Charmless B Decays to Final States with Radially Excited Vector Mesons

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Abstract

We consider the weak decays of a B meson to final states that contain a S-wave radially excited vector meson. We consider vector-pseudoscalar final states and calculate ratios of the type $B \rightarrow \rho'\pi/B \rightarrow \rho\pi$, $B \rightarrow \omega'\pi/B \rightarrow \omega\pi$ and $B \rightarrow \phi'\pi/B \rightarrow \phi\pi$ where $\rho'$, $\omega'$ and $\phi'$ are higher $\rho$, $\omega$ and $\phi$ S-wave radial excitations. We find such decays to have larger or similar branching ratios compared to decays where the final state $\rho$, $\omega$ and $\phi$ are in the ground state. We also study the effect of radial mixing in the vector system generated from hyperfine interaction and the annihilation term.

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The new data accumulating from B factories and other accelerators will include transitions to many new final states which have not been previously studied in detail; e.g. radially excited meson states. Many decays involve a transition from a low momentum spectator quark to a high momentum relativistic meson. The form factors for such transitions are expected to be sensitive to the high momentum components of the final meson wave function, and therefore to favor radially excited states. The data on B decays to these states will thus provide important new information, particularly for the form factors to the radially excited states and probe the high-momentum tails of their wave functions.

In this paper we calculate predictions for the ratios

\[ R_{\rho^+} = \frac{BR(\bar{B}^0 \to \pi^- \rho^{+\prime})}{BR(\bar{B}^0 \to \pi^- \rho^+)} \] (1)

\[ R_{\rho^0} = \frac{BR(\bar{B}^- \to \pi^- \rho^{0\prime})}{BR(\bar{B}^- \to \pi^- \rho^0)} \] (2)

\[ R_{\omega} = \frac{BR(B^- \to \pi^- \omega^{\prime})}{BR(B^- \to \pi^- \omega)} \] (3)

\[ R_{\phi} = \frac{BR(B_s \to \pi^0 \phi^{\prime})}{BR(B_s \to \pi^0 \phi)} \] (4)

where \( \rho^{\prime}, \omega^{\prime} \) and \( \phi^{\prime} \) are the radially excited states. Most studies of two-body nonleptonic B decays have concentrated on processes of the type \( B \to M_1 M_2 \) where both \( M_1 \) and \( M_2 \) are mesons in the ground state configuration. Nonleptonic decays, where one of the mesons in the final state containing the spectator quark is a radially excited state, are expected to have larger or similar branching ratios compared to decays where the final state contains the same meson in the ground state. This is easily seen in a simple model in which \( B \to \pi M \) and \( M \) is a simple flavor eigenstate with no flavor mixing beyond isospin. We follow the inactive spectator approach used [1] to treat B decays to charmonium in which the spectator quark does not participate in a flavor-changing interaction and later combines with a light antiquark to make the final light meson as shown in Fig. [1]. The decay amplitudes are then described as the product of a b-quark decay amplitude and a hadronization function describing the combination of a quark-antiquark pair to make the final meson. Neglecting the relative Fermi momentum of the b quark and the spectator quark in the B meson, the quark transition for the processes in Eq. (1-3) is

\[ b \to \pi^- (\bar{p}) u (\bar{-p}) \] (5)
where the b quark is at rest and $\vec{p}$ denotes the final momentum of the $\pi^-$. For the process in Eq.[3] the quark transition is essentially similar to the one above

$$b \to \pi^0(\vec{p}) s(-\vec{p})$$

where now $\vec{p}$ denotes the final momentum of the $\pi^0$.

![Diagram](image.png)

Figure 1: Factorization for the decay $B \to M\pi$.

Concentrating on the processes in Eq. (1-3) the transition matrix for the full decay has the form[4]

$$\langle \pi^-(\vec{p}) M(-\vec{p}) | T | B \rangle = \langle M(-\vec{p}) | F | u(-\vec{p}) \bar{q}(0) \rangle \cdot \langle \pi^-(\vec{p}) u(-\vec{p}) | W | b \rangle$$

where $T$ denotes the transition matrix for the hadronic decay which factors, as shown in Fig. [4], into a weak matrix element at the quark level denoted by $W$ and a recombination matrix element denoted by $F$. This latter matrix element describes the transition of a quark with momentum $-\vec{p}$ and an antiquark with zero momentum to make a meson with momentum $\vec{p}$. Radial excitations could be favoured over ground states, if the final momentum $\vec{p}$ is large, since the radial excitations are expected to have higher kinetic energies.

