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$B_{s,d} \to \gamma\gamma$ decay in the model with one universal extra dimension

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Abstract

We estimate the beyond the Standard Model (SM) contribution to the $B_{s,d} \to \gamma\gamma$ double radiative decay in the framework of the model with one universal extra dimension. This contribution gives a $\sim 3(6)\%$ enhancement of the branching ratio calculated in the SM for $B_{s(d)} \to \gamma\gamma$ (without QCD corrections).

1. Introduction

The exploration of B-physics, including rare decays of B-mesons, are one of the central issues of the physics programs at running and forthcoming accelerator facilities. The process $B_{s,d} \to \gamma\gamma$, which is the subject of this Letter, has a clean experimental signature: the final photons will be easily detected in the experiments. It would be noted that the two final photons produced in this process may be both in a CP-even state and in a CP-odd one. This circumstance provides a nonconventional source for CP-violation in B-physics. In general, the process $B_{s,d} \to \gamma\gamma$ is sensitive to effects beyond the Standard Model (SM). The above-mentioned experimental interest stimulates efforts of theoretical groups as well [1–18]. More precisely, $B_{s,d} \to \gamma\gamma$ was calculated in the framework of the SM with and without QCD corrections, in multi-Higgs doublet models, and in supersymmetric models.

It is known that in the SM the double radiative decays of the $B_{s,d}$ mesons, $B_{s,d} \to \gamma\gamma$, first arise at the one-loop level with the exchange in the loops by up-quarks and W-bosons. Branching ratios for above decays are of the order of $\sim 10^{-7}(10^{-9})$ in frame of the SM.

On the other hand there is possibility to enhance above mentioned decays in extended versions of the SM. It was shown that in extended versions of the SM (multi-Higgs doublet models, supersymmetric models) one could reach a branching ratio as large as $\mathrm{Br}(B_s \to \gamma\gamma) \sim 10^{-6}$ depending on the parameters of the models. This enhancement was achieved mainly due to exchange of charged scalar Higgs particles within the loop. There exists an analogous possibility in other exotic models as well for the scalar particle exchange inside the loop, which could potentially enhance this process. For example, the Appelquist, Cheng and Dobrescu (ACD) model with only one universal extra dimension [19] presents us with such an opportunity. One should note that in the above approach towers of charged Higgs particles arise as real objects with certain masses, not as fictitious (ghost) fields.

In this Letter we aim to calculate the contributions from these real scalars to the $B_{s,d} \to \gamma\gamma$ decay. The article is organized as follows: in Section 2 some useful information about the ACD model, necessary for the calculations, is provided. Section 3 is devoted to the calculation of the pertinent amplitudes. In Section 4, numerical estimates of the branching ratios are discussed.

2. Useful information on the structure of the ACD-model

The modern models [19–23] with extra space–time dimensions have received a great deal of attention because the scale at

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which extra dimensional effects can be relevant could be around a few TeV. The first proposal for using large (TeV) extra dimensions in the SM with gauge fields in the bulk and matter localized on the orbifold fixed points was developed in Ref. [24]. Models with extra space–time dimensions can be constructed in several ways. Among them the following major approaches are most remarkable: (i) the ADD model of Arkani-Hamed, Dimopoulos and Dvali [20]; in this approach all elementary particles except the graviton are localized on the brane, while the graviton propagates in the whole bulk; (ii) the RS model of Randall and Sundrum with a warped 5-dimensional space–time and a nonfactorized geometry [22,23]; (iii) the ACD model of Appelquist, Cheng and Dobrescu (so-called Universal Extra Dimensional Model), where all the particles move in the whole bulk [19]. It is this latter type of model that we will consider in the following.

In the Universal Extra Dimension (UED) scenarios all the fields presented in the SM live in extra dimensions, i.e. they are functions of all space–time coordinates. For bosonic fields one simply replaces all derivatives and fields in the SM Lagrangian by their 5-dimensional counterparts. These are the $U(1)_Y$- and $SU(2)_L$-gauge fields as well as the $SU(3)_C$-gauge fields from the QCD-sector. The Higgs doublet is chosen to be even under P_5 (P_5 is a parity operator in the five-dimensional space) and possesses a zero mode. Note that all zero modes remain massless before the Higgs mechanism is applied. In addition we should note that as a result of the action of the parity operator the fields receive additional masses $\sim n/R$ after dimensional reduction and transition to the four-dimensional Lagrangians.

