VOLUME 93, NUMBER 20 PHYSICAL REVIEW LETTERS week ending 12 NOVEMBER 2004

B-Factory Signals for a Warped Extra Dimension

Kaustubh Agashe,[1,*] Gilad Perez,[2,†] and Amarjit Soni[3,‡]
[1]Department of Physics and Astronomy, Johns Hopkins University, Baltimore, Maryland 21218-2686, USA
[2]Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
[3]Brookhaven National Laboratory, Upton, New York 11973, USA

(Received 23 June 2004; published 10 November 2004)

We study predictions for B physics in a class of warped extra dimension models recently introduced, where few ($\sim$3) TeV Kaluza-Klein masses are consistent with electroweak data due to custodial symmetry. As in the standard model (SM), flavor violations arise due to the heavy top quark leading to striking signals: (i) New physics contributions to $\Delta F = 2$ transitions are comparable to the SM, so the success of the SM unitarity triangle fit is a "coincidence." Thus, clean extractions of unitarity angles are likely to be affected, in addition to $O(1)$ deviation from the SM prediction in B_s mixing. (ii) $O(1)$ deviation from various SM predictions for $B \to X_s l^+ l^-$. (iii) Large mixing-induced CP asymmetry in radiative B decays. Also, the neutron electric dipole moment is roughly 20 times larger than the current bound so that this framework has a "CP problem."

DOI: 10.1103/PhysRevLett.93.201804 PACS numbers: 11.25.Wx, 13.25.Hw

Introduction.—The standard model (SM) is in very good agreement with data. However, it is widely perceived to be an incomplete theory. In particular, in the SM the hierarchy between the Planck scale and the electroweak symmetry breaking (EWSB) scale, Λ_{EWB}, is unnatural since the Higgs boson mass is ultraviolet (UV) sensitive.

Solutions to the hierarchy problem, therefore, involve extending the SM at just above the EWSB scale which, in general, spoils the good agreement of the SM with data, for example, by introducing new sources of flavor violation. Given this inherent tension, it is important to identify new physics (NP) frameworks which preserve the appealing features of the SM.

We consider the Randall-Sundrum scenario (RS1) [1], which provides an elegant solution to the hierarchy problem, and show that this framework with a mass scale of NP as low as a few TeV leads to many striking signals in B physics. This renders B facilities a valuable probe of the parameter space of this novel physics scenario.

In this framework, due to warped higher-dimensional spacetime, the mass scales in an effective 4D description depend on location in extra dimension: the Higgs sector is localized at the "TeV" brane where it is protected by a low warped-down fundamental scale of order a TeV, while 4D gravity is localized near the "Planck" brane which has a Planckian fundamental scale.

In the original RS1 model, the entire SM was localized on the TeV brane. In this setup, flavor issues are sensitive to the UV completion of the RS1 effective field theory: there is no understanding of hierarchies in fermion masses or of smallness of flavor-changing neutral currents (FCNC's) from higher-dimensional operators which are naively too large being suppressed only by the warped-down cutoff $\sim$TeV.

Allowing the SM fermions and gauge fields to propagate in the bulk makes flavor issues UV insensitive as follows. The light fermions can be localized near the Planck brane (using a 5D fermion mass parameter [2,3]) where the effective cutoff is much higher than TeV so that FCNC's from higher-dimensional operators are suppressed [3,4]. Moreover, this results in small 4D Yukawa couplings to the Higgs bosons, even if there are no small 5D Yukawa couplings [3,4]. The top quark can be localized near TeV brane to obtain a large 4D top Yukawa coupling. This provides an understanding of hierarchy of fermion masses (and mixing) *without* hierarchies in fundamental (5D) parameters solving the SM flavor puzzle.

With bulk fermions and gauge fields, FCNC's from the exchange of gauge Kaluza-Klein (KK) modes are induced. The couplings of light fermions to gauge KK modes are flavor dependent (due to different wave functions of fermions in the 5D), but, remarkably, this flavor dependence is small [5], since gauge KK modes are localized near the TeV brane, whereas light fermions are localized near the Planck brane (unlike the *flat* extra dimension case). Thus, FCNC's for light fermions from exchange of gauge KK modes are suppressed [3,4]. Recall that this is the same reason why these fermions are light; i.e., the Higgs boson is also localized near TeV brane just as the gauge KK modes. Thus, this RS1 model has a *built-in* analog of the SM Glashow-Iliopoulos-Maiani (GIM) mechanism and approximate flavor symmetries for the light fermions [6].