An alternative but equivalent way of understanding this effect is to note that for a heavy $b$ quark one can write [2]

$$\langle \pi^- (\vec{p}) M(-\vec{p}) | T | B \rangle = \langle M(-\vec{p}) | J_{1\mu} | B \rangle \cdot \langle \pi^- (\vec{p}) | J_{2\mu}^* | 0 \rangle$$

where $J_{1,2}$ are currents that occur in $W = J_1 \times J_2$. The transition matrix element for the hadronic decay can then be written in terms of $B \to M$ form factors and the pion decay constant. The form factors can be expressed as overlap integrals of the $B$ and the
meson wavefunctions. When $M$ is a light meson, with a mass much smaller than the $B$ meson, the overlap integrals get contributions mainly from the high momentum components of the meson wavefunctions. It is now clear that for a radially excited meson $M'$, which has more higher momentum components, the overlap integrals will be enhanced compared to the overlap integral with a ground state meson $M$. Consequently the $B \to M'$ form factors are likely to be enhanced relative to the $B \to M$ form factors which would then translate into higher branching ratio for $B \to M'\pi$ relative to $B \to M\pi$.

Our discussion above assumed the physical states to be pure radial excitations. However, additional interactions can mix the various radial excited components. For instance hyperfine interactions can mix radial excitations with the same flavor structure and so in general, in the $\rho$, $\omega$ and $\phi$ systems, the various physical states will be admixtures of radial excitations \[3, 4\]. Flavor mixing in the vector system is known to be small but is important in the pseudoscalar sector. We will consider the pseudoscalar case in a different publication \[5\]. To make quantitative predictions we use constituent quark wave functions with several potentials to test the dependence of the results on the confining potential. We shall see that the effects of the potential dependence and mixing are small so that the results are reasonably robust and are not seriously dependent on the fine details of the model.

Even though our discussion has so far only included vector-pseudoscalar final states we can also consider vector-vector final states such as $B \to \rho \rho$ or $B \to J/\psi K^*$. However vector-vector final states are complicated since different partial waves are present. Our purpose here is to demonstrate the effects of radial mixing in the simpler physical system of the vector-pseudoscalar final state. If the effects of radial enhancements are observed in the vector-pseudoscalar case we would expect them to be also present in the vector-vector final state.

We will first review the study the masses and mixing in the vector meson sector following the simple nonrelativistic approach in Ref\[3, 4\]. To obtain the eigenstates and eigenvalues in the vector meson system we diagonalize the mass matrix

$$<q'_a \bar{q}'_b, n'|M|q_a \bar{q}_b, n> = \delta_{aa'}\delta_{bb'}\delta_{nn'}(m_a + m_b + E_n) + \delta_{aa'}\delta_{bb'}\frac{B}{m_a m_b} \vec{s}_a \cdot \vec{s}_b \psi_n(0)\psi_{n'}(0)$$

where $\vec{s}_{a,b}$ and $m_{a,b}$ are the quark spin operators and masses. Here $n = 0, 1, 2$ and the basis states for the isovector mesons are chosen as $|N, I = 1, I_3 = 1> = |u\bar{d}>, |N, I = 1, I_3 = 0> = |u\bar{d} - d\bar{u}>/\sqrt{2}$ and $|N, I = 1, I_3 = -1> = |d\bar{u}>$ where $I, I_3$ stand for the isospin quantum numbers. In the above equation $E_n$ is the excitation energy of the $n^{th}$ radially excited state and $B$ is the strength of the hyperfine interaction.
To begin with, we use the same harmonic confining potential as well as the other parameters used in Ref\[4\] to obtain the eigenstates and eigenvalues for the mass matrix in Eqn. \[9\]. The various parameters used in the calculation are the constituent masses, $m_u = m_d = 0.350 \text{ GeV}$, $m_s = 0.503 \text{ GeV}$, the angular frequency, $\omega = 0.365 \text{ GeV}$ and $b = B/m_u^2 = 0.09$. The eigenvalues and eigenstates for the $\rho$ system with a harmonic potential are shown in Table. \[1\]. To see how this result changes with a different confining potential we use a power law potential $V(r) = \lambda r^n$ \[6\]. We will use a linear and a quartic confining potential and compare the spectrum with that obtained with a harmonic oscillator potential. To fix the coefficient $\lambda$ we require that the energy eigenvalues of the Schrödinger equation are similar in the least square sense with the energy eigenvalues used in Ref\[4\]. So for example, for the linear potential, we demand that

