

# Constraining the $Z'bs$ coupling from the $B \rightarrow X_s \gamma$ decay

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**Abstract.** The  $Z'$  one-loop effects on the flavor-violating  $b \rightarrow s \gamma$  process are analyzed. We employed the sequential  $Z$  model in order to establish a bound for the flavor-violating  $Z'bs$  coupling,  $|\Omega_{bs}|^2$ . We found a bound of the order of  $10^{-1}$  for the mentioned coupling in the mass range  $2 \text{ TeV} < m_{Z'} < 3 \text{ TeV}$ .

## 1. Introduction

The presence of a new neutral massive gauge boson ( $Z'$ ) is predicted in the context of numerous extensions of the Standard Model (SM). The  $SU_C(3) \times SU_L(2) \times U_Y(1) \times U'(1)$  extended electroweak gauge group is the simplest model that predicts the existence of the  $Z'$  boson [1, 2]. Although absent in the SM, the phenomenon of flavor violation can arise in many of its well-motivated extensions. One interesting feature of most models beyond the SM is the presence of generalized Yukawa sectors or generalized current sectors, which favor nondiagonal transitions mediated by neutral massive particles of spin-0 or spin-1 [1, 2]. Currently, experimental data have proven the existence of neutrino oscillations, which in simple words, tell us that lepton flavor conservation is violated in nature. However, the only signal of lepton flavor violation comes from transitions between neutral leptons. Thus, flavor violating transitions between charged fermions constitute an interesting subject of study, since if they occur in nature are additional evidence of flavor violation.

The purpose of this work is to study the effect of quark flavor violation mediated by the  $Z'$  boson on the  $b \rightarrow s \gamma$  process, exploiting the rich phenomenology that offers the meson weak decays. Theoretically, it has been shown that this decay is highly sensitive to possible new physics effects in different contexts [3]. Thus, the main goal in this work is to estimate numerically the strength of the  $Z'bs$  coupling from the  $b \rightarrow s \gamma$  decay. However, it is well known that this process can not be tackled in isolation, but must be considered as part of the meson decay  $B \rightarrow X_s \gamma$ .

## 2. The flavor-violating Lagrangian

We consider the most general renormalizable Lagrangian, which includes the lepton flavor violation mediated by a new neutral massive gauge boson, coming from any extended or grand



unification model [2]. This Lagrangian can be written as

$$\begin{aligned} \mathcal{L}_{NC} = \sum_{i,j} \left[ \bar{f}_i \gamma^\alpha (\Omega_{L f_i f_j} P_L + \Omega_{R f_i f_j} P_R) f_j \right. \\ \left. + \bar{f}_j \gamma^\alpha (\Omega_{L f_j f_i}^* P_L + \Omega_{R f_j f_i}^* P_R) f_i \right] Z'_\alpha, \end{aligned} \quad (1)$$

where  $f_i$  is any fermion of the SM and  $Z'_\alpha$  is the neutral gauge boson predicted by several extensions of the SM [1, 4, 5, 6]. The parameters  $\Omega_{L q_i q_j}$  and  $\Omega_{R q_i q_j}$  represent the strength of the coupling  $Z' q_i q_j$ , where  $q_i$  is any quark of the SM.

In the context of sequential  $Z$  model, the diagonal couplings of the  $Z'$  boson with pairs of fermions are parameterized by  $Q_{L,R}^{f_i}$  [7, 8], and are related to the coupling parameters  $\Omega$  as follows:  $\Omega_{L f_i f_i} = -g_2 Q_L^{f_i}$  and  $\Omega_{R f_i f_i} = -g_2 Q_R^{f_i}$ . Here,  $g_2$  is the gauge coupling of the  $Z'$  boson given as

$$g_2 = \frac{g}{\cos \theta_W}, \quad (2)$$

where  $\theta_W$  is the weak mixing angle.

