\frac{3}{2})$ strange mesons. The pionic transition rates given in Table II for the strange resonances are somewhat lower than the experimental values, but the ratios agree well with experiment.

The low-mass tail of $\rho(770)$ is kinematically accessible in decays $2\mathrm{P}(\frac{3}{2}) \to$ vector meson $+$ $1\mathrm{S}(\frac{1}{2})$. These decays are governed by three independent decay amplitudes characterized by

$(j_h, \ell) = (2,2)$, $(1,2)$, and $(1,0)$. $SU(6)$ symmetry identifies the $(2,2)$ transition strength with the $F_{2,2}^{\frac{3}{2},\frac{1}{2}}(0)$ for pion emission. The two new amplitudes occur in a fixed combination that should be dominated by the $\ell = 0$ amplitude. We have to evaluate one new transition strength, $F_{1,0}^{\frac{3}{2},\frac{1}{2}}(0)$. Lacking measurements of partial widths for vector meson emission in the charmed states, and encouraged by the pattern of pionic decay widths for the strange resonances, we use the decay rate $\Gamma(K_1(1270) \rightarrow \rho + K) = 37.8$ MeV to fix $F_{1,0}^{\frac{3}{2},\frac{1}{2}}(0)$. We smear the expression (3) for the partial width over a Breit-Wigner form to take account of the 150-MeV width of the ρ resonance. The resulting estimates for the ρ transitions are also shown in Table II. We predict that the $D\rho$ channel contributes about one-third of the total width of D_1. Rates for $K^{**} \rightarrow K\omega$ decays follow by $SU(3)$ symmetry.

The results collected in Table II show that both the B_2^* and the B_1 states should be narrow, 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^*. The consistent picture of K_1 and K_2^* decay rates supports the identification [14] of $K_1(1270)$ as the $2P_1(\frac{3}{2})$ level.

To assess the prospects for tagging B_s, we consider briefly the $L = 2$ heavy-light mesons with $j_q = \frac{5}{2}$. Only the strange resonances have been observed. The identification of the $K_3^*(1770)$ as a $3D_3(\frac{5}{2})$ level is clear. Two $J^P = 2^-$ levels, $K_2(1773)$ and $K_2(1816)$, are candidates for its partner [25]. We use the Buchmüller-Tye potential [15] to estimate the masses of the $L = 2$ heavy-light states shown in Table III [26]. Whatever the assignment for the $3D_2(\frac{5}{2})$ level, the splitting within the $j_q = \frac{5}{2}$ doublet will be very small for the $D^{***}(2830)$, $B^{***}(6148)$, $D_s^{***}(2880)$, and $B_s^{***}(6198)$ systems.

To evaluate the transition strength $F_{3,3}^{\frac{5}{2},\frac{1}{2}}(0)$ for pseudoscalar emission, we fix $\Gamma(K_3^* \rightarrow K^*\pi) = 45$ MeV. As before, $SU(6)$ symmetry determines the strength $F_{3,3}^{\frac{5}{2},\frac{1}{2}}(0)$ for vector meson emission. In the absence of measurements that would allow us to fix the other important decay amplitude, we have set $F_{2,1}^{\frac{5}{2},\frac{1}{2}}(0) = 0$. Our projections for vector-meson emission will therefore be underestimates. We summarize our expectations for the total widths of the $3D(\frac{5}{2})$ states in Table III. The $3D(\frac{5}{2})$ B mesons will be broad (≈ 175 MeV), but decay with about twenty percent probability to B_s and B_s^* by emitting a kaon. The favorable branching fraction means that it might be possible to use B_3^* and B_2 decays to tag the B_s, in spite of the large total widths.

The investigation of orbitally excited heavy-light mesons is important for the insights it can provide into strong-interaction dynamics and for engineering purposes as well. Heavy-quark symmetry provides a network that links the decay rates and masses of all the heavy-light families. It is even possible that heavy-quark symmetry may offer a new perspective on the spectrum of strange mesons. If the narrow B_2^* and B_1 are copiously produced with little background, efficient tagging of flavor and momentum may be at hand. Prospects for incisive studies of B^0-$\bar{B}^0$ mixing and CP violation at high energies would then be dramatically enhanced. We conclude this note with two "shopping lists" that summarize some of the urgent experimental issues in the spectroscopy of $c\bar{q}$ and $b\bar{q}$ mesons.

