

**FOURTH GENERATION EFFECTS ON  $B \rightarrow X_s \gamma$  DECAY****Levent SOLMAZ****Balıkesir University Faculty of Art and Sciences Department of Physics  
Balıkesir, TURKEY****Email:leventsolmaz@yahoo.com****ABSTRACT**

Using the theoretical and experimental results for  $B \rightarrow X_s \gamma$ , a four-generation SM is analyzed to restrict the combination of the  $4 \times 4$  Cabibbo-Kobayashi-Maskawa factor  $V_{t's}^* V_{tb}$  as a function of the  $t'$  quark mass. It is observed that the results for the above mentioned physical quantities are essentially different from the previous predictions of the literature. Influences of the new model are used to predict CP violation in  $B \rightarrow X_s \gamma$  decay at the order of  $A_{CP} = 5\%$ , stemming from the appearance of complex phases in  $V_{t's}^* V_{tb}$  and of Wilson coefficients  $C_7, C_8$ , in the related process. The above mentioned physical quantities can serve as the efficient tools in the search of the fourth generation.

**Keywords:** B Decay, Fourth Generation, QCD Corrections.**ÖZET**

$B \rightarrow X_s \gamma$  bozunumuna ait teorik ve deneysel sonuçları kullanarak dört-nesilli Standart Model analiz edilerek  $4 \times 4$  Cabibbo-Kobayashi-Maskawa faktörü  $V_{t's}^* V_{tb}$ ,  $t'$  kuarkının kütesine bağlı olarak sınırlandırılmıştır. Literatürdeki sonuçlarla yukarıda adı geçen nicelikler için elde edilen değerlerin farklı olduğu gözlenmiştir. Yeni modelin  $B \rightarrow X_s \gamma$  bozunumundaki CP kırılımı varsayımı yaklaşık olarak  $A_{CP} = 5\%$  düzeyindedir, bunun sebebi Wilson katsayıları  $C_7, C_8$  ve  $V_{t's}^* V_{tb}$  için ortaya çıkan kompleks fazlardır. Yukarıda adı geçen fiziksel nicelikler dördüncü nesil araştırmalarında etkili olarak kullanılabilirler.

**Anahtar Kelimeler:** B Bozunumu, Dördüncü Nesil, QCD Düzeltmeleri.

## 1- INTRODUCTION

It is well known that despite the success of the Standard Model (SM), from the theoretical point of view, it is incomplete. Since SM does not have a restriction on the number of fermions, generation issue can be mentioned as one of the open problems of the SM, for which we do not have a clear argument to restrict the SM to three known generations. As a matter of fact, mass of the extra generations, if ever exists, can be extracted from the measurements of neutrino experiments, which set a lower bound for extra generations of neutrinos ( $m_{\nu 4} > 45 \text{ GeV}$ ) (1).

The idea of generalizing SM is not new. Probable effects of the extra generations are extensively studied in many works (2–10). Generalizations of the SM can be used to introduce a new family, which was performed previously by using similar techniques, one can search the fourth generation effects in B meson decays. The existing electroweak data on the Z–boson parameters, the W boson and the top quark masses excluded the existence of the new generations with all fermions heavier than the Z boson mass, nevertheless, the same data allows few extra generations, if neutral leptons have masses close to 50 GeV. In addition to this, the recently observed neutrino oscillations require an enlarged neutrino sector, which also forces one to look at quark sector. From this respect,  $B \rightarrow X_s \gamma$  decay is one of the most appropriate candidates to be searched in the extensions of SM, since we have the solid experimental and theoretical background for the process under consideration. As it is well known, the new physics effects can manifest themselves through the Wilson coefficients and their values can be different from the ones in the SM (10-13), as well as through the new operators. Note that the inclusive  $B \rightarrow X_s \gamma$  decay has already been studied with the inclusion of the fourth generation to constrain  $V_{ts}^* V_{tb}$  at the leading order (LO) (12). The restrictions of the parameter space of the nonstandard models based on LO analysis are not as sensitive as in case of next to leading order (NLO) analysis. Therefore, we prefer to work at NLO, for the decay under consideration.

