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Imprint of SUSY in radiative B-meson decays

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We study the Wilson coefficients (WCs) for the radiative B-meson decays $B \to X_s \gamma$ at the b-quark mass scale $C_7(\mu_b)$ and $C_7'(\mu_b)$ in the Minimal Supersymmetric Standard Model (MSSM) with general quark-flavour violation (QFV) due to squark-generation mixing. We calculate the supersymmetric(SUSY)-loop contributions to $C_7(\mu_b)$ and $C_7'(\mu_b)$ at leading order (LO) in the MSSM. *For the first time* we perform a systematic MSSM parameter scan for the WCs $C_7(\mu_b)$ and $C_7'(\mu_b)$ respecting all the relevant theoretical and experimental constraints, such as the constraints from B-meson data and the 125 GeV Higgs boson data, and the SUSY-particle mass limits from the recent LHC experiments. From the parameter scan we find the following: (1) The MSSM-loop contribution to Re($C_7(\mu_b)$) can be as large as $\sim \pm 0.05$, which could yield a New Physics (NP) signal at about 3σ level in the future Belle II and LHCb Upgrade experiments. (2) The MSSM-loop contribution to Re($C_7'(\mu_b)$) can be as large as ~ -0.08, which could make a NP signal at about 4σ level in the future experiments. In case such large NP contributions to the WCs are really observed in the future Belle II and the LHCb Upgrade experiments, it could be the imprint of the QFV SUSY (the MSSM with squark-generation mixing) and would encourage to compute the WCs $C_7(\mu_b)$ and $C_7'(\mu_b)$ at NLO/NNLO level in this model.

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1. Introduction

In this talk based on Ref. [1] we present our study of the Wilson coefficients (WCs) for the radiative B-meson decays $B \to X_s\gamma$ at the b-quark mass scale $C_7(\mu_b)$ and $C'_7(\mu_b)$ in the Minimal Supersymmetric Standard Model (MSSM) with general quark-flavour violation (QFV) due to squark-generation mixing. We calculate the supersymmetric (SUSY)-loop contributions to $C_7(\mu_b)$ and $C'_7(\mu_b)$ at leading order (LO) in the MSSM. In our study, for the first time we perform a systematic MSSM-parameter scan respecting all the relevant constraints, i.e. the theoretical constraints from vacuum stability conditions and the experimental constraints, such as those from K- and B-meson data and electroweak precision data, as well as the H^0 mass and coupling data and the limits on SUSY-particle masses from recent LHC experiments. Here H^0 is the discovered SM-like Higgs boson which we identify as the lightest CP even neutral Higgs boson h^0 in the MSSM. The details of these constraints are summarized in Ref. [1] [1]. On the other hand, the WCs $C_7(\mu_b)$ and $C'_7(\mu_b)$ can be measured precisely in the ongoing and future experiments at Belle II and LHCb Upgrade [2–5]. Here we study a possibility that an imprint of SUSY can be found in radiative B-meson decays, focusing on the WCs $C_7(\mu_b)$ and $C'_7(\mu_b)$ with special emphasis on SUSY QFV.

2. Key parameters of the MSSM

Key parameters in this study are the quark flavor violating (QFV) parameters $M^2_{Q_u 23} (\simeq M^2_{Q23})$, M^2_{U23}, T_{U23}, T_{U32}, M^2_{Q23}, M^2_{D23}, T_{D23} and T_{D32} which describe the $\tilde{c}_L - \tilde{t}_L$, $\tilde{c}_R - \tilde{t}_R$, $\tilde{c}_R - \tilde{t}_L$, $\tilde{c}_L - \tilde{t}_R$, $\tilde{s}_L - \tilde{b}_L$, $\tilde{s}_R - \tilde{b}_R$, $\tilde{s}_R - \tilde{b}_L$, and $\tilde{s}_L - \tilde{b}_R$ mixing, respectively. The quark flavor conserving (QFC) parameters T_{U33} and T_{D33} which induce the $\tilde{t}_L - \tilde{t}_R$ and $\tilde{b}_L - \tilde{b}_R$ mixing, respectively, also play an important role in this study. All the parameters in this study are assumed to be real, except the CKM matrix. We also assume that R-parity is conserved and that the lightest neutralino $\tilde{\chi}^0_1$ is the lightest SUSY particle (LSP).

3. Parameter scan

We perform the MSSM parameter scan for the WCs $C_7(\mu_b)$ and $C'_7(\mu_b)$ computed at LO in the MSSM with QFV, respecting all the relevant constraints mentioned above. We generate the input parameter points by using random numbers in the ranges shown in Table 1, where some parameters are fixed as given in the last box. All input parameters are $\overline{\text{DR}}$ parameters defined at the scale Q = 1 TeV, except m_A(pole) which is the pole mass of the CP odd Higgs boson A^0. The parameters that are not shown explicitly are taken to be zero. We don't assume a GUT relation for the gaugino masses M_1, M_2, M_3.

