$B \to X_s\gamma$ in the minimal gauged $(B - L)$ supersymmetry

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Complete expressions of the $\bar{s}bg$ and $\bar{s}b\gamma$ vertices are derived in the framework of minimal supersymmetric extension of the standard model with local $B - L$ gauge symmetry. With some assumptions on parameters of the model, a numerical analysis of the supersymmetric contributions to the branching ratio and CP-asymmetry of $\bar{B} \to X_s\gamma$ is presented.

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I. INTRODUCTION

The analyses on rare B decays can detect new physics beyond the standard model (SM) since they are not seriously affected by the uncertainties due to unperturbative QCD effects. The average experimental data on the branching ratio of the inclusive $\bar{B} \to X_s\gamma$ [1]

$$BR(\bar{B} \to X_s\gamma)_{\rm EXP} = (3.40 \pm 0.21) \times 10^{-4}, \qquad (1)$$

which is consistent with the correspondingly SM prediction at NNLO order [2,3]

$$BR(\bar{B} \to X_s\gamma)_{\rm SM} = (3.15 \pm 0.23) \times 10^{-4}. \qquad (2)$$

In fact, the calculation of the $O(\alpha_S)$ virtual corrections to the matrix element for $b \to s\gamma$ is already presented in [4], the complete expressions for the corresponding bremsstrahlung corrections are given in [5] also. The relevant two-loop QCD anomalous dimension matrix (ADM) for all the flavor-changing four-quark dimension-six operators is given in [6].

The precise measurements on the rare B-decay processes set more strict constraints on new physics beyond the SM. The main purpose of investigation of B-decays is to search for traces of new physics and determine its parameter space.

In all extensions of the SM, the supersymmetry is considered as one of the most plausible candidates. In general supersymmetric extension of the SM, new sources of flavor violation may appear in those soft breaking terms [7]. If we believe that the SM is only an effective theory and the supersymmetry is more fundamental, study on rare B-processes will definitely enrich our knowledge in this field. But before we can really pin down any new physics effects, we need to carry out a thorough exploration in this field, not only in SM, but also in supersymmetric models.

Actually the analyses of constraints on extensions of the SM are extensively discussed in the literature. The calculation of the rate of inclusive decay $\bar{B} \to X_s\gamma$ is presented by the authors of [8–10] in the two-Higgs doublet model (2HDM). The supersymmetric effect on $\bar{B} \to X_s\gamma$ is discussed in [11–15] and the next-to-leading order (NLO) QCD corrections are given in [16]. The transition $b \to s\gamma\gamma$ in the supersymmetric extension of the standard model is computed in [17]. The hadronic B decays [18] and CP-violation in those processes [19] have been discussed also. The authors of [20] have discussed the possibility of observing supersymmetric effects in rare decays $\bar{B} \to X_s\gamma$ and $B \to X_s e^+e^-$ at the B-factory. Studies on decays $B \to (K, K^*)\mu^+\mu^-$ in the SM and supersymmetric models have been carried out in [21]. The supersymmetric effects on these processes are very interesting and studies on them may shed some light on the general characteristics of supersymmetric models. A relevant review on the CP violation in rare B decays can be found in [22]. For oscillations of $B_0 - \bar{B}_0$ ($K_0 - \bar{K}_0$), calculations have been done in the SM and 2HDM. As for supersymmetric extensions of the SM, the calculation involving the contributions from gluino and exotic gaugino should be restudied carefully because gluino and additional gaugino have nonzero masses and mediate $b \to s$ transitions through nonuniversal mass insertions of down-type squarks. At the NLO approximation, the QCD corrections to the $B_0 - \bar{B}_0$ mixing in the supersymmetry model have been discussed also. The authors of [23,24] applied the mass-insertion method to estimate QCD corrections to the $B_0 - \bar{B}_0$ mixing. The calculations including the gluon-mediated QCD were given in [25], and later we have rederived the formulation by including the contributions of gluinos [26] and gaugino of local $B - L$ symmetry.

The discovery of Higgs on the Large Hadron Collider (LHC) implies that we finish the spectrum of particles predicted by the SM now [27,28]. One main target of particle physics is testing the SM precisely and searching for the new physics (NP) beyond it. The rare B decays are considered as good implements searching for new physics since they are not seriously affected by the uncertainties from unperturbative QCD effects. The main purpose of investigation of rare B decays is seeking traces of new

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physics and determine its parameter space. Experimentally the LHCb experiment can measure the quantities of exclusive hadronic, semileptonic, and leptonic B and B_s decays at a high sensitivity [29]. In addition the measurements on inclusive rare B decay and decays with neutrino final states will be performed also in two next generation B factories in the near future [30,31].

In supersymmetric extensions of the SM, R-parity is defined through $R = (-1)^{3(B-L)+2S}$, where B, L and S are baryon number, lepton number and spin, respectively, for a concerned field [32]. In the minimal supersymmetric extension of SM (MSSM) with local $U(1)_{B-L}$ symmetry, R-parity is spontaneously broken when left- and right-handed sneutrinos acquire nonzero VEVs [33–36]. Meanwhile, the nonzero VEVs of left- and right-handed sneutrinos induce the mixing between neutralinos (charginos) and neutrinos (charged leptons). Furthermore, the MSSM with local $U(1)_{B-L}$ symmetry naturally predicates two sterile neutrinos [37–39], which are favored by the big-bang nucleosynthesis (BBN) in cosmology [40]. In other words, there are exotic sources to mediate flavor changing neutral current processes (FCNC) in this model.