On the experimental side, values related with  $B \rightarrow X_s \gamma$  are well known. First, the measurement of the  $B \rightarrow X_s \gamma$  was performed by CLEO collaboration, leading to CLEO branching ratio (14)

$$B \rightarrow X_s \gamma = (2.32 \pm 0.57 \pm 0.35) \times 10^{-4}. \quad (1)$$

In 1999, CLEO has presented an improved result

$$B \rightarrow X_s \gamma = (3.15 \pm 0.35 \pm 0.32 \pm 0.26) \times 10^{-4}. \quad (2)$$

The errors are statistical, systematic, and model dependent, respectively. The rate measured by ALEPH is consistent with the CLEO measurement (15). There exists also the result of BELLE with a larger central value (16):

$$B \rightarrow X_s \gamma = (3.37 \pm 0.53 \pm 0.42 \pm 0.54) \times 10^{-4}. \quad (3)$$

In addition to the measured branching ratios, observing CP asymmetry in the decay  $B \rightarrow X_s \gamma$  is presented by CLEO collaboration is interesting,

$$A_{CP}(B \rightarrow X_s \gamma) = (-0.079 \pm 0.108 \pm 0.022) \times (1.0 \pm 0.030), \quad (4)$$

for which prediction of the SM is around 0.6 %.

On the theoretical side, the situation within and beyond the SM is well settled. A collective theoretical effort has led to the practical determination of  $B \rightarrow X_s \gamma$  at the NLO, which was completed recently as a joint effort of many different groups (17-22). For a review, as to the complete computation of the NLO QCD corrections, we refer to Ref. (19) and references therein. It is also necessary to have the precise calculations also in the extensions of the SM, which is performed for certain models.

In this work, we study the contribution of the fourth generation in the rare  $B \rightarrow X_s \gamma$  decay to obtain the constraints on the parameter space of the fourth generation. Our basic assumption is to fill the gap between the theoretical and experimental results of  $B \rightarrow X_s \gamma$  with the fourth generation, once constraints are obtained emerging CP asymmetry is interesting even when the SM contribution is turned off.

With the appearance of the more accurate data, we will be able to provide the stringent constraints on the free parameters of the models beyond SM which is also true for the fourth generation case. We can state that the aim of the present paper is to obtain such certain constraints when the fourth generation case is considered. The paper is organized as follows. In section 2, we present the necessary theoretical expressions for the  $B \rightarrow X_s \gamma$  decay in the SM with four generations, where we investigated the effect of the introduction of the fourth generation at different scales upon branching ratio and CP asymmetry. Section 3 is devoted to the numerical analysis and our conclusion.

## 2- THEORETICAL RESULTS

We use the framework of an effective low-energy theory, obtained by integrating out heavy degrees of freedoms, which in our case are W-boson, top quark and an additional  $t'$  quark. Mass of the  $t'$  is at the order of  $m_W$ . In this approximation, the effective Hamiltonian relevant for  $B \rightarrow X_s \gamma$  decay reads (21)

$$H^{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^8 C_i(\mu) O_i(\mu), \quad (5)$$

where  $G_F$  is the Fermi coupling constant,  $V$  is the ordinary  $3 \times 3$  Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix, the full set of the operators  $O_i(\mu)$  and the

corresponding expressions for the Wilson coefficients  $C_i(\mu)$  in the SM can be found in Ref.(19). In the model under consideration, the fourth generation is introduced in a similar way to the three generations as introduced in the SM. Thus, no new operators appear and clearly the full operator set is exactly the same as in SM. The fourth generation changes values of the Wilson coefficients  $C_7(\mu_W)$ ,  $C_8(\mu_W)$ , via virtual exchange of the fourth generation up quark  $t'$  at matching scale. Notice that if we introduce the fourth generation effects at a different energy scale, the results would not be the same. With the definition  $\lambda_{t'} = V_{t's}^* V_{tb}$ ,  $i = u, c, t$  and  $t'$ , the above mentioned Wilson coefficients can be written in the following form:

$$\begin{aligned} C_7^{\text{eff}}(\mu_W) &= C_7^{\text{SM}}(\mu_W) + \lambda_{t'}/\lambda_t C_7^{\text{New}}(\mu_W), \\ C_8^{\text{eff}}(\mu_W) &= C_8^{\text{SM}}(\mu_W) + \lambda_{t'}/\lambda_t C_8^{\text{New}}(\mu_W), \end{aligned} \quad (6)$$

where the last terms in these expressions describe the contributions of the  $t'$  quark to the Wilson coefficients, and  $V_{t's}$  and  $V_{tb}$  are the two elements of the  $4 \times 4$  Cabibbo–Kobayashi–Maskawa (CKM) matrix. The explicit forms of the  $C_{7,8}^{\text{New}}$  can easily be obtained from the corresponding Wilson coefficient expressions in SM by simply substituting  $m_t \rightarrow m_{t'}$ . Neglecting the  $s$ -quark mass, we can define the Wilson coefficients at the matching scale, with the following LO functions

$$\begin{aligned} C_7^{\text{SM}} &= \frac{x}{24} \frac{-8x^3 + 3x^2 + 12x - 7 + (18x^2 - 12x) \ln x}{(x-1)^4} \\ C_8^{\text{SM}} &= \frac{x}{8} \frac{-x^3 + 6x^2 - 3x - 2 - 6x \ln x}{(x-1)^4}, \end{aligned} \quad (7)$$

where ( $x = m_{t'}^2/m_W^2$ ). In the calculations, we used the NLO theoretical expressions, and different experimental values to constraint the  $\lambda_{t'}$  parameter of the fourth generation. Since the extended models are very sensitive to NLO corrections, we used the NLO expression for the branching ratio of the decay  $B \rightarrow X_s \gamma$ , which has been presented in Ref. (20):

$$\begin{aligned} \text{BR}(B \rightarrow X_s \gamma) &= \text{BR}(B \rightarrow X_c e \bar{\nu}_e) \left| \frac{V_{ts}^* V_{tb}}{V_{cb}} \right|^2 \frac{6\alpha_e}{\pi f(z) \kappa(z)} \frac{\bar{m}_b^2(\mu_b)}{m_b^2} \\ &\times (|D|^2 + A) \left( 1 - \frac{\delta_{\text{SL}}^{\text{NP}}}{m_b^2} + \frac{\delta_\gamma^{\text{NP}}}{m_b^2} + \frac{\delta_c^{\text{NP}}}{m_c^2} \right). \end{aligned} \quad (8)$$

Explicit forms of the virtual, bremsstrahlung and non-perturbative parts of Eq. (8) can be found in (20,21) and references therein. In the numerical analysis, we obtained  $B \rightarrow X_s \gamma$  branching ratio in the Standard Model  $\text{BR}(B \rightarrow X_s \gamma) = (3.48 \pm 0.33) \times 10^{-4}$ , which is in complete agreement with the literature. We consider only the central value in our analysis,

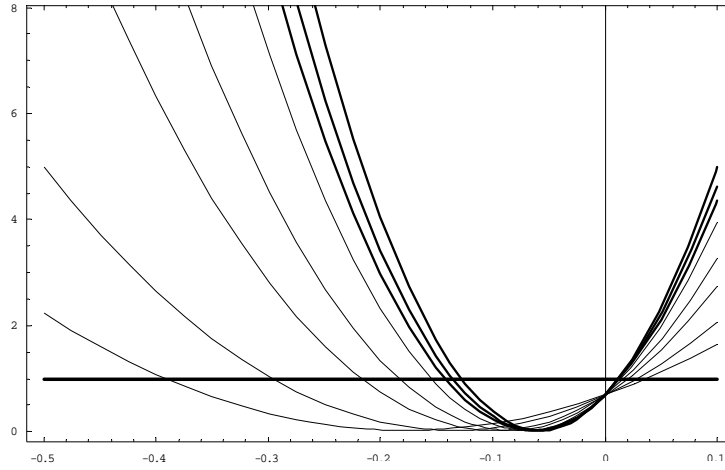
with the expectation of absorbing errors into the different experimental values. To obtain the quantitative results, we need the value of the fourth generation CKM matrix element  $\lambda_{t'}$ . For this aim following reference (22), we will use the experimental results of the decays  $\text{BR}(B \rightarrow X_s \gamma)$  and to determine the fourth generation CKM factor  $\lambda_{t'}$ . When we consider the possible effects of the fourth generation, we demand the theoretical value to be equal to the experimental values presented in the previous section, which can be summarized as