From the 8660000 input points generated in the scan, 72904 points survived all the constraints. These survived points projected in the $Re(C_7^{\text{MSSM}}(\mu_b))$ - $Re(C'_7(\mu_b))$ plane are shown in the scatter plot of Fig. 2.

[1]The recent W boson mass (m_W) data from CDF II [6] is quite inconsistent with the other experimental data. This issue of the m_W anomaly is not yet settled. Hence, we do not take into account this m_W constraint on the MSSM parameters in our analysis.

Table 1: Scanned ranges and fixed values of the MSSM parameters (in units of GeV or GeV^2, except for $\tan\beta$). The parameters that are not shown explicitly are taken to be zero. $M_{1,2,3}$ are the U(1), SU(2), SU(3) gaugino mass parameters, respectively.

$\tan\beta$	M_1	M_2	M_3	μ	$m_A(pole)$
$10 \div 80$	$100 \div 2500$	$100 \div 2500$	$2500 \div 5000$	$100 \div 2500$	$1350 \div 6000$

M^2_{Q22}	M^2_{Q33}	$\lvert M^2_{Q23}\rvert$	M^2_{U22}	M^2_{U33}	$\lvert M^2_{U23}\rvert$
$2500^2 \div 4000^2$	$2500^2 \div 4000^2$	$< 1000^2$	$1000^2 \div 4000^2$	$600^2 \div 3000^2$	$< 2000^2$

M^2_{D22}	M^2_{D33}	$\lvert M^2_{D23}\rvert$	$\lvert T_{U23}\rvert$	$\lvert T_{U32}\rvert$	$\lvert T_{U33}\rvert$
$2500^2 \div 4000^2$	$1000^2 \div 3000^2$	$< 2000^2$	< 4000	< 4000	< 5000

$\lvert T_{D23}\rvert$	$\lvert T_{D32}\rvert$	$\lvert T_{D33}\rvert$	$\lvert T_{E33}\rvert$
< 3000	< 3000	< 4000	< 500

M^2_{Q11}	M^2_{U11}	M^2_{D11}	M^2_{L11}	M^2_{L22}	M^2_{L33}	M^2_{E11}	M^2_{E22}	M^2_{E33}
4500^2	4500^2	4500^2	1500^2	1500^2	1500^2	1500^2	1500^2	1500^2

4. WCs $C_7(\mu_b)$ and $C'_7(\mu_b)$ in the MSSM with QFV

The effective Hamiltonian for the radiative transition $b \to s\gamma$ is given by

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts} \sum_i C_i O_i. \tag{1}$$

Here G_F is the Fermi constant and $V_{tb}V^*_{ts}$ is the CKM factor. The operators relevant to $b \to s\gamma$ are

$$\begin{aligned} O_2 &= \bar{s}_L \gamma_\mu c_L \bar{c}_L \gamma^\mu b_L, \\ O_7 &= \frac{e}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} b_R F_{\mu\nu}, \\ O_8 &= \frac{g_s}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} T^a b_R G^a_{\mu\nu}, \end{aligned} \tag{2}$$

and their chirality counterparts

$$\begin{aligned} O'_2 &= \bar{s}_R \gamma_\mu c_R \bar{c}_R \gamma^\mu b_R, \\ O'_7 &= \frac{e}{16\pi^2} m_b \bar{s}_R \sigma^{\mu\nu} b_L F_{\mu\nu}, \\ O'_8 &= \frac{g_s}{16\pi^2} m_b \bar{s}_R \sigma^{\mu\nu} T^a b_L G^a_{\mu\nu}, \end{aligned} \tag{3}$$

where m_b is the bottom quark mass, e and g_s are the electromagnetic and strong coupling, $F_{\mu\nu}$ and $G^a_{\mu\nu}$ are the $U(1)_{em}$ and $SU(3)_c$ field-strength tensors, T^a are colour generators, and the indices L and R denote the chirality of the quark fields. It is important to note that the SM contributions to $C'_{2,7,8}(\mu)$ are (almost) zero at LO. The WCs $C_7(\mu_b)$ and $C'_7(\mu_b)$ at the bottom quark mass scale μ_b

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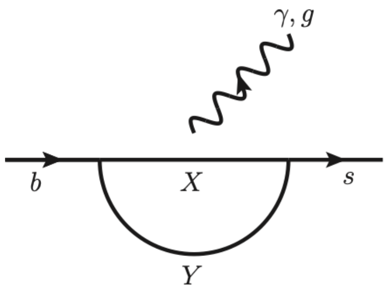