In spite of all these appealing features the above framework has another source of tension. It was shown that in order to be consistent with electroweak precision measurements (EWPM) one needs to assume $m_{\mathrm{KK}} \gtrsim 10$ TeV [7]. This brings a little hierarchy problem related to the smallness of $(\Lambda_{\mathrm{EWB}}/m_{\mathrm{KK}})^2 \sim 10^{-4}$, which is radiatively unstable.

Recently, it was shown that, with enhanced bulk electroweak (EW) gauge symmetry, $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R \times \mathrm{U}(1)_{B-L}$, few TeV KK masses are consistent with EWPM [8]. This gauge structure, with custodial symmetry, in warped space has also been used to construct Higgsless models of EWSB in [9,10].

Our goal is to systematically study the flavor structure of the above framework and to reinvestigate the NP contribution to FCNC processes [4] in the presence of rather light KK excitations. In this Letter, we will summarize the main effects and the ramifications for B factories [6]. Even though we mainly concentrate on RS1 model with the Higgs bosons strictly localized on TeV brane, our results will be valid for warped space models *without* the Higgs boson or with 5D profile for Higgs bosons as well. Thus these results are model independent within the new class of models which assume RS1 with custodial gauge symmetry in the bulk.

Flavor violation.—Most of the flavor-violating effects are related to the violation of RS-GIM mechanism by large top quark mass (just as in the SM) as follows. $(t, b)_L$ cannot be localized near the Planck brane. This is since the large top mass then requires a very large 5D Yukawa coupling such that the theory is strongly coupled at the scale of the first KK mode [11]. Thus $(t, b)_L$ must be localized near the TeV brane. This has two consequences: (i) In the interaction basis, the coupling of b_L to gauge KK modes (say, the gluons), $g^b_{G^{\mathrm{KK}}}$, is large compared with the ones of the lighter quarks. This is a source of flavor violation which combined with mixing yields FCNC processes. (ii) The Higgs vacuum expectation value mixes zero and KK modes of Z leading to a nonuniversal shift, in the interaction basis, of the coupling of b_L to the physical Z [8,12]:

$$\delta g^b_Z \sim g^b_{Z^{\mathrm{KK}}} \sqrt{\log(M_{Pl}/\mathrm{TeV})}\, \frac{m_Z^2}{m_{\mathrm{KK}}^2}, \tag{1}$$

where $g^b_{Z^{\mathrm{KK}}}$ is the (nonuniversal) coupling between b_L and a KK Z state before EWSB. The factor of $\sqrt{\log(M_{Pl}/\mathrm{TeV})}$ comes from enhanced Higgs coupling to gauge KK mode (since they are localized near the TeV brane). EWPM, which are not related to flavor mixing, require that this shift is smaller than ~1%. Note that in the above framework the interaction basis is unique. This is the basis in which all the interactions (except Yukawa ones), including ones with KK modes, are flavor diagonal.

There is, therefore, a tension between obtaining a large top Yukawa and not introducing a too large flavor violation in processes related to EWPM [8,12]. As a result, all the models assume the following: (i) A large (close to maximal) dimensionless 5D Yukawa, $\lambda_{5\mathrm{D}} \sim 4$ (such that the weakly coupled effective theory contains 3–4 KK modes). (ii) The wave function of (t_L, b_L) is localized as close to the TeV brane as is allowed by EWPM so that a large (close to maximal) shift in coupling of b_L to Z, $\delta g^b_Z \sim 1\%$ is obtained. Using Eq. (1) we can summarize the above by the following [6]:

$$g^b_{G^{\mathrm{KK}}} \sim g_s, \qquad g^b_{Z^{\mathrm{KK}}} \sim g_Z, \qquad m_{\mathrm{KK}} \sim 3\ \mathrm{TeV}. \tag{2}$$

This (unavoidable) setup leads to sizable NP contributions in the following three kinds of top quark dominated FCNC processes: (i) $\Delta F = 2$, (ii) $\Delta F = 1$ governed by box and EW penguin diagrams, and (iii) radiative decays. We will consider these effects, in turn, in what follows.

