Lepton-number-violating decays of B^+, D^+, and D_s^+ mesons induced by the doubly charged Higgs boson

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(Received 14 January 2009; revised manuscript received 10 February 2009; published 27 February 2009)

The lepton-number-violating decays of B^+, D^+, and D_s^+ mesons induced by the doubly charged Higgs boson have been studied. It is found that although the yielded results of the branch ratio are much smaller than the present limits from the data, they are consistent with the previous conclusions calculated in the framework of the relativistic quark model where the processes happened via light Majorana neutrinos.

DOI: 10.1103/PhysRevD.79.033014 PACS numbers: 12.15.Ji, 12.60.Fr, 14.80.Cp

Exploring the physics beyond the standard model is a hot topic in particle physics. To this aim, some extensions of the standard model were made and a typical kind of these models are the left-right symmetric models [1–5]. Recently, the left-right symmetric models were extended to incorporate the dark matter candidate [6,7]. One of the common characters of these models is that a doubly charged Higgs boson was introduced in a triplet Higgs representation. Because of the existence of this doubly charged Higgs boson many new phenomenologies arise, for example, the lepton-number-violating and lepton-flavor-violating processes that will be studied in this paper.

The phenomenologies relevant to the doubly charged Higgs boson have been investigated both theoretically and experimentally. For example, in Refs. [8,9] the production of the doubly charged Higgs boson H^{++} was studied. In Ref. [10], the role of the doubly charged Higgs boson in the lepton-number-violating decay of $K^+ \to \pi^\pm \mu^\mp \mu^\mp$ was studied, and it was found that although the decay rate due to the doubly charged Higgs boson is very small, it is of the same order of magnitude as the rate for a kaon double β decay induced by light or heavy Majorana neutrinos. Experimentally, the physics of the doubly charged Higgs boson have been performed by many collaborations as mentioned in the following references. Considering this, we will study the lepton-number-violating decays of bottom and charm mesons in this paper. This study is meaningful because some experiments such as the BESIII will improve the measurements of the branch ratio of some lepton-number-violating decay processes to the order of 10^{-9}.

The general form of the lepton-number-violating coupling to left-handed leptons is specified by the following Lagrangian:

$$\mathcal{L}_{\text{int}} = ih_{ij}\psi_{iL}^T C\sigma_2\Delta\psi_{jL} + \text{H.c.}, \tag{1}$$

where $h_{ij}(i, j = 1, 2, 3)$ are arbitrary coupling constants, σ_2 is the Pauli matrix, C is the Dirac charge conjugation operator, ψ_{iL} is the ith generation left-handed lepton doublet, and Δ is the 2×2 representation of the $Y = 2$ complex triplet. Explicitly,

$$\psi_{iL} = \begin{pmatrix} \upsilon_i \\ l_i \end{pmatrix}; \qquad \Delta = \begin{pmatrix} H^-/\sqrt{2} & H^{--} \\ H^0 & -H^-/\sqrt{2} \end{pmatrix}. \tag{2}$$

It should be noted that in the left-right symmetric models Δ should be specified as Δ_L and the left-handed gauge symmetry was specified as the standard model $\text{SU}(2)_L$ gauge symmetry.

From the Lagrangian (1), one can get the decay rate for $H^{\pm\pm} \to l_i^\pm l_j^\pm$ as

$$\Gamma(H^{\pm\pm} \to l_i^\pm l_j^\pm) = C_{ij}\frac{h_{ij}^2}{8\pi s\sqrt{s}}\lambda^{1/2}(s, m_i^2, m_j^2)(s - m_i^2 - m_j^2), \tag{3}$$

where $C_{ij} = 1(2)$ for $i = j(i \neq j)$ and s is the invariant momentum square transferred to the final leptons l_i and l_j. In the case of real doubly charged Higgs boson H^{++}, $s = m_{H^{++}}^2$. When the final leptons are both massless, the width (3) can be simplified as

$$\Gamma(H^{\pm\pm} \to l_i^\pm l_j^\pm) = C_{ij}\frac{h_{ij}^2}{8\pi}m_{H^{++}}. \tag{4}$$

