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Resonance background to the decays $b \to s l^+ l^-$, $B \to K^* l^+ l^-$, and $B \to K l^+ l^-$

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We consider background to the rare decay modes $b \to s l^+ l^-$, $B \to K^* l^+ l^-$, and $B \to K l^+ l^-$ arising from the process $b \to s V_i$ followed by on- and off-resonance transition $V_i \to l^+ l^-$. We obtain dilepton mass spectrum including short-distance effects and then suggest cuts to enhance the signal over background.

In a recent Letter,[1] we presented estimates for the one-loop flavor-changing decays $b \to s l^+ l^-$, $B \to K l^+ l^-$, and $B \to K^* l^+ l^-$. In this paper we consider the background for those processes arising from the tree-level processes $B \to s V_i$, $B \to K V_i$, and $B \to K^* V_i$ where V_i are vector mesons, followed by $V_i \to l^+ l^-$. We shall consider both on- and off-shell vector mesons by using a Breit-Wigner form for the resonance propagator. This investigation is motivated by the fact that the one-loop calculation[2] of $B \to K^* \gamma$ could have substantial background from the process $B \to K^* V_i$ followed by V_i-γ transition.[3,4] Certainly, the rate for the on-shell process $b \to s V_i$, etc., followed by $V_i \to l^+ l^-$ can easily be calculated, and is 2 orders of magnitude larger than the short-distance one-loop flavor-changing process. The dominant contribution arises from the Kobayashi-Maskawa-favored processes where V_i are charmonium states ψ, ψ', etc. In this paper we calculate the $l^+ l^-$ mass spectrum for the processes to show that the resonances can be eliminated by suitable mass cuts.

The branching ratio for $b \to s l^+ l^-$ from short-distance effects has been estimated at 10^{-5} for $m_t \sim 80$ GeV and is a slowly varying function of m_t. The rate for $b \to s\psi$, $b \to s\psi'$, etc., can be estimated from the effective Hamitonian

$$H_{\rm eff} = \kappa g_\psi \bar{s}_i \gamma_\mu (1-\gamma_5) b_i \epsilon_\psi^\mu \ ,$$
$$\kappa = (G_F/\sqrt{2})(c_- + c_+/3) V_{cs}^* V_{cb} \ , \tag{1}$$

where $c_\pm$ are coefficients of the QCD-corrected Hamiltonian:

$$c_\pm = \tfrac{1}{2}\{[\alpha_s(\mu)/\alpha_s(m_W)]^{-6/23} \pm [\alpha_s(\mu)/\alpha_s(m_W)]^{12/23}\} \ . \tag{2}$$

The constant g_ψ is defined as $\langle 0|\bar{c}\gamma_\mu c|\psi\rangle = g_\psi \epsilon_\mu^\psi$. The combination $(c_- + c_+/3)$ is very sensitive to QCD, so we shall instead fix κ from experimental rate for $B \to \psi +$anything. In Ref. 3 we have discussed how this can be done and find

$$\frac{\Gamma(b \to s\psi)}{\Gamma(b \to {\rm all})} = (1.0 \pm 0.24) \times 10^{-2} \ . \tag{3}$$

This yields for $\kappa = (G_F/\sqrt{2})\ (0.13)$.

The rate for $b \to s\psi'$, etc. can be found from knowledge of $g_{\psi'}$, etc., which in turn is found from e^+e^- decays of charmonium states. We then find for $b \to s e^+ e^-$ through resonances to be

$$\frac{\Gamma_{\rm res}(b \to s e^+ e^-)}{\Gamma_{\rm tot}(b \to {\rm all})} = \sum_i \frac{\Gamma(b \to s V_i)}{\Gamma_{\rm tot}(b \to {\rm all})} \frac{\Gamma(V_i \to e^+ e^-)}{\Gamma_{\rm tot}(V_i \to {\rm all})} = 7.9 \times 10^{-4} \ . \tag{4}$$

The major contribution in the above formula arises from $\psi(3100)$ and $\psi'(3700)$. In Ref. 1 we have given the short-distance contribution to $b \to s l^+ l^-$. We generalize the effective Lagrangian to include resonance contributions:

$$L_{\rm eff}^{\rm tot} = \frac{G_F}{\sqrt{2}} \left[\frac{\alpha}{4\pi s_W^2} \right] \times \sum_{(i=u,c,\dots)} U_i (A_i \bar{s} L_\mu b \bar{l} L^\mu l + B_i \bar{s} L_\mu b \bar{l} R^\mu l + 2 m_b s_W^2 F_2^i \bar{s} T_\mu b \bar{l} \gamma^\mu l) \ , \tag{5}$$

where

$$L_\mu = \gamma_\mu (1-\gamma_5), \quad R_\mu = \gamma_\mu (1+\gamma_5) \ ,$$
$$T_\mu = -i\sigma_{\mu\nu} q^\nu (1+\gamma_5)/q^2 \ , \tag{6}$$

$$A_i(z) = \bar{C}_i^{\rm box} + \bar{C}_i^z - s_W^2 [F_1^i + 2\bar{C}_i^z + F_R^i(z)\delta_{ic}] \ , \tag{7}$$

$$B_i(z) = -s_W^2 [F_1^i + 2\bar{C}_i^z + F_R^i(z)\delta_{ic}], \quad l = e, \mu \ . \tag{8}$$