The vertices associated with flavor-violating ( $Z' f_i f_j$ ) and flavor-conserving ( $Z' f_i f_i$ ) couplings can be extracted from the Lagrangian given in Eq. (1):

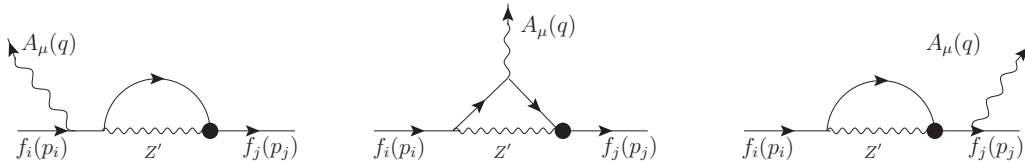
$$\gamma^\alpha (\Omega_{L f_i f_j} P_L + \Omega_{R f_i f_j} P_R) \quad (3)$$

and

$$-g_2 \gamma^\alpha (Q_L^{f_i} P_L + Q_R^{f_i} P_R). \quad (4)$$

### 3. The $b \rightarrow s\gamma$ decay

The contribution of the flavor-violating coupling,  $Z'bs$ , to the  $b \rightarrow s\gamma$  decay is calculated from Feynman diagrams shown in Figure 1. The tensorial amplitude of the  $b \rightarrow s\gamma$  process was obtained through FeynCalc program by using the Passarino-Veltman reduction scheme. Once applied the Gordon identities and contracting with the photon polarization vector, the tensorial amplitude for the  $b \rightarrow s\gamma$  decay is reduced to



**Figure 1.** Feynman Diagrams contributing to the  $b \rightarrow s\gamma$  decay.

$$\begin{aligned} \mathcal{M}_{\text{Tot}}^\mu = \frac{ie g_2 Q_{f_i}}{64\pi^2 m_i} \bar{u}(p_j) \sigma^{\mu\alpha} q_\alpha \epsilon_\mu(q) \left[ F_1(Q_L^{f_i} - Q_R^{f_i})(\Omega_{L f_i f_j} - \Omega_{R f_i f_j}) \right. \\ + F_2(Q_L^{f_i} \Omega_{L f_i f_j} + Q_R^{f_i} \Omega_{R f_i f_j}) + \left( F_1(Q_L^{f_i} - Q_R^{f_i})(\Omega_{L f_i f_j} + \Omega_{R f_i f_j}) \right. \\ \left. + F_2(Q_L^{f_i} \Omega_{L f_i f_j} - Q_R^{f_i} \Omega_{R f_i f_j}) \right) \gamma^5 \Big] u(p_i), \end{aligned}$$

where

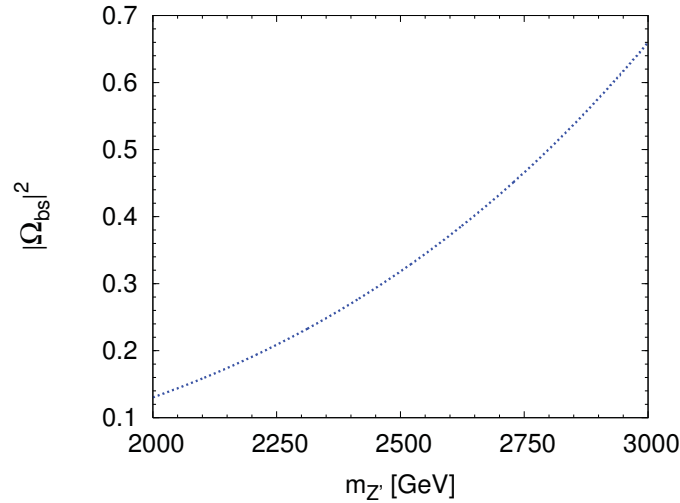
$$F_1 = \frac{m_i^2}{m_{Z'}^2} - 6 \left( B_0(0) - B_0(1) \right),$$

$$F_2 = 2 \left[ 1 + 2 \left( C_0(1) m_i^2 + \frac{m_{Z'}^2}{m_i^2} \left( B_0(0) - B_0(1) \right) \right) \right],$$