$$F = \sum_n (E_n(\text{harmonic}) - E_n(\text{linear}))^2$$

is a minimum. This fixes the constant $\lambda$ in $V(r) = \lambda r$ and we obtain the eigenvalues and eigenstates in Table. \[2\]. We follow the same procedure for the quartic potential and obtain

| Harmonic | $N_0$ | $N_1$ | $N_2$ |
|----------|-------|-------|-------|
| $\rho(0.768)$ | 0.990 | 0.124 | -0.066 |
| $\rho(1.545)$ | 0.108 | -0.973 | 0.204 |
| $\rho(2.370)$ | 0.089 | -0.195 | 0.977 |

Table 1: Eigenvalues and Eigenstates for the $\rho$ system-Harmonic potential

the eigenvalues and eigenstates in Table. \[3\]. We observe from Tables. (1-3) that the mass eigenstates and eigenvalues of the $\rho$ system are not very sensitive to the confining potential and the radial mixing effects are small.
Table 3: Eigenvalues and Eigenstates for the $\rho$ system- Quartic potential

| $\rho$ | $N_0$ | $N_1$ | $N_2$ |
|---|---|---|---|
| 0.759 | 0.988 | 0.129 | -0.077 |
| 1.567 | 0.103 | -0.955 | 0.278 |
| 2.370 | 0.11 | -0.267 | 0.957 |

To obtain the eigenstates and eigenvalues in the $\omega - \phi$ system we diagonalize the mass matrix

$$<q'_a q'_b, n'|M|q_a \bar{q}_b, n> = \delta_{aa'} \delta_{bb'} \delta_{nn'} (m_a + m_b + E_n) + \frac{B}{m_a m_b} \bar{s}_a \cdot \bar{s}_b \psi_n(0) \psi_{n'}(0)$$

$$+ \frac{A}{m_a m_b} \psi_n(0) \psi_{n'}(0)$$

(10)

This has a similar structure as the $\rho$ system but now we have the additional annihilation interaction with strength $A$ that causes flavor mixing. 3, 4.

Diagonalizing the mass matrix in Eqn. (10), with the basis states $|N\rangle = |u \bar{u} + d \bar{d}\rangle / \sqrt{2}$ and $|S\rangle = |s \bar{s}\rangle$, we obtain the eigenvalues and the eigenstates of the $\omega - \phi$ system. We use the same value for the hyperfine interaction as used for the $\rho$ system. For the linear potential we obtain with $B = 0.09 m_u^2$ and $A = 0.005 m_u^2$ the eigenstates and eigenvalues in Table. 4. For the harmonic potential we obtain with $B = 0.09 m_u^2$ and $A = 0.015 m_u^2$ the eigenstates and eigenvalues in Table. 5.

Table 4: Eigenvalues and Eigenstates for the $\omega - \phi$ system- Linear potential

| Linear | $N_0$ | $N_1$ | $N_2$ | $S_0$ | $S_1$ | $S_2$ |
|---|---|---|---|---|---|---|
| $\omega$ (0.782) | 0.991 | 0.123 | -0.058 | -0.014 | 0.004 | -0.002 |
| $\phi$ (1.05) | 0.012 | 0.011 | -0.004 | 0.997 | 0.071 | -0.034 |
| $\omega$ (1.52) | -0.113 | 0.982 | 0.144 | -0.006 | -0.034 | 0.004 |
| $\phi$ (1.66) | 0.007 | -0.030 | -0.014 | 0.068 | -0.994 | -0.077 |

and eigenvalues in Table. 5. For the quartic potential we obtain with $B = 0.09 m_u^2$ and $A = 0.023 m_u^2$ the eigenstates and eigenvalues in Table. 6. As in the $\rho$ system we find the mixing to be insensitive to the confining potential and the effects of radial mixing to be small. We also find, as expected, a small value for the annihilation term in the fits to the masses.
Table 5: Eigenvalues and Eigenstates for the $\omega - \phi$ system- Harmonic potential

| Harmonic | $N_0$ | $N_1$ | $N_2$ | $S_0$ | $S_1$ | $S_2$ |
|----------|-------|-------|-------|-------|-------|-------|
| $\omega(0.783)$ | 0.984 | 0.154 | -0.081 | -0.033 | 0.011 | -0.007 |
| $\phi(1.05)$ | 0.026 | 0.029 | -0.011 | 0.994 | 0.089 | -0.048 |
| $\omega(1.57)$ | -0.126 | 0.948 | 0.256 | -0.008 | -0.139 | 0.010 |
| $\phi(1.68)$ | 0.025 | -0.12 | -0.07 | 0.082 | -0.976 | -0.143 |