$$\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = \{2.66, 3.15, 3.37\}. \quad (9)$$

Theoretical results of the branching ratio for  $m_{t'} = 75, \dots, 500$  GeV values are obtained as a function of  $t'$ . Notice that in the expressions related with  $\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}}$ , the theoretical and experimental results are multiplied by a factor of  $10^4$ . For instance, when we chose  $m_{t'} = 75$  GeV,

$$\begin{aligned} \text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = & 0.65450 + 6.6996 \lambda_{t'} + 20.350 \lambda_{t'}^2 + 0.39625 | -0.30573 - 1.8782 \lambda_{t'}|^2 \\ & + 23.992 |(-0.34087 - 0.015407 i) - (1.6428 + 0.0544 i) \lambda_{t'}|^2. \end{aligned} \quad (10)$$

When  $t'$  is neglected, branching ratio reduces to the re-scaled central value (3.48) of SM prediction. During the calculations we obtained similar expressions for different  $m_{t'}$  values.



**Figure 1:**  $\text{BR}(B \rightarrow X_s \gamma)$  normalized to unity with the experimental value  $\text{BR}(B \rightarrow X_s \gamma) = 3.37$ , in order to extract values of  $\lambda_{t'}$ , for  $m_{t'} = 75, \dots, 500$  GeV with the increasing order of thickness, respectively. Constraints are obtained for Eq. (6), and can be inferred from the intersection points.

It suffices to present the case of a very heavy quark, for  $m_{t'} = 500$  GeV :

$$\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = 0.65450 + 20.986 \lambda_{t'} + 198.86 \lambda_{t'}^2 + 0.39625 | -0.30573 - 5.9562 \lambda_{t'}|^2$$

$$+23.992 |(-0.34087 - 0.015407 i) - (5.166 + 0.1189 i) \lambda_{t'}|^2. \quad (11)$$

In the numerical analysis, as a first step,  $\lambda_{t'}$  is assumed real and constraints are obtained as a function of the mass of the extra generation top-quark  $m_{t'}$ , and the values are presented in Tab.(1) and can be obtained from Fig.(1). Those values can also be extracted from the figure where the solution is the intersection point on the BR = 1 line. Notice that in the figure, we normalized branching ratio to unity, using the experimental value (3.37), hence  $\lambda_{t'}$  values can be obtained from the intersection points on the normalized line.

We also performed a similar analysis for introducing the fourth generation effects at the  $\mu_b$  scale to see the difference between the previous results. Following (22), it can be written as follows:

$$\begin{aligned} C_7^{\text{eff}}(\mu_b) &= C_7^{\text{SM}}(\mu_b) + \lambda_{t'} / \lambda_t C_7^{\text{New}}(\mu_b), \\ C_8^{\text{eff}}(\mu_b) &= C_8^{\text{SM}}(\mu_b) + \lambda_{t'} / \lambda_t C_8^{\text{New}}(\mu_b), \end{aligned} \quad (12)$$

Using Eq. (9) and demanding theoretical results to be equal to the experimental results again, we obtained the following expression for  $m_{t'} = 75$ :

$$\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = 0.6915 + 23.992 |(-0.3408 - 0.015407 i) - (8.130 + 0.4237 i) \lambda_{t'}|^2. \quad (13)$$