For the coupling constants h_{ij}, the present experiments give the following constraints. From the Bhabha scattering one obtains the limit for h_{ee} as [11]

$$h_{ee}^2 \simeq 9.7 \times 10^{-6}\ \text{GeV}^{-2}M_{H^{--}}^2. \tag{5}$$

The $(g-2)_\mu$ measurement [12] provides an upper limit for $h_{\mu\mu}$ as

$$h_{\mu\mu}^2 \simeq 2.5 \times 10^{-5}\ \text{GeV}^{-2}M_{H^{--}}^2. \tag{6}$$

For the flavor changing interaction, the most stringent constraint comes from the upper limit for the flavor changing decay $\mu \to \bar{e}ee$, which puts the following limit on the relevant coupling constants:

$$h_{e\mu}h_{ee} \leq 3.2 \times 10^{-11}\ \text{GeV}^{-2}M_{H^{--}}^2 \tag{7}$$

and the nonobservation of the decay $\mu \to e\gamma$ leads to

$$h_{e\mu}h_{\mu\mu} \leq 2.0 \times 10^{-10}\ \text{GeV}^{-2}M_{H^{--}}^2. \tag{8}$$

From the Bhabba scattering with LEP data, the flavor violating coupling constants are found as [13]

$$h_{e(\mu,\tau)}^2 \leq 1.0 \times 10^{-6}\ \text{GeV}^{-2}M_{H^{--}}^2. \tag{9}$$

In the following calculation we will adopt the upper limits of the relevant coupling constants. Combining (6) with (8) one can get

$$h_{e\mu}^2 \leq 1.6 \times 10^{-15}\ \text{GeV}^{-2}M_{H^{--}}^2. \tag{10}$$

This numerical value means, compared with the lepton-flavor-concerving processes, the lepton-flavor-violating processes are dramatically suppressed.

The mass of doubly charged Higgs boson H^{++} has been searched by several collaborations [14–18]. The data have excluded H^{++} boson below the mass of about 100 GeV by assuming exclusive H^{++} decays to a given dilepton channel. And the search performed by the CDF and D0 Collaborations at the Fermi Tevatron in the $\mu\mu$ channel have excluded the H^{++} below a mass of 136(113) GeV [17] and 118 GeV [18]. In the following calculation, we will adopt the lower limit of H^{++} mass, that is, adopt $m_{H^{++}} = 100$ GeV.

Next, we will calculate the lepton-number-violating decays of some heavy mesons induced by the doubly charged Higgs boson H^{++}, i.e., the decays of $M_{(s)}^- \to P^+(V^+)l_il_j$. To calculate these decay processes, the diagrams at quark level shown in Fig. 1 should be considered.

For the relevant leptonic decay constants, we will adopt the following ordinary definitions:

$$\begin{aligned} \langle 0|\bar{q}\gamma_\mu\gamma_5 q'|P(p)\rangle &= -ip_\mu f_P \\ \langle 0|\bar{q}\gamma_\mu q'|V(p)\rangle &= \epsilon_\mu m_V f_V, \end{aligned} \tag{11}$$

where P and V denote pseudoscalar and vector mesons, respectively. ϵ_μ is the polarization vector of relevant vector meson and m_V is the vector meson mass. The numerical values of the leptonic decay constants can be yielded from the relevant processes as [19–24]

$$\begin{aligned} &f_\pi = 135\ \text{MeV}; \qquad f_K = 160\ \text{MeV}; \\ &f_{\rho^+} = 209\ \text{MeV}; \qquad f_{K^{*+}} = 218\ \text{MeV}; \\ &f_{D^+} = 222.6\ \text{MeV}; \qquad f_{D_s^+} = 280.1\ \text{MeV}; \\ &f_{B^+} = 216\ \text{MeV}. \end{aligned}$$

To calculate the decay widths, the following interaction Lagrangian besides the Lagrangian (1) should be applied:

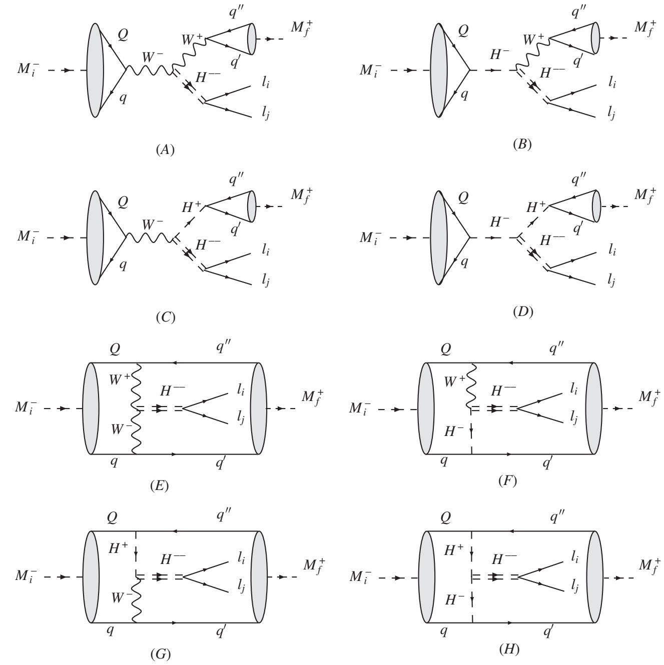

FIG. 1. Diagrams contribute to the decay of $M_i^- \to M_f^+ l_i l_j$. M_i is the initial heavy mesons and M_f^+ is the pseudoscalar or vector meson in the final states.

$$\begin{aligned} \mathcal{L}_{\text{int}} &= \mathcal{L}_{\text{int}}^{\text{SM}} + \mathcal{L}_{\text{int}}^{\text{BSM}} \\ \mathcal{L}_{\text{int}}^{\text{SM}} &= \frac{g}{\sqrt{2}} V_{ud} W_\mu^+ \bar{u}_L \gamma_\mu d_L + \text{H.c.} \\ \mathcal{L}_{\text{int}}^{\text{BSM}} &= -\sqrt{2} g m_W s_H g_{\mu\nu} H^{++} W_\mu^- W_\mu^- \\ &\quad + \frac{\sqrt{2}}{2} c_H g W_\mu^- H^- \overleftrightarrow{\partial_\mu} H^{++} \\ &\quad + \frac{igs_H}{\sqrt{2} m_W c_H} H^+ (m_{q'} \bar{q}_R q'_R - m_q \bar{q}_L q'_L) \\ &\quad + 3\sqrt{2} s_H \bar{\lambda}_{45} v H^{++} H^- H^- + \text{H.c.}, \end{aligned} \tag{12}$$

where $g = e/\sin\theta_W$ with θ_W as the Weinberg angle, V_{ud} is the Cabibbo-Kobayashi-Maskawa matrix element and c_H and s_H are the cosine and sine of the mixing angle, and it was found the current data lead to the limit $s_H \leq 0.0056$ at 95% confidence level [25]. To write down $\mathcal{L}_{\text{int}}^{\text{BSM}}$ we have applied the convention of Ref. [26].

As an example, we will consider the lepton-number-violating decay of $B^- \to \pi^+ l_i l_j$. In this case, $Q = b$, $q = \bar{u}$, $q' = u$, and $q'' = \bar{d}$ in Fig. 1. After analyzing the analytic forms of the matrix elements, one can see the contributions from diagrams (A) and (E) are dominant. The argument is the following: According to the Lagrangian (12), the matrix element of the first diagram is proportional to $m_W \sin_H$, while that of the second diagram is proportional to $c_H \frac{s_H m_q p}{m_W C_W} = \frac{s_H m_q p}{m_W}$, where p would be maximally a few GeV and m_q is the quark mass, so the second diagram is suppressed. A similar analysis can be made on diagram (C). For diagram (D), it is even suppressed relative to diagram (B) concerning the Lagrangian (12). So that, for the first four diagrams, contribution from the diagram (A) is dominant. Along the same reasoning, for the last four diagrams, the contribution from the diagram (E) is dominant. Then we have the dominant contributions as

$$iM_{(A)} = \frac{\sqrt{2}g^3}{2} V_{ub}^* V_{ud} \langle \pi^+(p_\pi)|[\bar{b}\gamma_\mu P_L u] \times [\bar{u}\gamma_\mu P_L d]|B^-(p_B)\rangle \frac{1}{m_W^3 m_{H^{++}}^2} s_H h_{l_i l_j} \langle \text{leptons}\rangle, \tag{13}$$

$$iM_{(E)} = \left(\frac{1}{3}\right) \frac{\sqrt{2}g^3}{2} V_{ub}^* V_{ud} \langle \pi^+(p_\pi)|[\bar{d}\gamma_\mu P_L u] \times [\bar{b}\gamma_\mu P_L u]|B^-(p_B)\rangle \frac{1}{m_W^3 m_{H^{++}}^2} s_H h_{l_i l_j} \langle \text{leptons}\rangle, \tag{14}$$

where the factor $(1/3)$ is from the Fierz transformations of Dirac indices and color indices and $\langle \text{leptons}\rangle = \bar{v}^s(p_i) P_L u^s(p_j) - (p_i \leftrightarrow p_j)$.