Table 6: Eigenvalues and Eigenstates for the $\omega - \phi$ system- Quartic potential

| Quartic | $N_0$ | $N_1$ | $N_2$ | $S_0$ | $S_1$ | $S_2$ |
|---------|-------|-------|-------|-------|-------|-------|
| $\omega(0.783)$ | 0.980 | 0.163 | -0.096 | -0.049 | 0.012 | -0.009 |
| $\phi(1.05)$ | 0.041 | 0.034 | -0.015 | 0.991 | 0.100 | -0.060 |
| $\omega(1.58)$ | -0.122 | 0.932 | 0.322 | -0.010 | -0.113 | 0.006 |
| $\phi(1.7)$ | 0.022 | -0.089 | -0.067 | 0.086 | -0.968 | -0.207 |

We now use these wavefunctions to predict the ratios in Eq. (1-4). These decays are dominated by diagrams which satisfy the inactive spectator approach and are treated with Eq.(7-8). Some of the diagrams which violate this assumption; e.g. penguin and annihilation contributions, may not be as negligible here as in the charmonium case treated in Ref[1] for the decays to the ground state configurations. But they are expected to have much smaller form factors for radial excitations. Therefore it is reasonable to neglect them for this preliminary investigation of the order of magnitude of these ratios. Note that for the $B_s \rightarrow \pi^0 \phi$ decay the QCD penguin is isospin forbidden, the annihilation contribution is OZI forbidden and the electroweak penguin is also described by Eq. [7].

We obtain, using factorization for the nonleptonic amplitude,

$$R_{\rho^+} = \left| \frac{\langle \rho^+ | \bar{u} \gamma^\mu (1 - \gamma_5) b | B^0 \rangle \langle \pi^- | \bar{d} \gamma^\mu (1 - \gamma_5) u | 0 \rangle}{\langle \rho^+ | \bar{u} \gamma^\mu (1 - \gamma_5) b | B^0 \rangle \langle \pi^- | \bar{d} \gamma^\mu (1 - \gamma_5) u | 0 \rangle} \right|^2$$

$$= \left| \frac{A_{\rho^+}^0}{A_{\rho^+}^0} \right|^2 \frac{P_3^3}{P_3^3}$$

(11)

where $P$ is the magnitude of the three momentum of the final states and the form factor $A^0$.
is defined through
\[ \langle V_f | A_\mu | P_i \rangle = (M_i + M_f)A_1 \left( \epsilon^*_\mu - \frac{e^* \cdot q}{q^2} q_\mu \right) - A_2 \frac{e^* \cdot q}{M_i + M_f} \left( (P_i + P_f)_\mu - \frac{M_i^2 - M_f^2}{q^2} q_\mu \right) + 2M_f A_0 \frac{e^* \cdot q}{q^2} q_\mu \]  
(12)

where \( A_\mu \) is the axial vector current. Similarly we obtain
\[ R_{\rho} \approx \left| \frac{\langle \rho^0 | \bar{u} \gamma^\mu (1 - \gamma_5)b | B^0 \rangle \langle \pi^- | d \gamma^\mu (1 - \gamma_5)u | 0 \rangle}{\langle \rho^0 | \bar{u} \gamma^\mu (1 - \gamma_5)b | B^0 \rangle \langle \pi^- | d \gamma^\mu (1 - \gamma_5)u | 0 \rangle} \right|^2 \]
\[ = \left| \frac{A_{0\rho}^0}{A_0^\mu} \right|^2 \frac{P_{3\rho}^3}{P_{3}^3} \]  
(13)

\[ R_{\omega} \approx \left| \frac{\langle \omega^0 | \bar{u} \gamma^\mu (1 - \gamma_5)b | B^0 \rangle \langle \pi^- | d \gamma^\mu (1 - \gamma_5)u | 0 \rangle}{\langle \omega^0 | \bar{u} \gamma^\mu (1 - \gamma_5)b | B^0 \rangle \langle \pi^- | d \gamma^\mu (1 - \gamma_5)u | 0 \rangle} \right|^2 \]
\[ = \left| \frac{A_{0\omega}^0}{A_0^\omega} \right|^2 \frac{P_{3\omega}^3}{P_{3}^3} \]  
(14)