Figure 1: The SM and MSSM one-loop contributions to the WCs $C_{7,8}(\mu_W)$ and $C'_{7,8}(\mu_W)$ at the weak scale μ_W for the transitions $b_R \to s_L\ \gamma_L, g_L$ and $b_L \to s_R\ \gamma_R, g_R$, respectively (see Eqs. (1, 2, 3)). Here γ_L, g_L and γ_R, g_R denotes the left-handed photon, gluon and the right-handed photon, gluon, respectively. The photon is emitted from any electrically charged line and the gluon from any colour charged line. For the SM one-loop contributions (X, Y) = (t/c/u, W^+). For the MSSM one-loop contributions (X, Y) = (stop/scharm/sup, chargino), (sbottom/sstrange/sdown, gluino), (sbottom/sstrange/sdown, neutralino) and (t/c/u, H^+), where stop/scharm/sup denotes top-, charm- , up-squark mixtures and so on.

can be measured precisely in the experiments at Belle II and LHCb Upgrade [2–5]. We compute $C_7(\mu_b)$ and $C'_7(\mu_b)$ at LO in the MSSM with QFV and study the deviation of the MSSM predictions from their SM ones [2].

Following the standard procedure, first we compute $C_{7,8}(\mu_W)$ and $C'_{7,8}(\mu_W)$ at the weak scale μ_W at LO in the MSSM and then we compute $C_7(\mu_b)$ and $C'_7(\mu_b)$ by using the QCD RGEs for the scale evolution at leading log (LL) level [7]. In our numerical analysis, we take $\mu_W = 160$GeV and $\mu_b = 4.8$GeV [4]. We use the numerical results for $C^{(\prime)}_{7,8}(\mu_W)$ at LO in the MSSM obtained from the public code SPheno-v3.3.8 [8], which takes into account the following one-loop contributions to $C^{(\prime)}_{7,8}(\mu_W)$ at the weak scale μ_W (see Fig. 1):

1) SM one-loop contributions:
up-type quark - W^+ loops

2) MSSM one-loop contributions:
up-type squark - chargino loops
down-type squark - gluino loops
down-type squark - neutralino loops
up-type quark - H^+ loops

Here the chargino $\tilde{\chi}^\pm_{1,2}$ is a mixture of charged wino $\tilde{W}^\pm$ and charged higgsino $\tilde{H}^\pm$, the neutralino $\tilde{\chi}^0_{1,2,3,4}$ is a mixture of photino $\tilde{\gamma}$, zino $\tilde{Z}$ and two neutral higgsinos $\tilde{H}^0_{1,2}$, and H^+ is the charged Higgs boson.

Before we show the results of the full parameter scan, we comment on the expected qualitative behavior of the MSSM one-loop contributions to $C^{(\prime)}_7(\mu_b)$ at the bottom mass scale μ_b. We find that large squark trilinear couplings $T_{U23,32,33}$, $T_{D23,32,33}$, large M^2_{Q23}, M^2_{U23}, M^2_{D23}, large bottom Yukawa coupling Y_b for large $\tan\beta$, and large top Yukawa coupling Y_t can lead to large MSSM

[2]Note that these WCs are related to the photon polarization in radiative B-meson decays $b \to s\gamma$.

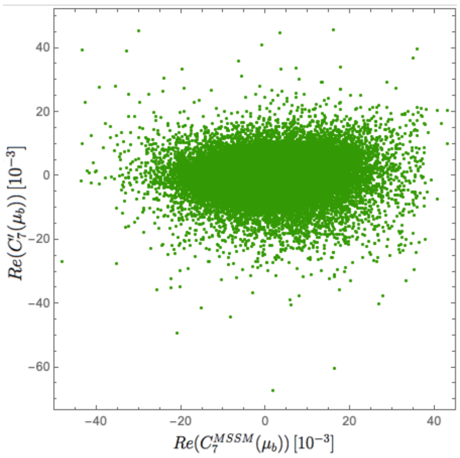

Figure 2: The scatter plot of the scanned parameter points within the ranges given in Table 1 in the $Re(C_7^{\rm MSSM}(\mu_b))$ - $Re(C'_7(\mu_b))$ plane.

one-loop contributions to $C_{7,8}^{(\prime)}(\mu_W)$ at the weak scale μ_W, which results in large MSSM one-loop contributions to $C_7^{(\prime)}(\mu_b)$ at the bottom mass scale μ_b.