Using the leptonic constants defined in (11), we can rewrite the matric elements as

$$iM = iM_{(A)} + iM_{(E)} = \frac{\sqrt{2}g^3 s_H}{6 m_W^3 m_{H^{++}}^2} V_{ub}^* V_{ud} f_B f_\pi p_B \cdot p_\pi h_{l_i l_j} \langle \text{leptons}\rangle, \tag{15}$$

which leads to

$$|iM|^2 = \frac{g^6 |V_{ub}|^2 |V_{ud}|^2 f_\pi^2 f_B^2 s_H^2}{18 m_W^6 m_{H^{++}}^4} \times (p_B \cdot p_\pi)^2 h_{l_i l_j}^2 \sum_s |\langle \text{leptons}\rangle|^2, \tag{16}$$

where s is the spins of the final leptons.

With this expression one can write the decay width of $B^- \to \pi^+ l_i l_j$ as

$$\begin{aligned}\frac{d\Gamma(B^- \to \pi^+ l_i l_j)}{ds} &= \frac{1}{2m_B} \int \frac{d^3 p_\pi}{(2\pi)^3} \frac{1}{2E_\pi} \int \frac{d^3 p_{l_i}}{(2\pi)^3} \frac{1}{2E_{l_i}} \int \frac{d^3 p_{l_j}}{(2\pi)^3} \frac{1}{2E_{l_j}} |M|^2 (2\pi)^4 \delta^4(q - p_{l_i} - p_{l_j}) \delta[q^2 - (p_B - p_\pi)^2] \\ &= C_{ij} \left(\frac{h_{l_i l_j} s_H}{m_{H^{++}}^2}\right)^2 \frac{\alpha_{\text{em}}^3 |V_{ub}|^2 |V_{ud}|^2 f_\pi^2 f_B^2}{144 \sin^6\theta_W m_B^3 m_W^6} \lambda^{1/2}(s, m_i^2, m_j^2) \lambda^{1/2}(s, m_B^2, m_\pi^2) \frac{(s - m_B^2 - m_\pi^2)^2 (s - m_i^2 - m_j^2)}{s},\end{aligned} \tag{17}$$

where λ is the *Källen* function, m_i is the mass of ith flavor lepton. s is the invariant momentum square transferred to the leptons and its amplitude is between the region $(m_{l_i} + m_{l_j})^2 \leq s \leq (m_B - m_\pi)^2$. Along the same method, one can easily write down the decay width of $B^- \to \rho^+ l_i l_j$ as

$$\frac{d\Gamma(B^- \to \rho^+ l_i l_j)}{ds} = C_{ij} \left(\frac{h_{l_i l_j} s_H}{m_{H^{++}}^2}\right)^2 \frac{\alpha_{\text{em}}^3 |V_{ub}|^2 |V_{ud}|^2 f_\rho^2 f_B^2}{144 \sin^6\theta_W m_B^3 m_W^6} \times \lambda^{1/2}(s, m_i^2, m_j^2) \lambda^{3/2}(s, m_B^2, m_\rho^2) \times \frac{(s - m_i^2 - m_j^2)}{s}, \tag{18}$$

where the region of s is $(m_{l_i} + m_{l_j})^2 \leq s \leq (m_B - m_\rho)^2$ in this case.

Substituting the relevant physical quantities, one can get the following numerical results:

$$\begin{aligned}\Gamma(B^- \to \pi^+ e^- e^-) &< 5.80 \times 10^{-15} \text{ eV} \\ \Gamma(B^- \to \rho^+ e^- e^-) &< 1.04 \times 10^{-14} \text{ eV}.\end{aligned} \tag{19}$$

In Tables I, II, and III, we list our numerical results for the branch ratio of all the channels that we are interested in and the corresponding data from PDG [20]. From the tables one can see that the branch ratio induced by the doubly charged Higgs boson is very small. Our results also show that the lepton-flavor-violating decays are dramatically suppressed, which agree with our above expectation. Compared with the pseudoscalar channel, the corresponding vector meson channel is improved because of the larger leptonic decay constant of the relevant vector meson. And among all the three initial states, B^+, D^+, and D_s^+, the branch ratio of D_s^+ channel is the most important. The reason is that the Cabibbo-Kobayashi-Maskawa matrix element V_{cs} is the largest one among V_{ub}, V_{cd}, and V_{cs}.

TABLE I. The branch ratio of the lepton-number-violating B meson decays.