Let us elaborate more on how the NP contributions arise in the above framework. Since the couplings of fermions of a given type to gauge KK modes are nonuniversal, flavor mixing is induced when a transformation from the (unique) interaction to the mass basis is performed for the quarks. Here, we mostly consider couplings of *left-handed* down quarks. This is since coupling of b_L to gauge KK modes is abnormally large [13] compared with the couplings of other down-type quarks (which are localized near the Planck brane): the coupling of b_L to gauge KK modes is "dictated" by m_t. Consequently, a large RS-GIM violation is induced.

Signals.—To study flavor-changing effects, we need to estimate the mixing angles of the unitary transformations. Generically, 5D Yukawa matrices are expected to be anarchic. Thus the mixing angles of the transformations are roughly given by ratio of wave functions at TeV brane. The unitary transformations for left-handed up, U_L, and down quarks, D_L, are similar due to the fact that u_L and d_L have the same wave function. Since $U_L D_L^\dagger = V_{\mathrm{CKM}}$, we get $D_L \sim V_{\mathrm{CKM}}$. It follows, therefore, that the gluon KK mode-b_L-$(s, d)_L$ vertex is roughly given by $g^b_{G^{\mathrm{KK}}} V_{t(s,d)}$, while the gluon KK mode-d_L-s_L one is $g^b_{G^{\mathrm{KK}}} V_{ts} V_{td}$.

This results in the *tree-level* exchange of gluon KK mode contributing to $\Delta F = 2$ operators:

$$\frac{M_{12}^{\mathrm{RS}}}{M_{12}^{\mathrm{SM}}} \sim 16\pi^2 \frac{(g^b_{G^{\mathrm{KK}}})^2}{g_2^4} \frac{m_W^2}{m_{\mathrm{KK}}^2} \sim C (g^b_{G^{\mathrm{KK}}})^2 \left(\frac{3\ \mathrm{TeV}}{m_{\mathrm{KK}}}\right)^2, \tag{3}$$

where C is an order one complex coefficient, mixing angles are of the same size in both RS1 and SM contributions, and $M_{12}^{\mathrm{SM,RS}}$ is the SM (box diagram) and RS1 (KK gluon exchange) $\Delta F = 2$ transition amplitudes, respectively. We see that the KK gluon contribution to $B_d^0 - \bar{B}_d^0$, $B_s^0 - \bar{B}_s^0$ mass difference, ϵ_K, and the CP asymmetry in $B \to \psi K_S$ is comparable to the SM ones.

The SM predictions depend on V_{td}, which is currently not severely constrained by tree-level decays and unitarity [14], which are not affected by NP contributions. The data, therefore, can be fitted even with RS1 contributions comparable to the SM [6].

This, however, leads to a "coincidence problem": why is the SM fit (usually presented as a plot of the constraints in the $\rho - \eta$ plane; see, e.g., [14]) so good? At present, this problem is not so severe since there are $\mathcal{O}(20\%)$ uncertainties in SM predictions for ϵ_K and Δm_{B_d} (due mainly to hadronic matrix elements) [15], and also the RS1 contributions have $O(1)$ uncertainties due to fluctuations in $\lambda_{5\mathrm{D}}$. Consequently, clean measurements of α and γ via $B \to \pi\pi, \pi\rho, \rho\rho, DK$ are likely to be affected.

The case of $B_s - \bar{B}_s$ mixing is slightly different than $B_d - \bar{B}_d$ mixing and ϵ_K as the SM contribution is known (up to hadronic matrix elements) since V_{ts} is constrained by unitarity and tree-level decays [14]. Hence, for a generic order one complex coefficient (it is complex due to physical phases in D_L [6]), we expect an $\mathcal{O}(1)$ deviation from the SM prediction in Δm_{B_s} (see Ref. [13] for a larger effect). Similarly, an $\mathcal{O}(1)$ time-dependent CP asymmetry in $B_s \to J/\psi\phi$ is induced compared with the SM $\mathcal{O}(\lambda_c^2)$ prediction, where $\lambda_c \sim 0.22$. Also deviations from the SM expectation for γ ought to occur in $B_s \to DK$.