As another example for  $m_{t'} = 500$  we obtained

$$\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = 0.6915 + 23.992 |(-0.3408 - 0.015407 i) - (12.45 + 0.4845 i) \lambda_{t'}|^2. \quad (14)$$

It is interesting to notice that if we assume  $\lambda_{t'}$  can have imaginary parts, experimental values can also be satisfied. This case is presented with a graphical solution in figure (2) for  $m_{t'} = 75$  and the decomposition  $\lambda_{t'} = \lambda_{t'}^{\text{real}} + i \lambda_{t'}^{\text{imaginary}}$ . Real and imaginary parts of this approach is presented in Tables (2) and (3), respectively.

BR( $B \rightarrow X_s \gamma$ ) <sub>4th</sub> = $2.66 \times 10^{-4}$							
$m_{t'}(\text{GeV})$	75	100	150	200	300	400	500
$\lambda_{t'}^{(I)} \times 10^{-1}$	-3.63	-2.85	-2.04	-1.72	-1.42	-1.29	-1.22
$\lambda_{t'}^{(I)} \times 10^{-3}$	-1.01	-0.75	-0.54	-0.45	-0.37	-0.34	-0.32
BR( $B \rightarrow X_s \gamma$ ) <sub>4th</sub> = $3.15 \times 10^{-4}$							
$m_{t'}(\text{GeV})$	75	100	150	200	300	400	500

$\lambda_{t'}^{(I)} \times 10^{-1}$	-3.90	-2.90	-2.08	-1.74	-1.45	-1.31	-1.25
$\lambda_{t'}^{(I)} \times 10^{-3}$	-3.4	-2.5	-1.8	-1.5	-1.2	-1.1	-1.1
$\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = 3.37 \times 10^{-4}$							
$m_{t'}(\text{GeV})$	75	100	150	200	300	400	500
$\lambda_{t'}^{(I)} \times 10^{-1}$	-3.67	-2.73	-1.96	-1.63	-1.35	-1.23	-1.12
$\lambda_{t'}^{(I)} \times 10^{-3}$	-2.6	-1.9	-1.4	-1.1	-1.0	-0.9	-0.8

**Table 1:** The numerical (real parts only) values of  $\lambda_{t'}$  for different values of the  $m_{t'}$  quark mass and experimental values. The superscripts (I),..., (V I) correspond to the first and last solutions of Eq. (9) with the approximation of Eq. (12). In order to check the consistency of the results of present work, one can demand  $\lambda_{t'}$  values to satisfy the unitarity condition. If we impose the unitarity condition of the CKM matrix, we then have

$$\lambda_u + \lambda_c + \lambda_t + \lambda_{t'} = 0. \quad (15)$$

$\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = 2.66 \times 10^{-4}$							
$m_{t'}(\text{GeV})$	75	100	150	200	300	400	500
$\lambda_{t'}^{(I)} \times 10^{-2}$	-8.81	-7.03	-6.27	-5.85	-5.41	-5.17	-5.03
$\lambda_{t'}^{(I)} \times 10^{-3}$	-7.76	-6.18	-5.51	-5.13	-4.74	-4.53	-4.41
$\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = 3.15 \times 10^{-4}$							
$m_{t'}(\text{GeV})$	75	100	150	200	300	400	500
$\lambda_{t'}^{(I)} \times 10^{-2}$	-9.29	-7.41	-6.61	-5.70	-5.45	-5.30	-5.09
$\lambda_{t'}^{(I)} \times 10^{-3}$	-3.03	-2.41	-2.14	-1.99	-1.84	-1.76	-1.71
$\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = 3.37 \times 10^{-4}$							

$m_t (GeV)$	75	100	150	200	300	400	500
$\lambda_t^{(I)} \times 10^{-2}$	-9.49	-7.56	-6.74	-6.29	-5.81	-5.56	-5.41
$\lambda_t^{(I)} \times 10^{-3}$	-1.07	-0.84	-0.75	-0.69	-0.64	-0.61	-0.59

**Table 2:** The numerical values of  $\lambda_t$  for different values of the  $m_t$  quark mass and experimental values. The superscripts (I), ..., (V I) correspond to the first and last solutions of Eq. (9) with the approximation of Eq. (6). Notice that in this table, real values of  $\lambda_t$  are presented only. In Table 3, imaginary parts can be found.