U_i in (5) are the appropriate entries in Kobayashi-Maskawa matrix, and the quantities $\bar{C}_i^{\rm box}$, $\bar{C}_i^z$, and $F_{(1,2)}^i$ are defined[5] in Ref. 1. The resonance contribution is

$$F_R^i(z) = \sum_j [F_R^i(z)]_j = a_j (z - m_{V_j}^2/m_b^2 + i\Gamma_{V_j} m_{V_j}/m_b^2)^{-1} \ , \tag{9}$$

$$a_j = \frac{16\pi^2}{3 s_W^2} (c_- + \tfrac{1}{3} c_+) \left[\frac{g_{V_j}}{m_{V_j} m_b} \right]^2 \ , \tag{10}$$

where j runs over all the charmonium 1^- states.

The general decay distribution for $X_b \to X_s l^+ l^-$ over the dilepton mass is given by

$$\frac{d}{dz}\Gamma(X_b \to X_s l^+ l^-) = \frac{G_F^2 m_{X_b}^5}{192\pi^3}\left[\frac{\alpha}{4\pi s_W^2}\right]^2 F_{x_b \to x_s}(z) , \tag{11}$$

where

$$X_b = b, B, \quad X_s = s, K, K^*, \quad z = q^2/m_{x_b}^2 ,$$
$$q = pl^+ + pl^- = p_{x_b} - p_{x_s} , \tag{12}$$

$$F_{x_b \to x_s}(z) = [\,|U_i A_i(z)|^2 + |U_i B_i(z)|^2] f_1^{x_b \to x_s}(z) + s_W^2\{U_i^* U_j [A_i(z) + B_i(z)]^* \tilde{F}_2^j + \text{H.c.}\} \times f_{12}^{x_b \to x_s}(z) + 2 s_W^4 |U_i \tilde{F}_2^i|^2 f_2^{x_b \to x_s}(z) . \tag{13}$$

For the quark decay $b \to s l^+ l^-$ we have

$$f_1^{b \to s}(z) = 2(1-z)(1+z-2z^2) , \tag{14}$$

$$f_{12}^{b \to s}(z) = 6(1-z)^2 , \tag{15}$$

$$f_2^{b \to s}(z) = 4(1-z)(1/z - \tfrac{1}{2} - z/2) . \tag{16}$$

In Fig. 1 we plot $F_{b \to s}(z)$ between $z_{\min} = (2m_l/m_b)^2$ and $z_{\max} = (1 - m_s/m_b)^2$ for the case without resonances (i.e., $F_R^c = 0$) and with resonances. It can be seen that away from resonances, the differential rate for $b \to s l^+ l^-$ does not change much.

To obtain the decay distribution for $B \to K l^+ l^-$ and $B \to K^* l^+ l^-$ one needs the matrix elements of operators $\bar{s}\gamma_\mu(1-\gamma_5)b$ and $i\bar{s}\sigma_{\mu\nu}(1+\gamma_5)b$ between B and K^*/K states. We shall use the same notation (and the values) as in Ref. 1 and obtain

$$f_1^{B \to K}(z) = (1-z)^3 [f^{(+)}(z)]^2 , \tag{17}$$

$$f_{12}^{B \to K}(z) = (1-z)^3 [f^{(+)}(z) f_T(z)] , \tag{18}$$

$$f_2^{B \to K}(z) = (1-z)^3 [f_T(z)]^2 , \tag{19}$$

for $B \to K l^+ l^-$ decay, while for $B \to K^* l^+ l^-$ expressions are more complicated:

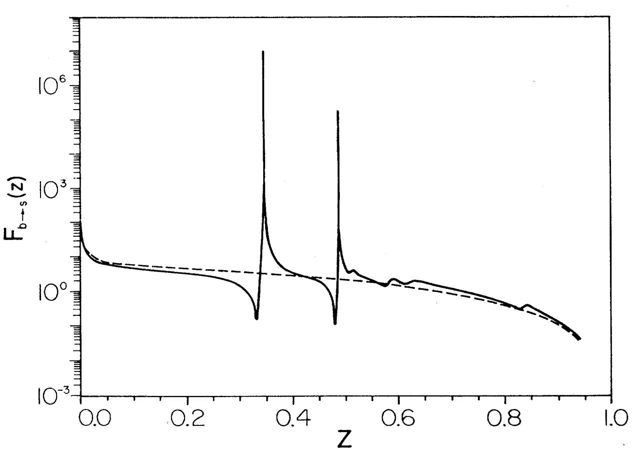

FIG. 1. The dilepton z distributions for $b \to s e^+ e^-$ with resonances (solid line) and without resonances (dashed line).