Next, we consider $\Delta F = 1$ transitions. We start with the discussion of processes which in the SM are dominated by QCD penguin diagrams such as $b \to s\bar{s}s$. There is a contribution from KK gluon exchange as in the $\Delta F = 2$ case. The coupling of KK gluon to s is suppressed by $\sim\sqrt{\log(M_{Pl}/\mathrm{TeV})}$ since the strange quark is localized near Planck brane, whereas the KK gluon is localized near TeV brane (this is the universal part of coupling of fermions to gauge KK modes). Thus, it is clear that KK gluon contribution $\sim 1/5$ the SM QCD penguin diagram. In addition, there is dilution of the NP effect in QCD penguin diagram after RG scaling from TeV to m_b. So, KK gluon NP contributions in $\Delta F = 1$ transition cannot compete with SM QCD penguin ones (see, however, [13] for a $O(1)$ effect with ~ 1 TeV KK masses).

The contribution from exchange of the KK mode of Z is smaller than that from the KK gluon. However, as mentioned above, the KK mode of Z mixes with the *zero* mode of Z due to Higgs vacuum expectation value, in turn, generating a flavor-violating coupling to the physical Z. Thus, we get the following contributions to coefficients of EW penguin operators, C_{7-10} (four quark) and $C_{9V,10A}$ (leptonic operators):

$$\frac{C^{Z,\mathrm{RS}}_{7-10,9V,10A}}{C^{Z,\mathrm{SM}}_{7-10,9V,10A}} \sim \frac{16\pi^2}{g_2^2}\,\frac{g^b_{Z^{\mathrm{KK}}}}{g_Z}\sqrt{\log(M_{Pl}/\mathrm{TeV})}\,\frac{m_Z^2}{m_{\mathrm{KK}}^2} \sim \frac{g^b_{Z^{\mathrm{KK}}}}{g_Z}\left(\frac{3\ \mathrm{TeV}}{m_{\mathrm{KK}}}\right)^2, \tag{4}$$

where superscript Z on $C_{7-10,9V,10A}$ denotes Z penguin part and, as for the $\Delta F = 2$ case, the SM contribution is from top quark loop and mixing angles are of same size in both contributions. Thus, the two contributions are comparable. This leads to an $\mathcal{O}(1)$ effect in the branching ratio for rare flavor-changing decays, for example, $b \to sl^+l^-$ [12,16], where uncertainty in theory prediction is of $\mathcal{O}(20\%)$ and current experimental error (from *BABAR* and BELLE) is of $\mathcal{O}(30\%)$ [17]. In addition, a smoking gun signal is that significant departure from the SM is expected in the direct CP asymmetry and in the spectrum of leptons in this decay, as well as in the forward-backward asymmetry since the new physics effect is only in the Z penguin (with almost axial couplings of leptons, i.e., in C_{10A}) and not in the photon penguin (with vector couplings of leptons, i.e., in C_{9V}).

As mentioned above, the $b \to s\bar{s}s$ transition is dominated by the SM QCD penguin diagram. Similar RS1 contribution from flavor-violating Z vertex is suppressed by at least $\sim g_Z^2/g_s^2 \sim 20\%$ and therefore subleading [12,16]. Consequently, RS1 can accommodate only mild deviations[6] (unlike [13], as mentioned above) from the SM in time-dependent CP asymmetry in "penguin-doiminated" B decays, such as $\phi(\eta', \pi^0, \omega, \rho^0)K_s$.

We next consider radiative decay processes. Since these require helicity flip, related NP contributions appear only at the loop level in our framework. The dominant contribution comes from loops of Higgs bosons and KK fermions since couplings of KK fermions to Higgs bosons are enhanced. We show elsewhere [6] that KK gluon contribution is aligned in flavor space with fermion mass matrix and hence is not flavor violating. We find the following contribution to dipole operator for $b \to s$ transition:

$$\frac{C'^{\mathrm{RS}}_{7\gamma}}{C^{\mathrm{SM}}_{7\gamma}} \sim \frac{\lambda_{5\mathrm{D}}^2}{g_2^2}\,\frac{m_W^2}{m_{\mathrm{KK}}^2}\,\frac{(D_R)_{23}}{V_{ts}} \sim (D_R)_{23}\left(\frac{\lambda_{5\mathrm{D}}}{4}\right)^2\left(\frac{3\ \mathrm{TeV}}{m_{\mathrm{KK}}}\right)^2, \tag{5}$$

where $C_{7\gamma}$ and $C'_{7\gamma}$ are coefficients of dipole operators with b_R and b_L, respectively, and $(D_R)_{23} \to (D_L)_{23}$ for $C^{RS}_{7\gamma}$. For $b \to d$ transition, $(D_{L,R})_{23} \to (D_{L,R})_{13}$ and $V_{ts} \to V_{td}$.