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TABLES

TABLE I. Masses (in MeV/c^2) predicted for the 2P($\frac{3}{2}$) levels of the B, D_s, and B_s systems. Underlined entries are Particle Data Group averages [10] used as inputs.

Meson Family	K	D	B	D_s	B_s
$M(1S)$	<u>794.3</u>	<u>1973.2</u>	<u>5313.1</u>	<u>2074.9</u>	5403.0[a]
$M(2^+(\frac{3}{2}))$	<u>1429 ± 6</u>	<u>2459.4 ± 2.2</u>	5771	2561	5861
$M(1^+(\frac{3}{2}))$	<u>1270 ± 10</u>	<u>2424 ± 6</u>	5759	2526	5849
$M(2^+(\frac{3}{2})) - M(1^+(\frac{3}{2}))$	159	35	12	35	12

[a]Assuming that $M(1S) = M(1S_0) + 34.5$ MeV/c^2, as in the B system. The pseudoscalar mass, $M(B_s) = 5368.5$ MeV/c^2, is an average of the reported values [11].

TABLE II. Heavy-quark-symmetry predictions for decays of $2P(\frac{3}{2})$ heavy-light mesons.

		Width (MeV)		
Transition	Calculated	PDG 1992[a]	CLEO 1993[b]	E687 1993[c]
$D_2^*(2459) \to D^*\pi$	9[d]			
$D_2^*(2459) \to D\pi$	16[d]			
$D_2^*(2459) \to D\eta$	~ 0.1			
$D_2^*(2459) \to D^*\rho$	3			
$D_2^*(2459) \to D\rho$	< 1			
$D_2^*(2459) \to$ all	28	19 ± 7	28^{+8+6}_{-7-6}	$24 \pm 7 \pm 5$
$D_1(2424) \to D^*\pi$	11			
$D_1(2424) \to D^*\rho$	< 1			
$D_1(2424) \to D\rho$	6			
$D_1(2424) \to$ all	18	20^{+9}_{-5}	20^{+6+3}_{-5-3}	$15 \pm 8 \pm 5$
$D_{s2}^*(2573) \to D^*K$	1.2			
$D_{s2}^*(2573) \to DK$	9.4			
$D_{s2}^*(2573) \to D_s\eta$	~ 0.1			
$D_{s2}^*(2573) \to$ all	11	16^{+5+3}_{-4-3}[e]		
$D_{s1}(2536) \to D^*K$	< 1	< 4.6	< 2.3	< 3.2
$B_2^*(5771) \to B^*\pi$	11			
$B_2^*(5771) \to B\pi$	11			
$B_2^*(5771) \to B^*\rho$	3			
$B_2^*(5771) \to B\rho$	< 1			
$B_2^*(5771) \to$ all	25			
$B_1(5759) \to B^*\pi$	17			
$B_1(5759) \to B^*\rho$	1			
$B_1(5759) \to B\rho$	3			
$B_1(5759) \to$ all	21			
$B_{s2}^*(5861) \to B^*K$	~ 1			
$B_{s2}^*(5861) \to BK$	2.6			
$B_{s2}^*(5861) \to$ all	4			
$B_{s1}(5849) \to B^*K$	~ 1			
$K_2^*(1429) \to K^*\pi$	12	25		
$K_2^*(1429) \to K\pi$	27	50		
$K_2^*(1429) \to K\rho$	12	9		
$K_2^*(1429) \to K\omega$	3	3		
$K_2^*(1429) \to$ all	55	~ 103		
$K_1(1270) \to K^*\pi$	6	14		
$K_1(1270) \to K\rho$	38[f]	38		
$K_1(1270) \to K\omega$	7	10		
$K_1(1270) \to$ all	51	(90 ± 20)		

[a]Particle Data Group. Ref. [10].
[b]P. Avery, et al. (CLEO Collaboration). Ref. [3].
[c]P.L. Frabetti et al. (E687 Collaboration). Ref. [3].
[d]Sum fixed at 25 MeV.
[e]Y. Kubota et al. (CLEO Collaboration). Ref. [18].
[f]Input value.