Decay modes	Present results	Data [20]
$B^- \to \pi^+ e^- e^-$	$<5.81 \times 10^{-24}$	$<1.6 \times 10^{-6}$
$B^- \to \pi^+ \mu^- \mu^-$	$<1.49 \times 10^{-23}$	$<1.4 \times 10^{-6}$
$B^- \to \pi^+ e^- \mu^-$	$<1.91 \times 10^{-33}$	$<1.3 \times 10^{-6}$
$B^- \to K^+ e^- e^-$	$<4.31 \times 10^{-25}$	$<1.0 \times 10^{-6}$
$B^- \to K^+ \mu^- \mu^-$	$<1.10 \times 10^{-24}$	$<1.8 \times 10^{-6}$
$B^- \to K^+ e^- \mu^-$	$<1.41 \times 10^{-34}$	$<2.0 \times 10^{-6}$
$B^- \to \rho^+ e^- e^-$	$<1.04 \times 10^{-23}$	$<2.6 \times 10^{-6}$
$B^- \to \rho^+ \mu^- \mu^-$	$<2.67 \times 10^{-23}$	$<5.0 \times 10^{-6}$
$B^- \to \rho^+ e^- \mu^-$	$<3.43 \times 10^{-33}$	$<3.3 \times 10^{-6}$
$B^- \to K^{*+} e^- e^-$	$<5.60 \times 10^{-25}$	$<2.8 \times 10^{-6}$
$B^- \to K^{*+} \mu^- \mu^-$	$<1.43 \times 10^{-24}$	$<8.3 \times 10^{-6}$
$B^- \to K^{*+} e^- \mu^-$	$<1.84 \times 10^{-34}$	$<4.4 \times 10^{-6}$

TABLE II. The branch ratio of the lepton-number-violating D meson decays.

Decay modes	Present results	Data [20]
$D^- \to \pi^+ e^- e^-$	$<7.71 \times 10^{-24}$	$<3.6 \times 10^{-6}$
$D^- \to \pi^+ \mu^- \mu^-$	$<1.86 \times 10^{-23}$	$<4.8 \times 10^{-6}$
$D^- \to \pi^+ e^- \mu^-$	$<2.46 \times 10^{-33}$	$<5.0 \times 10^{-5}$
$D^- \to K^+ e^- e^-$	$<4.63 \times 10^{-25}$	$<4.5 \times 10^{-6}$
$D^- \to K^+ \mu^- \mu^-$	$<1.11 \times 10^{-24}$	$<1.3 \times 10^{-5}$
$D^- \to K^+ e^- \mu^-$	$<1.47 \times 10^{-34}$	$<1.3 \times 10^{-4}$
$D^- \to \rho^+ e^- e^-$	$<2.52 \times 10^{-24}$	
$D^- \to \rho^+ \mu^- \mu^-$	$<5.68 \times 10^{-24}$	$<5.6 \times 10^{-4}$
$D^- \to \rho^+ e^- \mu^-$	$<7.79 \times 10^{-34}$	
$D^- \to K^{*+} e^- e^-$	$<7.90 \times 10^{-26}$	
$D^- \to K^{*+} \mu^- \mu^-$	$<1.72 \times 10^{-25}$	$<8.5 \times 10^{-4}$
$D^- \to K^{*+} e^- \mu^-$	$<2.40 \times 10^{-35}$	

TABLE III. The branch ratio of the lepton-number-violating D_s meson decays.

Decay modes	Present results	Data [20]
$D_s^- \to \pi^+ e^- e^-$	$<1.46 \times 10^{-22}$	$<6.9 \times 10^{-4}$
$D_s^- \to \pi^+ \mu^- \mu^-$	$<3.55 \times 10^{-22}$	$<2.9 \times 10^{-5}$
$D_s^- \to \pi^+ e^- \mu^-$	$<4.68 \times 10^{-32}$	$<7.3 \times 10^{-4}$
$D_s^- \to K^+ e^- e^-$	$<9.02 \times 10^{-24}$	$<6.3 \times 10^{-4}$
$D_s^- \to K^+ \mu^- \mu^-$	$<2.17 \times 10^{-23}$	$<1.3 \times 10^{-5}$
$D_s^- \to K^+ e^- \mu^-$	$<2.88 \times 10^{-33}$	$<6.8 \times 10^{-4}$
$D_s^- \to \rho^+ e^- e^-$	$<5.76 \times 10^{-23}$	
$D_s^- \to \rho^+ \mu^- \mu^-$	$<1.32 \times 10^{-22}$	
$D_s^- \to \rho^+ e^- \mu^-$	$<1.80 \times 10^{-32}$	
$D_s^- \to K^{*+} e^- e^-$	$<1.92 \times 10^{-24}$	
$D_s^- \to K^{*+} \mu^- \mu^-$	$<4.32 \times 10^{-24}$	$<1.4 \times 10^{-3}$
$D_s^- \to K^{*+} e^- \mu^-$	$<5.92 \times 10^{-34}$	