In the five-dimensional ACD model the same procedure for gauge fixing is possible as in the models in which fermions are localized on the 4-dimensional subspace. With the gauge fixed, one can diagonalize the kinetic terms of the bosons and finally derive expressions for the propagators. Compared to the SM, there are additional Kaluza–Klein (KK) mass terms. As they are common to all fields, their contributions to the gauge boson mass matrix is proportional to the unity matrix. As a consequence, the electroweak angle remains the same for all KK-modes and is the ordinary Weinberg angle θ_W. Because of the KK-contribution to the mass matrix, charged and neutral Higgs components with $n \neq 0$ (n being the number of the KK-mode) no longer play the role of Goldstone bosons. Instead, they mix with $W_5^\pm$ and Z_5 to form, in addition to the Goldstone modes $G^0_{(n)}$ and $G^\pm_{(n)}$, three additional physical states $a^0_{(n)}$ and $a^\pm_{(n)}$. It is precisely the role of these additional charged physical states to double radiative neutral B-meson decays that is studied in this Letter.

The Lagrangian responsible for interaction of charged scalar KK towers $a^*_{(n)}$ with the ordinary down quarks reads

$$\mathcal{L} = \frac{g_2}{\sqrt{M_{(n)}}} \bar{Q}_{i(n)} \big(C_L^{(1)} P_L + C_L^{(1)}\big) a^*_{(n)} d_j + \frac{g_2}{\sqrt{M_{(n)}}} \bar{U}_{i(n)} \big(C_L^{(2)} P_L + C_L^{(2)}\big) a^*_{(n)} d_j, \tag{1}$$

utilizing the following notations [25]:

$$C_L^{(1)} = -m_3^{(i)} V_{ij}, \qquad C_L^{(2)} = m_4^{(i)} V_{ij},$$
$$C_R^{(1)} = M m_3^{(i,j)} V_{ij}, \qquad C_R^{(2)} = -M_4^{(i,j)} V_{ij},$$
$$M^2_{W(n)} = m^2\big(a^*_{(n)}\big) = M_W^2 + \frac{n^2}{R^2}, \tag{2}$$

where V_{ij} are elements of the CKM matrix. The mass parameters in Eq. (2) are defined as

$$m_3^{(i)} = -M_W c_{i(n)} + \frac{n}{R}\frac{m_i}{M_W} s_{i(n)},$$
$$m_4^{(i)} = M_W s_{i(n)} + \frac{n}{R}\frac{m_i}{M_W} c_{i(n)},$$
$$M_3^{(i,j)} = \frac{n}{R}\frac{m_j}{M_W} c_{i(n)},$$
$$M_4^{(i,j)} = \frac{n}{R}\frac{m_j}{M_W} s_{i(n)}. \tag{3}$$

Here, M_W and the masses of up (down)-quarks m_i (m_j) in the right-hand side of Eq. (3) are zero mode masses and the $c_{i(n)}$, $s_{i(n)}$ stand for the cos and sin of the fermions mixing angles, respectively,

$$\tan 2\alpha_{f(n)} = \frac{m_f}{n/R}, \quad n \geqslant 1. \tag{4}$$

The masses for the fermions are calculated as

$$m_{f(n)} = \sqrt{\frac{n^2}{R^2} + m_f^2}. \tag{5}$$

In the phenomenological applications we use the restriction $n/R \geqslant 250$ GeV and hence we assume that all the fermionic mixing angles except $\alpha_{t(n)}$ are equal zero.

3. Structure of $B_{s,d} \to \gamma\gamma$ in the ACD model with one extra dimension

The Feynman graphs, describing the contributions of scalar physical states to process under consideration, are shown in Fig. 1.

The amplitude for the decay $B_{s,d} \to \gamma\gamma$ has the form

$$T(B \to \gamma\gamma) = \epsilon_1^\mu(k_1)\epsilon_2^\nu(k_2)\big[A g_{\mu\nu} + i B \epsilon_{\mu\nu\alpha\beta} k_1^\alpha k_2^\beta\big]. \tag{6}$$

This equation is correct after gauge fixing for the final photons which we have chosen as

$$\epsilon_1 \cdot k_1 = \epsilon_2 \cdot k_2 = \epsilon_1 \cdot k_2 = \epsilon_2 \cdot k_2 = 0, \tag{7}$$

where ϵ_1 and ϵ_2 are photon polarization vectors, respectively. The condition Eq. (7) together with energy–momentum conservation leads to

$$\epsilon_i \cdot P = \epsilon_i \cdot p_1 = \epsilon_i \cdot p_2 = 0, \tag{8}$$

where

$$P = k_1 + k_2 \quad \text{and} \quad p_1 = p_2 + k_1 + k_2. \tag{9}$$

Let us write down some useful kinematical relations which are