TABLE III. Heavy Quark Symmetry predictions for decays of 3D($\frac{5}{2}$) heavy-light mesons.

Transition	Width (MeV) Calculated	Observed[a]
$K_3^*(1770) \to K^*\pi$	45[b]	45
$K_3^*(1770) \to K\pi$	62	32
$K_3^*(1770) \to K^*\rho$	13	
$K_3^*(1770) \to K\rho$	73	74
$K_3^*(1770) \to$ all	193	(164 ± 17)
$K_2(1768) \to K^*\pi$	78	
$K_2(1768) \to K^*\rho$	21	
$K_2(1768) \to K\rho$	0[c]	
$K_2(1768) \to$ all	99	(136 ± 18)
$D_3^*(2830) \to D^*\pi$	54	
$D_3^*(2830) \to D\pi$	58	
$D_3^*(2830) \to D_s^*K$	14	
$D_3^*(2830) \to D_sK$	39	
$D_3^*(2830) \to D^*\rho$	18	
$D_3^*(2830) \to D\rho$	41	
$D_3^*(2830) \to D_s^*K^*$	< 1	
$D_3^*(2830) \to D_sK^*$	14	
$D_3^*(2830) \to$ all	238	
$D_2(2830) \to D^*\pi$	95	
$D_2(2830) \to D_s^*K$	20	
$D_2(2830) \to D^*\rho$	23	
$D_2(2830) \to D\rho$	0[c]	
$D_2(2830) \to D_s^*K^*$	< 1	
$D_2(2830) \to D_sK^*$	0[c]	
$D_2(2830) \to$ all	138	
$D_{s3}^*(2880) \to D^*K$	34	
$D_{s3}^*(2880) \to DK$	47	
$D_{s3}^*(2880) \to D^*K^*$	2	
$D_{s3}^*(2880) \to DK^*$	15	
$D_{s3}^*(2880) \to$ all	98	
$D_{s2}(2880) \to D^*K$	60	
$D_{s2}(2880) \to D^*K^*$	3	
$D_{s2}(2880) \to DK^*$	0[c]	
$D_{s2}(2880) \to$ all	63	
$B_3^*(6148) \to B^*\pi$	70	
$B_3^*(6148) \to B\pi$	60	
$B_3^*(6148) \to B_s^*K$	18	
$B_3^*(6148) \to B_sK$	20	
$B_3^*(6148) \to B^*\rho$	7	
$B_3^*(6148) \to B\rho$	8	
$B_3^*(6148) \to B_s^*K^*$	< 1	
$B_3^*(6148) \to B_sK^*$	< 1	
$B_3^*(6148) \to$ all	183	

$B_2(6148) \to B^*\pi$	122
$B_2(6148) \to B_s^* K$	32
$B_2(6148) \to B^*\rho$	12
$B_2(6148) \to B\rho$	0^c
$B_2(6148) \to B_s^* K^*$	< 1
$B_2(6148) \to B_s K^*$	0^c
$B_2(6148) \to$ all	167
$B_{s3}^*(6198) \to B^* K$	49
$B_{s3}^*(6198) \to BK$	45
$B_{s3}^*(6198) \to B^* K^*$	2
$B_{s3}^*(6198) \to BK^*$	2
$B_{s3}^*(6198) \to$ all	98
$B_{s2}(6198) \to B^* K$	85
$B_{s2}(6198) \to B^* K^*$	3
$B_{s2}(6198) \to BK^*$	0^c
$B_{s2}(6198) \to$ all	88

[a]Particle Data Group values, Ref. [10].
[b]Input value.
[c]Set to zero in the absence of experimental information.