Finally,
\[ R_{\phi} = \left| \frac{\langle \phi^0 | \bar{s} \gamma^\mu (1 - \gamma_5)b | B_s \rangle \langle \pi^0 | \bar{u} \gamma^\mu (1 - \gamma_5)u | 0 \rangle}{\langle \phi^0 | \bar{s} \gamma^\mu (1 - \gamma_5)b | B_s \rangle \langle \pi^0 | \bar{u} \gamma^\mu (1 - \gamma_5)u | 0 \rangle} \right|^2 \]
\[ = \left| \frac{A_{0\phi}^0}{A_0^\phi} \right|^2 \frac{P_{3\phi}^3}{P_{3}^3} \]  
(15)

To calculate the ratios we need the form factor \( A_0 \). Note that the wavefunctions for the various vector meson states are not enough to calculate non leptonic decay amplitudes. In particular, with the factorization assumption for non leptonic decays, the calculations of decay amplitudes require the matrix elements of current operators between the physical states. These matrix elements can be expressed in terms of form factors and decay constants. In this work we use a constituent quark model(CQM) model for the form factors \[ \] that incorporates some relativistic features and is relatively simple to adapt to the case of radially excited states. In this model the form factor \( A_0 \) is given by
\[ A_0 = Z[I_1 - \frac{M_-}{M_+}I_2] \]
where

\[ Z = \frac{\sqrt{4M_i M_f M_+}}{M_+^2 - q^2} \]

\[ I_1 = \int d^3p \phi_f^\dagger(\vec{p} + \vec{a}) \phi_i(\vec{p}) \]

\[ I_2 = m_s \int d^3p \phi_f^\dagger(\vec{p} + \vec{a}) \phi_i(\vec{p}) \left[ \frac{\vec{p} \cdot \vec{a}}{\mu a^2} + \frac{1}{m_f} \right] \]

\[ M_\pm = M_f \pm M_i \]

\[ \vec{a} = 2m_s \vec{\beta} = 2m_s \vec{\tilde{q}} \]

\[ \vec{\tilde{q}}^2 = \frac{M_+^2}{M_+^2 - q^2} \]

\[ \mu = \frac{m_i m_f}{m_i + m_f} \]  

(16)

and \( \phi_f \) and \( \phi_i \) represent the momentum space wave functions while \( \vec{\beta} \) is the velocity of the mesons in the equal velocity frame (also called the Breit frame or the brick wall frame) and \( m_{i,f} \) are the non spectator quark masses of the initial and final meson. The equal velocity frame in a convenient frame to calculate the Lorentz invariant form factors where the velocities, \( \vec{\beta}_i \) and \( \vec{\beta}_f \) of the mesons with masses \( M_i \) and \( M_f \) are equal in magnitude but opposite in direction. We use the momentum wavefunction \( \phi_f \) obtained from spectroscopy in section (2) while for \( \phi_i \) we use the wave function

\[ \phi_i = \phi_B = N_B e^{-p^2/p_F^2} \]  

(17)

where \( p_F \) is the Fermi momentum of the B meson. In our calculations we will take \( p_F = 300 \text{MeV} \). Note that in the analysis presented in the introduction we have neglected the Fermi momentum of the b quark, since \( p_F/m_b \) is small.