With the values of the CKM matrix elements in the SM, the sum of the first three terms in Eq. (15) is about  $7.6 \times 10^{-2}$ , where the error in sum of first three terms is about  $\pm 0.6 \times 10^{-2}$ . By substituting the values of  $\lambda_t$  from Tables 1 and 2, we observe that the sum of the four terms on the left-hand side of Eq. (15) may get very close to zero or diverge from the prediction of SM. When  $\lambda_t$  is very close to the sum of the first three terms, but with opposite sign, this is a very desirable result. Using Table 2 for  $m_t = 100$  GeV and the experimental branching ratio ( $3.37 \times 10^{-4}$ ), our result reads  $\lambda_t = -7.56 \times 10^{-2}$ . On the other hand, the same prediction contains an imaginary part ( $-0.19 \times 10^{-2}$ ), which may be absorbed within the error range. In other words, the results presented in Table (2) satisfy the unitarity constrain to a good extend. Nevertheless, it is a matter of taste to accept or reject  $\lambda_t$  values, according to the unitarity condition. Because it is possible that, the existence of the extra generations can affect the present constraints on  $V_{CKM}$  to a certain extent,

$BR(B \rightarrow X_s \gamma)_{4th} = 2.66 \times 10^{-4}$							
$m_t (GeV)$	75	100	150	200	300	400	500
$\lambda_t^{(I)} \times 10^{-2}$	0.28	0.17	0.13	0.11	0.09	0.08	0.07
$\lambda_t^{(I)} \times 10^{-3}$	-0.17	-0.14	-0.13	-0.12	-0.11	-0.11	-0.10
$BR(B \rightarrow X_s \gamma)_{4th} = 3.15 \times 10^{-4}$							
$m_t (GeV)$	75	100	150	200	300	400	500



$\lambda_t^{(I)} \times 10^{-2}$	-0.31	-0.19	-0.15	-0.11	-0.09	-0.08	-0.07
$\lambda_t^{(I)} \times 10^{-3}$	-2.10	-1.68	-1.50	-1.41	-1.30	-1.25	-1.21
$\text{BR}(B \rightarrow X_s \gamma)_{4\text{th}} = 3.37 \times 10^{-4}$							
$m_t (\text{GeV})$	75	100	150	200	300	400	500
$\lambda_t^{(I)} \times 10^{-2}$	-0.32	-0.19	-0.15	-0.13	-0.11	-0.09	-0.09
$\lambda_t^{(I)} \times 10^{-3}$	-2.1	-1.6	-1.5	-1.4	-1.3	-1.24	-1.21

**Table 3:** Imaginary parts of  $\lambda_t$  values, presented in table 2.

The constrains may get relaxed, which is beyond the scope of this work. From this respect it is hard to claim that all results presented here can satisfy the unitarity. Nevertheless, in order to give the full picture, we did not exclude the regions that violate the unitarity condition.

### 2.1- DIFFERENCES IN THE DEFINITIONS OF $\lambda_t$

In order to explain the difference, between the results of the two different approaches given in Eq. (6) and Eq. (12) or Tables (1) and (2), we can perform the analysis in LO, to extract the value of the fourth generation CKM matrix element  $\lambda_t$ . Following (20), one can use the experimental results of the decays  $\text{BR}(B \rightarrow X_s \gamma)$  and  $\text{Br}(B \rightarrow X_c e \bar{\nu}_e)$ . In order to reduce the uncertainties arising from b quark mass, consider the following ratio:

$$R = \frac{\text{Br}(B \rightarrow X_s \gamma)}{\text{Br}(B \rightarrow X_c e \bar{\nu}_e)} \quad (16)$$