Let us now estimate the right-handed (RH) down quark mixing appearing in the above RS1 contribution. Because of anarchic $\lambda_{5\mathrm{D}}$, the ratio of masses are also given by ratio of wave functions on the TeV brane (just as the mixing angles) so that

$$\frac{m_s}{m_b}(D_L)^{-1}_{23} \sim (D_R)_{23} \sim \frac{m_s}{m_b}V_{ts}^{-1} = \mathcal{O}(1), \tag{6}$$

where we used the bottom and strange quark masses at the $\sim$ TeV scale and also $(D_L)_{23} \sim V_{ts}$. Similarly, we find $(D_R)_{13} \sim \lambda_c$; i.e., RH down quark mixing are much larger than left-handed down quark mixing. Then, from Eq. (5), we see that RS1 contribution to $b_L \to (s, d)_R\gamma$ is comparable to the SM contribution to $b_R \to (s, d)_L\gamma$ for $\lambda_{5\mathrm{D}} \sim 4$. Also, NP contribution to $b_R \to (s, d)_L\gamma$ is negligible (see Ref. [18] for an earlier study of only this operator).

This leads to another smoking gun signal: $\mathcal{O}(1)$ mixing-induced CP violation due to interference between the SM amplitude for $b_R \to (s, d)_L\gamma$ and the NP contribution to $b_L \to (s, d)_R\gamma$ [19] and also deviation from a pure left-handed polarization of the emitted photon [20]. This will be tested in $B \to K^*\gamma$, $B_s \to \phi\gamma$ ($b \to s$) transitions, and $B \to \rho\gamma$, $B_s \to K^*\gamma$ ($b \to d$) transitions.

Finally, we discuss contributions to the neutron's electric dipole moment which arise from diagrams similar to

TABLE I. Contrasting signals from RS1 with the SM.

	Δm_{B_s}	$S_{B_s \to \psi\phi}$	$S_{B_d \to \phi K_s}$	$Br[b \to s l^+ l^-]$	$S_{B_{d,s} \to K^*, \phi\gamma}$	$S_{B_{d,s} \to \rho, K^*\gamma}$
RS1	$\Delta m_{B_s}^{\mathrm{SM}}[1 + O(1)]$	$O(1)$	$\sin 2\beta \pm O(0.2)$	$Br^{\mathrm{SM}}[1 + O(1)]$	$O(1)$	$O(1)$
SM	$\Delta m_{B_s}^{\mathrm{SM}}$	λ_c^2	$\sin 2\beta$	Br^{SM}	$\frac{m_s}{m_b}(\sin 2\beta, \lambda_c^2)$	$\frac{m_d}{m_b}(\lambda_c^2, \sin 2\beta)$

those giving $b \to s\gamma$ above. We find that while contributions from Cabibbo-Kobayashi-Maskawa (CKM)-like phases vanish at the one loop level sizable contributions are induced by Majorana-like phases. Though this requires flavor mixing, even with two flavors we find unsuppressed one loop amplitudes [6]. With $O(1)$ complex phases, the contribution [which can be estimated from Eq. (5), without the mixing angle] exceeds the experimental limits by $\mathcal{O}(20)$ (see Sect. 5.4 in Ref. [6] for details). Thus, our framework has a CP problem.

Conclusions.—Within the RS1 framework, localization of light fermions far from the TeV brane leads to three virtues: (i) suppression of higher-dimensional flavor-violating operators, (ii) suppression of flavor-violating coupling to KK excitations, and (iii) a solution to the SM flavor puzzle. There is a built-in analog of the GIM mechanism of the SM and approximate flavor symmetries. As in the SM, inclusion of heavy top quark leads to RS-GIM violation, in particular, to large couplings of left-handed bottom to gauge KK modes, in turn, resulting in $O(1)$ effects in $\Delta F = 2$ processes and in rare flavor-changing decays, for example, $b \to s l^+ l^-$. Also, the large 5D Yukawa required to obtain top mass coupled with large RH down quark mixing leads to $O(1)$ effect in radiative B decays. These B-physics signals should be of great relevance to B facilities in hadronic and in e^+e^- environments. Finally, the above framework suffers from a CP problem.