with  $Q_{f_i} = 1/3$ . Also,  $B_0(0) \equiv B_0(0, m_i^2, m_{Z'}^2)$ ,  $B_0(1) \equiv B_0(m_i^2, m_i^2, m_{Z'}^2)$  y  $C_0(1) \equiv C_0(m_i^2, 0, 0, -m_i^2, m_{Z'}^2, m_i^2)$  are the Passarino-Veltman scalar functions. The tensorial amplitude presented above is free of ultraviolet divergences because the functions  $B_0$  are mutually subtracted. Moreover, it becomes evident the explicit gauge invariance, since this amplitude is of dipolar type and whenever it is contracted with the photon momentum tensor,  $q_\mu$ , the simple Ward identity is satisfied.

#### 4. Calculation of the $Z'bs$ coupling

In order to obtain the strength of the  $Z'bs$  coupling, we use the discrepancy between the SM theoretical prediction and experimental measurement on the  $B \rightarrow X_s \gamma$  process to quantify possible effects of new physics that might be in this gap [9]. Such a mismatch is identified by the following hypothesis



**Figure 2.** Strength of the  $Z'bs$  coupling as a function of the  $Z'$  boson mass.

$$R_{TOT-ME} \approx R_{EXP-ME} = \frac{\Gamma_{ME+NF} - \Gamma_{ME}}{\Gamma_{ME}} = \frac{Br_{ME+NF}}{Br_{ME}} - 1, \quad (5)$$

where  $\Gamma_{EXP}$  is the experimental decay width of the process and  $\Gamma_{ME}$  is the theoretical prediction of the SM <sup>1</sup>. Also,  $Br_{EXP}$  and  $Br_{ME}$  are the associated decay fractions, respectively. By making use of the experimental results found by the collaborations BABAR, Belle and CLEO, along with the analysis of the Heavy Flavor Averaging Group [9], we have that  $Br(B \rightarrow X_s \gamma) = (3.52 \pm 0.23 \pm 0.09) \times 10^{-4}$ , which should be contrasted with the theoretical

<sup>1</sup> Since this contribution was presented, an updated evaluation of this observable at NNLO in QCD became available [14], making the bound more restrictive and thus favouring heavier LFV  $Z'$  bosons than here considered.

prediction in the SM:  $Br(B \rightarrow X_s \gamma) = (3.15 \pm 0.23) \times 10^{-4}$  [10]. This implies that the discrepancy between theory and experiment is  $R_{EXP-ME} = 0.117 \pm 0.113$  [11]. To restrict the strength of the  $Z'bs$  coupling we assume that the total theoretical prediction agrees with the experimental value. Details of calculation of the contributions of the  $b \rightarrow s \gamma$  process on the decay  $B \rightarrow X_s \gamma$  can be found in Ref. [12].

The graph of the intensity of the  $Z'bs$  coupling as a function of the mass of the  $Z'$  boson is shown in Fig. 2. It can be seen that the intensity of the parameter  $|\Omega_{bs}|^2$  increases as  $Z'$  boson mass grows up; the mass range studied corresponds to  $2 \text{ TeV} < m_{Z'} < 3 \text{ TeV}$ , which is consistent with the experimental bound on the  $Z'$  mass reported by experimental collaborations ATLAS and CMS [13]. It is clear that this is not a restrictive bound, since  $|\Omega_{bs}|^2$  is of order  $10^{-1}$  and it is an unfavorable scenario to search for new physics.

## 5. Conclusions

We calculated the analytical expression of the amplitude associated with the  $b \rightarrow s \gamma$  process that violates flavor, which is mediated by a neutral boson called  $Z'$ . We obtained a result which is free of ultraviolet divergences and consistent with the decoupling theorem. We estimated the intensity of the  $Z'bs$  coupling as a function of the  $Z'$  boson mass. By making use of the experimental measurement for the branching ratio of the  $B \rightarrow X_s \gamma$  decay it was calculated a bound for the  $|\Omega_{bs}|^2$  parameter, which is about  $10^{-1}$  for the mass range  $2 \text{ TeV} < m_{Z'} < 3 \text{ TeV}$ . The bound estimated results poorly restrictive.

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