In the leading logarithmic approximation, this ratio can be written as

$$R = \alpha_m |C_7^{\text{eff}}(\mu_b)|^2 \quad (17)$$

where  $\alpha_m = \left| \frac{V_{ts}^* V_{tb}}{V_{cb}} \right|^2 \frac{6\alpha_e}{\pi f(z)\kappa(z)}$ , the phase factor  $f(\hat{m}_c)$  and  $O(\alpha_s)$ , QCD correction factor  $\kappa(z)$  of  $b \rightarrow cl\bar{\nu}$  are given in Ref.(23). Using the LO definition of  $C_7^{\text{eff}}(\mu_b)$ , one can write

$$C_7^{\text{eff}}(\mu_b) = \eta^{16/23} C_7^{\text{eff}}(\mu_w) + (\eta^{14/23} - \eta^{16/23}) C_8^{\text{eff}}(\mu_w) + C_2^{\text{eff}}(\mu_w) \sum_{i=1}^8 h_i \eta^{a_i} \quad (18)$$

For the present purpose, it can be written as

$$C_7^{\text{eff}}(\mu_b) = \eta_1 C_7^{\text{eff}}(\mu_W) + \eta_2 C_8^{\text{eff}}(\mu_W) + \eta_3 C_2^{\text{eff}}(\mu_W) \quad (19)$$

When the effect of 4th generation it is defined as in Eq. (12)

$$C_{7,8}^{\text{eff}}(\mu_b) = C_{7,8}^{\text{SM}}(\mu_b) + \lambda_{t'} / \lambda_t C_{7,8}^{\text{New}}(\mu_b), \quad (20)$$

The solution of Eq. (17) for  $\lambda_{t'}$  can be written as follows:

$$\lambda_{t'}^{\pm} = \left[ \pm \sqrt{\frac{R}{\alpha_m}} - C_7^{\text{SM}}(\mu_b) \right] \frac{\lambda_t}{C_7^{\text{New}}(\mu_b)}. \quad (21)$$

whereas in the case of the following approach ( Eq. (12))

$$C_{7,8}^{\text{eff}}(\mu_W) = C_{7,8}^{\text{SM}}(\mu_W) + \lambda_{t'} / \lambda_t C_{7,8}^{\text{New}}(\mu_W), \quad (22)$$

Eq. (21) is modified into the following form

$$\lambda_{t'}^{\pm} = \left[ \pm \sqrt{\frac{R}{\alpha_m}} - C_7^{\text{SM}}(\mu_b) \right] \frac{\lambda_t}{\eta_1 C_7^{\text{New}}(\mu_b) + \eta_2 C_8^{\text{New}}(\mu_b)}. \quad (23)$$

This analysis can also be performed for NLO expressions. By comparing Eq. (21) and Eq. (23) the difference in Tables (1) and (2) can be inferred. Notice that for Eq. (17) a complex solution can satisfy the equality, hence in addition to real solutions a complex phase should be taken into consideration, which is assumed at the order of  $10^{-2}$  of the real values.

## 2.2- DIRECT CP VIOLATION IN $B \rightarrow X_s \gamma$

Observation of CP violation in  $B \rightarrow X_s \gamma$  is attractive, because it could lead to a direct evidence related with the new physics. Theoretical predictions for  $B \rightarrow X_s \gamma$  can be written as

$$A_{\text{CP}}(B \rightarrow X_s \gamma) = \frac{\Gamma(\bar{B} \rightarrow X_s \gamma) - \Gamma(B \rightarrow X_s \gamma)}{\Gamma(\bar{B} \rightarrow X_s \gamma) + \Gamma(B \rightarrow X_s \gamma)}. \quad (24)$$