Using the AdS/conformal field theory correspondence, the *weakly* coupled RS1 model can be viewed as a tool to study a purely 4D *strongly* coupled conformal Higgs sector [21]. Thus, a key point of our study is that a 4D strongly interacting Higgs sector can solve the flavor puzzle and have suppressed FCNC's with striking signals (see Table I) at B facilities.

K. A. is supported by the Leon Madansky Fellowship and by NSF Grant No. P420D3620414350; G. P. and A. S. are supported by DOE under Contracts No. DE-AC0376SF00098 and No. DE-AC02-98CH10886. We thank G. Burdman, Z. Chacko, W. Goldberger, Y. Grossman, I. Hinchliffe, D. E. Kaplan, Y. Nir, Y. Nomura, F. Petriello, R. Sundrum, and M. Suzuki for discussions.

---

*Electronic address: kagashe@pha.jhu.edu
†Electronic address: gperez@lbl.gov
‡Electronic address: soni@quark.phy.bnl.gov

[1] L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999).
[2] Y. Grossman and M. Neubert, Phys. Lett. B **474**, 361 (2000).
[3] T. Gherghetta and A. Pomarol, Nucl. Phys. **B586**, 141 (2000).
[4] For earlier work assuming ~10 TeV KK masses, see S. J. Huber and Q. Shafi, Phys. Lett. B **498**, 256 (2001); G. Burdman, Phys. Rev. D **66**, 076003 (2002); S. J. Huber, Nucl. Phys. **B666**, 269 (2003); S. Khalil and R. Mohapatra, Nucl. Phys. **B695**, 313 (2004).
[5] There is a sizable flavor-universal part of this coupling.
[6] For further details, see K. Agashe, G. Perez, and A. Soni, hep-ph/0408134.
[7] S. J. Huber and Q. Shafi, Phys. Rev. D **63**, 045010 (2001); S. J. Huber, C. A. Lee, and Q. Shafi, Phys. Lett. B **531**, 112 (2002); C. Csaki, J. Erlich, and J. Terning, Phys. Rev. D **66**, 064021 (2002); J. L. Hewett, F. J. Petriello, and T. G. Rizzo, J. High Energy Phys. 09 (2002) 030.
[8] K. Agashe *et al.*, J. High Energy Phys. 08 (2003) 050.
[9] C. Csaki *et al.*, Phys. Rev. Lett. **92**, 101802 (2004); Phys. Rev. D **70**, 015012 (2004).
[10] Y. Nomura, J. High Energy Phys. 11 (2003) 050.
[11] There is also a limit on how close t_R can be to the TeV brane since its custodial isospin partner becomes too light, which leads to phenomenological problems. Thus this cannot be used to enhance the top Yukawa coupling [8].
[12] G. Burdman and Y. Nomura, Phys. Rev. D **69**, 115013 (2004).
[13] For an earlier RS1 study with low KK masses, see G. Burdman, Phys. Lett. B **590**, 86 (2004). It differs from our work since hierarchies in the 5D Yukawas were allowed and constraints from $Z \to b\bar{b}$ were *not* correlated with the FCNC analysis.
[14] Particle Data Group Collaboration, K. Hagiwara *et al.*, Phys. Rev. D **66**, 010001 (2002).
[15] G. Eyal, Y. Nir, and G. Perez, J. High Energy Phys. 08 (2000) 028.
[16] K. Agashe, "Workshop on a B Factory at 10^{36} Luminosity," SLAC, 2003 (to be published).
[17] T. Hurth, Rev. Mod. Phys. **75**, 1159 (2003); A. Ghinculov *et al.*, Nucl. Phys. **B685**, 351 (2004); for a recent experimental review, see M. Nakao, Int. J. Mod. Phys. A **19**, 934 (2004).
[18] C. S. Kim *et al.*, Phys. Rev. D **67**, 015001 (2003).
[19] D. Atwood, M. Gronau, and A. Soni, Phys. Rev. Lett. **79**, 185 (1997); *BABAR* Collaboration, B. Aubert *et al.*, arXiv:hep-ex/0405082 [Phys. Rev. Lett. (to be published)].
[20] M. Gronau *et al.*, Phys. Rev. Lett. **88**, 051802 (2002).
[21] N. Arkani-Hamed, M. Porrati, and L. Randall, J. High Energy Phys. 08 (2001) 017.