In Fig. 2 we show a scatter plot in the $Re(C_7^{\rm MSSM}(\mu_b))$-$Re(C'_7(\mu_b))$ plane [3]. We see that the $Re(C'_7(\mu_b))$ and $Re(C_7^{\rm MSSM}(\mu_b))$ can be quite sizable simultaneously. We find also that the MSSM contribution to $Re(C'_7(\mu_b))$ can be as large as ~ -0.08 [4] , which could correspond to an about 4σ New Physics (NP) signal significance in the combination of the future LHCb Upgrade (Phase III) and Belle II (Phase II) experiments (see Figure A.13 of [4]). Note that $|Im(C'_7(\mu_b))|$ is very small ($\lesssim 0.004$) and that $C'_7(\mu_b) \simeq 0$ in the SM. The MSSM contribution to $Re(C_7(\mu_b))$ can be as large as $\sim \pm 0.05$, which could correspond to an about 3σ NP signal significance in the combination of the future LHCb Upgrade (50 fb^{-1}) and Belle II (50 ab^{-1}) experiments (see Figure 8 of [4]). Note that $|Im(C_7^{\rm MSSM}(\mu_b))|$ is very small ($\lesssim 0.003$) and that the MSSM contribution $C_7^{\rm MSSM}(\mu_b)$ can be quite sizable compared to the SM contribution $C_7^{\rm SM}(\mu_b) \simeq -0.325$.

5. Conclusions

We have studied the Wilson coefficients (WCs) for the radiative B-meson decays $B \to X_s\gamma$ at the b-quark mass scale $C_7(\mu_b)$ and $C'_7(\mu_b)$ in the MSSM with general QFV due to squark-generation mixing. We have calculated the SUSY-loop contributions to these two WCs at LO in the MSSM. *For the first time* we have performed a systematic MSSM parameter scan for the WCs $C_7(\mu_b)$ and $C'_7(\mu_b)$ respecting all the relevant constraints, such as the constraints from B-meson data and the 125 GeV Higgs boson data, and the SUSY-particle mass limits from the recent LHC experiments. From the parameter scan, we have found the following:

[3]We have confirmed that almost all of the MSSM points shown in this plot are still allowed by the latest constraints including that from LHCb [9].

[4]In Ref.[1] from the $Re(C'_7(\mu_b))$ contour plot analysis we found that the MSSM contribution to $Re(C'_7(\mu_b))$ can be as large as ~ -0.08.

- The MSSM contribution to $\mathrm{Re}(C_7(\mu_b))$ can be as large as $\sim \pm 0.05$, which can yield a NP signal at about 3σ level in the future Belle II and LHCb Upgrade experiments.
- The MSSM contribution to $\mathrm{Re}(C'_7(\mu_b))$ can be as large as ~ -0.08, which can make a NP signal at about 4σ level in the future experiments.
- These large MSSM contributions to the WCs are mainly due to (i) large scharm-stop mixings M^2_{Q23} and M^2_{U23}, and large scharm/stop involved trilinear couplings T_{U23}, T_{U32} and T_{U33}, (ii) large sstrange-sbottom mixings M^2_{Q23} and M^2_{D23}, and large sstrange-sbottom involved trilinear couplings T_{D23}, T_{D32} and T_{D33}, and (iii) large bottom Yukawa coupling Y_b for large $\tan\beta$ and large top Yukawa coupling Y_t.

In case such large NP contributions to the WCs are really observed in the future Belle II and the LHCb Upgrade experiments, it could be the imprint of the QFV SUSY (the MSSM with squark-generation mixing) and would encourage to compute the WCs $C_7(\mu_b)$ and $C'_7(\mu_b)$ at NLO/NNLO level in this model.

References

[1] H. Eberl, K. Hidaka, E. Ginina and A. Ishikawa, Phys. Rev. D104 (2021) 7, 075025 [arXiv:2106.15228 [hep-ph]].

[2] E. Kou et al. (Belle II collaboration), PTEP 2019 (2019) 12, 123C01, PTEP 2020 (2020) 2, 029201 (erratum) [arXiv:1808.10567 [hep-ex]].

[3] R. Aaij et al. (LHCb collaboration), arXiv:1808.08865 [hep-ex].

[4] J. Albrecht et al., arXiv:1709.10308 [hep-ph].

[5] A. Paul and D.M. Straub, JHEP 04 (2017) 027 [arXiv:1608.02556 [hep-ph]].

[6] T. Aaltonen et al. (CDF Collaboration), Science 376 (2022) 170.

[7] K. Chetyrkin, M. Misiak and M. Munz, Phys. Lett. B400 (1997) 206 [Erratum-ibid. B425 (1998) 414] [arXiv:hep-ph/9612313].

[8] W. Porod, Comput. Phys. Commun. **153** (2003) 275 [arXiv:hep-ph/0301101]; W. Porod and F. Staub, Comput. Phys. Commun. **183** (2012) 2458 [arXiv:1104.1573 [hep-ph]].

[9] R. Aaij et al. (LHCb collaboration), JHEP 12 (2020) 081 [arXiv:2010.06011 [hep-ex]].