For transitions to higher resonant states, we use the same quark masses as those used in the transition of the B meson to the lowest resonant state. This is reasonable, as the spectator quark still comes from the B meson and therefore has the same value for its mass irrespective of whether the final state is in the lowest or the first excited state. The values for the masses of the non spectator masses are taken to be the same as those used for spectroscopy. However for the calculation of the velocity \( \vec{\beta} \) and hence \( \vec{a} \) defined in Eqn. (16) we use the physical mass of the higher resonant state. In Table. 7 we give our predictions for the various ratios defined above. We find that the transitions to higher excited states can be comparable or enhanced relative to the transitions to the ground state. From Table. 7
we see that the ratios of branching ratios are slightly sensitive to the confining potential and the ratios of branching ratios increase as we go from the quartic to the linear potential. This is because the wavefunction for the linear potential has a longer tail and hence more high momentum components than the wavefunction for the quadratic and the quartic potentials. The wavefunction for the quadratic potential, has in turn, a longer tail and hence more high momentum components than the wavefunction for the quartic potential. Hence we would expect the hierarchy $(A_0)_\text{linear} > (A_0)_\text{quadratic} > (A_0)_\text{quartic}$ and a similar one for the radially excited states $(A'_0/A_0)_\text{linear} > (A'_0/A_0)_\text{quadratic} > (A'_0/A_0)_\text{quartic}$ where $A_0$ and $A'_0$ are the form factors for the transition of $B$ to the ground state and the first radially excited state of the meson $M$. We see from Table. 7 that this hierarchy is maintained for the ratios of form factors and so we have $(A'_0/A_0)_\text{linear} > (A'_0/A_0)_\text{quadratic} > (A'_0/A_0)_\text{quartic}$. Note that the ratio of form factors also depend on the choice of the Fermi momentum of the $B$ meson, as a smaller(larger) Fermi momentum would make the form factors more(less) sensitive to the tail of the wavefunction of $M$, as well as mixing effects in the wavefunction of the meson $M$. The effect of mixing between the various radially excited states and the ground state is generally small.

We observe in Table. 4 that there can be a large enhancement for $R_\phi$. This decay is suppressed in the standard model. One can get a rough estimate of the branching ratio for $B_s \to \phi \pi^0$ using factorization as

$$
\frac{BR[B_s \to \phi \pi^0]}{BR[B^0 \to \rho^+ \pi^-]} \approx \frac{1}{2} \left| \frac{V_{ub}V_{us}^*(c_1 + c_2/N_c) - V_{tb}V_{ts}^*3c_9/2}{V_{ub}V_{ud}^*(c_2 + c_1/N_c)} \right| \approx 0.02
$$

where we have neglected form factor and phase space differences between $B_s \to \phi \pi^0$ and $\bar{B}^0 \to \rho^+ \pi^-$. The Wilson coefficients $c_i$ can be found in Ref[8] while $V_{ub}, V_{us}, V_{ud}, V_{tb}$ and $V_{ts}$ are the various CKM elements [10]. Using the measured $BR[B \to \rho^+ \pi^-] \sim 28 \times 10^{-6}$ [11] we get $BR[B_s \to \phi \pi^0] \sim 6 \times 10^{-7}$. Hence the large enhancement for $R_\phi$ indicates that $BR[B_s \to \phi' \pi^0]$ can be around $\sim 4 \times 10^{-6}$.

Table 7: Ratios of branching ratios for different confining potentials

| Ratio   | Linear | Quadratic | Quartic |
|---------|--------|-----------|---------|
| $R_{\rho^+}$ | 2.3    | 2.0       | 1.9     |
| $R_{\rho^0}$ | 2.3    | 2.0       | 1.9     |
| $R_{\omega}$ | 3.5    | 2.5       | 1.7     |
| $R_{\phi}$  | 6.7    | 6.2       | 5.2     |
Note that in the $\rho(\omega)$ system there are two resonances, $\rho(1450)[\omega(1420)]$ and $\rho(1700)[\omega(1650)]$, which can be identified a S-wave radial excitation(2S) and a D wave orbital excitation in the quark model. However recent studies of the decays of these resonances show that it is possible that these states are mixtures of $q\bar{q}$ and hybrid states Ref[10]. Hence the state $\rho(1450)[\omega(1420)]$ is interpreted as a 2S state with a small mixture of a hybrid state. We do not take into account such possible mixing with a hybrid state in our calculation and the meson masses for these excited states used in our calculation are the ones we predict in section 2. For the $\phi$ system there is only state at $\phi(1680)$ which we interpret as a 2S state in the absence of mixing effects.

In conclusion we have considered the weak decays of a B meson to final states that are mixtures of S-wave radially excited components. We calculated nonleptonic decays of the type $B \rightarrow \rho'\pi/B \rightarrow \rho\pi$, $B \rightarrow \omega'\pi/B \rightarrow \omega\pi$ and $B \rightarrow \phi'\pi/B \rightarrow \phi\pi$ where $\rho'$, $\omega'$ and $\phi'$ are higher $\rho$, $\omega$ and $\phi$ resonances. We found that the transitions to the excited states can be comparable or enhanced relative to transitions to the ground state. It would, therefore, be extremely interesting to test these predictions. We also studied the effect of radial mixing in the vector system generated from hyperfine interaction and the annihilation term; these turn out to be generally small.

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