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$\bar{B} \to X_s \gamma$ with a warped bulk Higgs

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Abstract

We study the decay $\bar{B} \to X_s \gamma$ in Randall–Sundrum models with an IR-localised bulk Higgs. The two models under consideration are a minimal model and a model with a custodial protection mechanism. We include the effects of tree- and one-loop diagrams involving 5D gluon and Higgs exchanges as well as QCD corrections arising from the evolution from the Kaluza–Klein scale to the typical scale of the decay. We find the RS corrections to the branching fraction can be sizeable for large Yukawas and moderate KK scales T; for small Yukawas the RS contribution is small enough to be invisible in current experimental data.

1. Introduction

One of the best studied processes in flavour physics is the inclusive radiative $\bar{B} \to X_s \gamma$ decay. On the experimental side numerous experiments [1–8] provide an ever increasing amount of data; leading to the current HFAG average [9] of

$$\mathrm{Br}(\bar{B} \to X_s \gamma)^{exp}_{E_\gamma > 1.6\,\mathrm{GeV}} = (342 \pm 21 \pm 7) \times 10^{-6}\,, \tag{1}$$

where all contributing experimental results were converted as to correspond to a lower photon energy cut of 1.6 GeV. A further improvement of this number can be anticipated: the Belle II

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experiment is expected to be able to measure the branching fraction with an uncertainty of about 6% [10].

On the theory side, the fact that the rare radiative decay provides both powerful check for the Standard Model (SM) of particle physics and is sensitive to physics beyond the SM (BSM) fuelled a tremendous effort (see e.g. [11–14] and the references therein) to understand the intricacies of the $b \to s\gamma$ transition. The most recent result [15] is given by

$$\text{Br}(\bar{B} \to X_s\gamma)^{th}_{E_\gamma > 1.6\,\text{GeV}} = (336 \pm 23) \times 10^{-6}\,. \tag{2}$$

It is in very good agreement with experiment, cp. (1), and therefore provides non-trivial constraints to any New Physics model that can generate additional flavour-changing neutral currents (FCNCs).

Extra-dimensional models of the Randall–Sundrum (RS) type [16] are known to have a particularly rich flavour phenomenology and can, despite an inherent protection mechanism [17], give rise to sizeable FCNCs. The characteristic five-dimensional metric of RS models can be written as

$$ds^2 = \left(\frac{1}{kz}\right)^2 \left(\eta_{\mu\nu} dx^\mu dx^\nu - dz^2\right), \tag{3}$$

in conformal coordinates. Here $k = 2.44 \cdot 10^{18}$ GeV is of order of the Planck scale M_{Pl}. The fifth coordinate z is restricted to the interval $[1/k, 1/T]$. The boundaries $z = 1/k$ and $z = 1/T$ are typically referred to as Planck and IR brane respectively. The a priori arbitrary scale T is assumed of the order of a TeV in order to alleviate gauge-gravity hierarchy issues [18].

One of the main reasons for the popularity of these models is the interplay of (SM) flavour and properties of 5D wave functions [19–21]. In particular, mass and CKM hierarchies can be related to the strength of the Planck or IR brane localisation of the corresponding KK zero-mode wave functions [22]. This intimate relationship of geometry and flavour makes the study of flavour physics observables all the more intriguing. For most processes like meson mixing [23,24] or electroweak pseudo-observables [25–27] the RS contribution arises (to leading order) from tree-level corrections to dimension-six operators, e.g., four-quark operators in the case of meson mixing.

In the last few years loop-induced processes, that is processes that to leading order do not receive contributions from tree-level diagrams in RS models, have been studied quite extensively. Observables that have been investigated include $\mu \to e\gamma$ [28–30], $(g-2)_\mu$ [31,32], Higgs production and decay [33–38] as well as $c \to u\gamma$ and $c \to ug$ [39]. The latter process just as $\mu \to e\gamma$ receives contributions from Kaluza–Klein (KK) states of the Higgs (in models where these are present). The subtleties involving their determination have only recently been pointed out [40].

The decay $\bar{B} \to X_s\gamma$ has been studied previously in the context of RS models in [41] in the 5d picture and in [42] using a Kaluza–Klein mode decomposition. [42] maintains its focus on the decay $\bar{B} \to K^* \mu^+ \mu^-$. Both works consider only the dominant effects of 5D penguin diagrams and neglect the so-called wrong-chirality Higgs couplings terms [28,43]. This is equivalent to an RS model with a naively brane-localised Higgs that does not arise from a well-defined limiting procedure.

In this letter we want to consider the case of a bulk Higgs field. This scenario is quite general as it requires us to take into account both Higgs and KK Higgs contributions. In order to keep the advantages of the original setup, we still impose that the bulk Higgs is strongly IR localised.