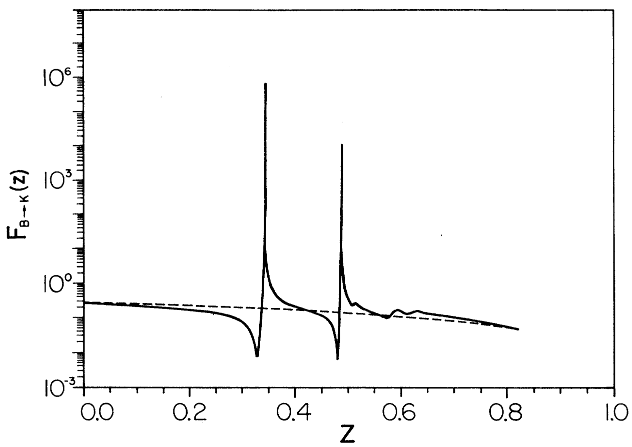

FIG. 2. The dilepton z distributions for $B \to K e^+ e^-$ with resonances (solid line) and without resonances (dashed line).

$$f_1^{B \to K^*}(z) = z(1-z)w(z) \times \{2V^2(z) + 3A_1^2(z)(1 - m_{K^*}^2/m_B^2)^2/w(z) + [z(m_B/2m_{K^*})^2 - 1]A_2^2(z)\} , \tag{20}$$

$$f_{12}^{B \to K^*}(z) = (1-z)w(z) \times \{2V(z)T_1(z) + 3A_1(z)T_2(z)(1 - m_{K^*}^2/m_B^2)^2/w(z) + [z(m_B/2m_{K^*})^2 - 1]A_2(z)T_2(z)\} , \tag{21}$$

$$f_2^{B \to K^*}(z) = [(1-z)/z]w(z) \times \{2T_1^2(z) + [3(1 - m_{K^*}^2/m_B^2)^2/w(z) + z(m_B/2m_{K^*})^2 - 1]T_2^2(z)\} , \tag{22}$$

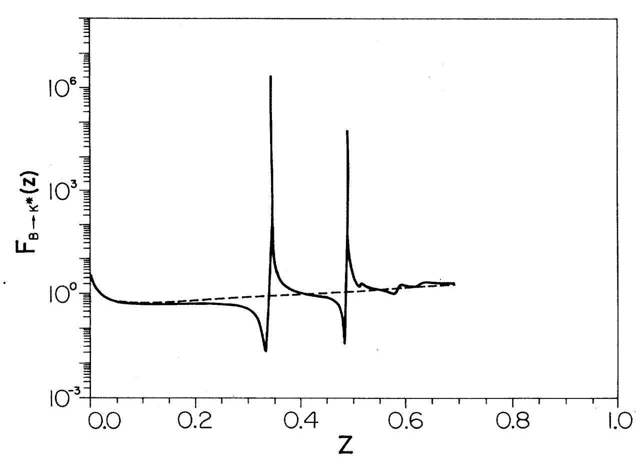

FIG. 3. The dilepton z distributions for $B \to K^* e^+ e^-$ with resonances (solid line) and without resonances (dashed line).

$$w(z)=(1-z-m_{K^*}^2/m_B^2)^2-4z(m_{K^*}/m_B)^2 . \quad (23)$$

Formulas (11)–(23) are generalizations of Eqs. (7), (14), (15), and (22)–(25) of Ref. 1. In the above formulas we assume the z dependence of all form factors to be of the $(1-z)^{-1}$ form and at $z=0$ their values are

$$m_b f_T(0)\simeq f^{(+)}(0)=0.38, \quad T_1\simeq V=0.37 ,$$
$$T_2\simeq A_1\simeq A_2=0.33 . \quad (24)$$

Using these values we plotted $F_{B\to K}(z)$ and $F_{B\to K^*}(z)$ with and without resonances in Figs. 2 and 3, respectively. It is clear that away from resonances differential rates change very little.

The way to eliminate the resonance background is to restrict oneself to dilepton mass well below the resonance region. From the figures a reasonable cut seems to be $z<0.3$. The signal from short distance is reduced by this cut. For each of the three cases we have integrated from $z_{\min}$ to $z_{\max}=0.3$ and obtain the following reduction. For $b\to se^+e^-$ the reduction is 25%, for $B\to K^*e^+e^-$ the reduction is 55%, and for $B\to Ke^+e^-$ it is 50%. The same should be valid for the $\mu^+\mu^-$ pair. This should nevertheless permit one to observe the pure short-distance contributions.

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