D^{**} Shopping List

√ Observe $D_{s2}^* \to DK$.

$$M(D_{s2}^*) = M(D_{s1}) + 35 \text{ MeV}/c^2 = 2572 \text{ MeV}/c^2 \; .$$

- Determine branching ratios for D_2^*, D_1, D_{s2}^*.
- How narrow is D_{s1}? (This probes mixing between the $j_q = \frac{1}{2}$ and $j_q = \frac{3}{2}$ p-wave states.)
- Determine strength of the transitions

$$\begin{aligned} D_2^* &\to D^*\rho \, (D\rho) \\ D_1 &\to (D^*\rho) \, D\rho \; . \end{aligned}$$

- Observe (or infer from total widths and observed partial widths) transitions between $D^{**}(j_q = \frac{3}{2}^+)$ and $D^{**}(j_q = \frac{1}{2}^+)$ levels. Can the broad 0^+ and 1^+ charm states be detected through

$$\begin{aligned} D_2^* &\to \pi(D_0^*, D_1') \\ D_1 &\to \pi D_0^* \text{ transitions?} \end{aligned}$$

Will the charm-strange 0^+ and 1^+ states be narrow because of the limited phase space for kaon emission?

- Discover

$$\begin{aligned} D_3^*(2830) &\to D^*\pi, \; D\pi, \; D_sK, \; D\rho \\ D_2(2830) &\to D^*\pi, \; D_sK, \; D^*\rho, \; \underline{D\rho}, \; \underline{D_sK^*} \\ D_{s3}^*(2880) &\to D^*K, \; D^*K, \; DK^* \\ D_{s2}(2880) &\to D^*K, \; \underline{DK^*} \; . \end{aligned}$$

The underlined channels would provide a direct measure of the strength of the amplitude that we have been forced, by ignorance, to set to zero.

- Observe the cascade transitions

$$\begin{aligned} D_3^*(2830) &\to D_2^*\pi, \; D_1\pi \\ D_2(2830) &\to D_2^*\pi \; . \end{aligned}$$

Given one partial width, we can use heavy-quark symmetry to predict all other $3\text{D}(\frac{5}{2}) \to 2\text{P}(\frac{3}{2}) +$ pseudoscalar transitions.

- Observe $B_2^*(5767) \to B^{(*)}\pi$ and $B_1(5755) \to B^*\pi$. If these states are important channels for the production of B, they may make possible highly efficient flavor tagging for the study of CP violation and B^0-$\bar{B}^0$ mixing.

- Observe $B_{s2}^*(5846) \to B^{(*)}K$ and $B_{s1}(5834) \to B^*K$.

- Determine branching ratios for B_2^*, B_1, B_{s2}^*.

- How narrow is B_{s1}? (This probes mixing between the $j_q = \frac{1}{2}$ and $j_q = \frac{3}{2}$ p-wave states.) Will the $j_q = \frac{1}{2}$ levels B_{s0}^* and B_{s1} be narrow because of the limited phase space for kaon emission?

- Search for

$$\begin{aligned} &B_3^*(6148) \to B^{(*)}\pi,\ B_sK,\ B^{(*)}\rho \\ &B_2(6148) \to B^*\pi,\ B_s^*K,\ B^*\rho,\ \underline{B\rho},\ \underline{B_sK^*} \end{aligned}$$

  If these states are narrow and prominent, they may be useful for tagging the flavor of B_s and $\bar{B}_s$.

$$\begin{aligned} &B_{s3}^*(6198) \to B^*K,\ BK,\ BK^* \\ &B_{s2}(6198) \to B^*K,\ \underline{BK^*}\ . \end{aligned}$$

  These narrow states may be especially easy to identify.

  The underlined channels would provide a direct measure of the strength of the amplitude that we have been forced, by ignorance, to set to zero.

- Do the B^{***} states (B_3^*, B_2) cascade through the B^{**} levels? Observe the cascade transitions

$$\begin{aligned} &B_3^*(6148) \to B_2^*\pi,\ B_1\pi \\ &B_2(6148) \to B_2^*\pi\ . \end{aligned}$$