At last, we would like to say that, in the second identity of (15) the naive factorization has been applied. When the QCD corrections are included, minor corrections should be made to our numerical results. For example, for the charm sector, the improvement of the branch ratio is about 20%, but for the bottom sector the corrections are much smaller and can even be neglected. Concerning the present status of the relevant experiments, our results are meaningful and when the precision of the experiments are improved one should calculate the QCD corrections explicitly.

In summary, in this paper we studied the lepton-number-violating decays of B^+, D^+, and D_s^+ mesons induced by the doubly charged Higgs boson H^{++}. It is found that the branch ratio we yielded here are much smaller than the present limits from corresponding data. It should be noted that our conclusion is consistent with that of Ref. [10], where the lepton-number-violaing decay of $K^\pm \to \pi^\mp \mu^\pm \mu^\pm$ induced by doubly charged Higgs boson was studied.

We would like to thank W-L Guo for his valuable discussions on the left-right symmetry models. This work was supported in part by the Project of Knowledge Innovation Program (PKIP) of Chinese Academy of Sciences under Contract No. KJCX2-YW-W10.

[1] J. C. Pati and A. Salam, Phys. Rev. D **10**, 275 (1974) **11**, 703(E) (1975).
[2] R. N. Mohapatra and J. C. Pati, Phys. Rev. D **11**, 566 (1975).
[3] R. N. Mohapatra and J. C. Pati, Phys. Rev. D **11**, 2558 (1975).
[4] G. Senjanovic and R. N. Mohapatra, Phys. Rev. D **12**, 1502 (1975).
[5] R. E. Marshak and R. N. Mohapatra, Phys. Lett. B **91**, 222 (1980).
[6] W-l Guo, L-m Wang, Y-l Wu, and C. Zhuang, Phys. Rev. D **78**, 035015 (2008).
[7] W-L Guo, L-M Wang, Y-L Wu, Y-F Zhou, and C. Zhuang, arXiv:0811.2556.
[8] H. Georgi and M. Machacek, Nucl. Phys.**B262**, 463 (1985).
[9] R. Vega and D. A. Dicus, Nucl. Phys.**B329**, 533 (1990).
[10] C. Picciotto, Phys. Rev. D **56**, 1612 (1997).
[11] M. L. Swartz, Phys. Rev. D **40**, 1521 (1989).
[12] H. N. Brown *et al.* (Muon g-2 Collaboration), Phys. Rev. Lett. **86**, 2227 (2001).
[13] S. Atag and K. O. Ozansoy, Phys. Rev. D **70**, 053001 (2004).
[14] G. Abbiendi *et al.* (OPAL Collaboration), Phys. Lett. B **577**, 93 (2003).
[15] P. Achard *et al.* (L3 Collaboration), Phys. Lett. B **576**, 18 (2003).
[16] J. Abdallah *et al.* (DELPHI Collaboration), Phys. Lett. B **552**, 127 (2003).
[17] D. E. Acosta *et al.* (CDF Collaboration), Phys. Rev. Lett. **93**, 221802 (2004).
[18] V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **93**, 141801 (2004).
[19] M. B. Wise, Phys. Rev. D **45**, R2188 (1992).
[20] C. Amsler *et al.* (Particle Data Group), Phys. Lett. B **667**, 1 (2008).
[21] M. Artuso *et al.*, Eur. Phys. J. C **57**, 309 (2008).
[22] A. Gray *et al.* (HPQCD Collaboration), Phys. Rev. Lett. **95**, 212001 (2005).
[23] P. Ball and V. M. Braun, Nucl. Phys. **B543**, 201 (1999).
[24] M. Beneke and M. Neubert, Nucl. Phys. **B675**, 333 (2003).
[25] S. Chakrabarti, D. Choudhury, R. M. Godbole, and B. Mukhopadhyaya, Phys. Lett. B **434**, 347 (1998).
[26] J. F. Gunion, R. Vega, and J. Wudka, Phys. Rev. D **42**, 1673 (1990).