Numerically, prediction of the SM is (24)

$$A_{\text{CP}}(B \rightarrow X_s \gamma) \approx 0.6 \%, \quad (25)$$

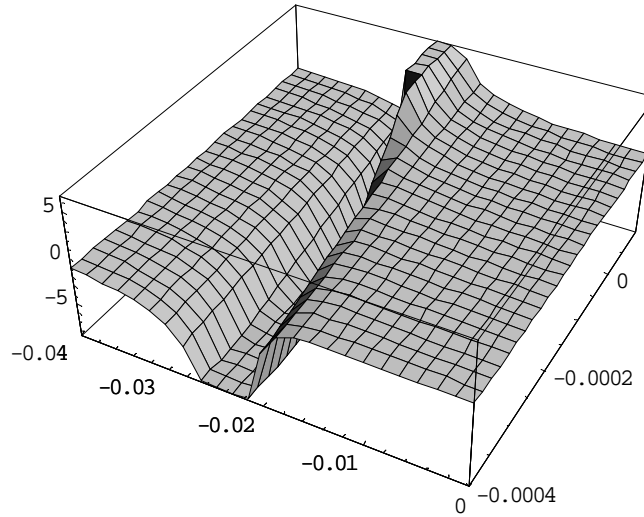
From the experimental side, we have the measurement of the CP asymmetry (25),

$$A_{\text{CP}}(B \rightarrow X_s \gamma) = (-0.079 \pm 0.108 \pm 0.022) \times (1.0 \pm 0.030), \quad (26)$$

We used the CP asymmetry expression to look for 4 generation effects,

$$A_{CP}(B \rightarrow X_s \gamma) = \frac{10^{-2}}{|C_7|^2} (1.17 \times \text{Im} [C_2 C_7^*] - 9.51 \times \text{Im} [C_8 C_7^*] + 0.12 \times \text{Im} [C_2 C_8^*] - 9.40 \times \text{Im} [\varepsilon_s C_2 (C_7^* - 0.013 C_8^*)]); \quad \varepsilon_s = \frac{V_{us}^* V_{ub}}{V_{ts}^* V_{tb}} \approx -\lambda^2 (\rho - i\eta). \quad (27)$$

The large coefficient of the second term in (27) is very attractive. We observed that the enhanced chromomagnetic dipole contribution ( $C_8$ ) induces a large direct CP violation in the decay  $B \rightarrow X_s \gamma$ . This is due to the complex phases of  $\lambda_{t'}$ , which in result affects  $C_7$ ,  $C_8$ . Such an enhancement of the chromo-magnetic contribution may lead to a natural explanation of the phenomenology of the semileptonic B decays and charm production in B decays. Notice that in Fig. (2), when the real values of  $\lambda_{t'}$  is around  $-6 \times 10^{-2}$ , the peak values for  $A_{CP}$  are observed.



**Figure 2:**  $A_{CP} \times [10^2]$  as a function of  $\lambda_{t'}$  with the experimental value  $\text{BR}(B \rightarrow X_s \gamma) = 3.37$  and the choice of  $m_{t'} = 400$  GeV. In the figure the x-axis represents  $\text{Re}[\lambda_{t'}]$  in the range  $[-0.04, 0]$ , for y-axis.  $\text{Im}[\lambda_{t'}]$  is in the range  $[-0.004, 0.001]$ . Notice that by respecting the current ( $V_{CKM}$ ) the imaginary phases are taken at the  $10^{-2}$  order of real values which can be accepted as a worst scenario.

### 3- CONCLUSION

To summarize, the  $B \rightarrow X_s \gamma$  decay has a clean experimental and theoretical base, very sensitive to the various extensions of the Standard Model, and can be used to constrain the fourth generation model. In the present work, this decay is studied in the SM with the

fourth generation model. The solutions of the fourth generation CKM factor  $\lambda_{t'}$  have been obtained, which could be used in other decays like  $B \rightarrow X_s l^+ l^-$ . It is observed that different choices of the factor  $\lambda_{t'}$ , could be very informative, especially due to new CP violation effects, in searching new physics. CP asymmetry in the  $B \rightarrow X_s \gamma$  decay can be enhanced up to 5 %, which is ten times larger compared to the SM prediction. Fourth generation can be used among the probes of new physics.

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