Here we investigate the FCNC processes with a $\bar{B} \to X_s\gamma$ transition in the MSSM with local $U(1)_{B-L}$ symmetry, our presentation is organized as follows. In Sec. II, we briefly summarize the main ingredients of the MSSM with local $U(1)_{B-L}$ symmetry, then present effective Hamilton for $b \to s\gamma$ in Sec. III, respectively. The numerical analyses are given in Sec. IV, and our conclusions are summarized in Sec. V.

II. THE MSSM WITH LOCAL $U(1)_{B-L}$ SYMMETRY

When $U(1)_{B-L}$ is a local gauge symmetry, one can enlarge the local gauge group of the SM to $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{(B-L)}$. In the model proposed in Refs. [33–36], the exotic superfields are three generation right-handed neutrinos $\hat{N}_i^c \sim (1, 1, 0, 1)$. Meanwhile, quantum numbers of the matter chiral superfields for quarks and leptons are given by

$$\begin{aligned}
\hat{Q}_I &= \begin{pmatrix} \hat{U}_I \\ \hat{D}_I \end{pmatrix} \sim \left(3, 2, \frac{1}{3}, \frac{1}{3}\right),\\
\hat{L}_I &= \begin{pmatrix} \hat{\nu}_I \\ \hat{E}_I \end{pmatrix} \sim (1, 2, -1, -1),\\
\hat{U}_I^c &\sim \left(3, 1, -\frac{4}{3}, -\frac{1}{3}\right),\\
\hat{D}_I^c &\sim \left(3, 1, \frac{2}{3}, -\frac{1}{3}\right),\\
\hat{E}_I^c &\sim (1, 1, 2, 1),
\end{aligned} \tag{3}$$

with $I = 1, 2, 3$ denoting the index of generation. In addition, the quantum numbers of two Higgs doublets are assigned as

$$\begin{aligned}
\hat{H}_u &= \begin{pmatrix} \hat{H}_u^+ \\ \hat{H}_u^0 \end{pmatrix} \sim (1, 2, 1, 0),\\
\hat{H}_d &= \begin{pmatrix} \hat{H}_d^0 \\ \hat{H}_d^- \end{pmatrix} \sim (1, 2, -1, 0).
\end{aligned} \tag{4}$$

The superpotential of the MSSM with local $U(1)_{B-L}$ symmetry is written as

$$\mathcal{W} = \mathcal{W}_{\mathrm{MSSM}} + \mathcal{W}^{(1)}_{(B-L)}. \tag{5}$$

Here $\mathcal{W}_{\mathrm{MSSM}}$ is the superpotential of the MSSM, and

$$\mathcal{W}^{(1)}_{(B-L)} = (Y_N)_{IJ} \hat{H}_u^T i\sigma_2 \hat{L}_I \hat{N}_J^c. \tag{6}$$

Correspondingly, the soft breaking terms for the MSSM with local $U(1)_{B-L}$ symmetry are generally given as

$$\mathcal{L}_{\mathrm{soft}} = \mathcal{L}_{\mathrm{soft}}^{\mathrm{MSSM}} + \mathcal{L}_{\mathrm{soft}}^{(1)}. \tag{7}$$

Here $\mathcal{L}_{\mathrm{soft}}^{\mathrm{MSSM}}$ is the soft breaking terms of the MSSM, and

$$\begin{aligned}
\mathcal{L}_{\mathrm{soft}}^{(1)} = &-(m^2_{\tilde{N}^c})_{IJ} \tilde{N}_I^{c*} \tilde{N}_J^c - (m_{BL}\lambda_{BL}\lambda_{BL} + \mathrm{H.c.})\\
&+ \{(A_N)_{IJ} H_u^T i\sigma_2 \tilde{L}_I \tilde{N}_J^c + \mathrm{H.c.}\},
\end{aligned} \tag{8}$$

with λ_{BL} denoting the gaugino of $U(1)_{B-L}$. After the $SU(2)_L$ doublets $H_u, H_d, \tilde{L}_I$, and $SU(2)_L$ singlets $\tilde{N}_I^c$ acquire the nonzero VEVs,

$$\begin{aligned}
H_u &= \begin{pmatrix} H_u^+ \\ \frac{1}{\sqrt{2}}(\upsilon_u + H_u^0 + iP_u) \end{pmatrix},\\
H_d &= \begin{pmatrix} \frac{1}{\sqrt{2}}(\upsilon_d + H_d^0 + iP_d) \\ H_d^- \end{pmatrix},\\
\tilde{L}_I &= \begin{pmatrix} \frac{1}{\sqrt{2}}(\upsilon_{L_I} + \tilde{\nu}_{L_I} + iP_{L_I}) \\ \tilde{L}_I^- \end{pmatrix},\\
\tilde{N}_I^c &= \frac{1}{\sqrt{2}}(\upsilon_{N_I} + \tilde{\nu}_{R_I} + iP_{N_I}),
\end{aligned} \tag{9}$$

the R-parity is broken spontaneously, and the local gauge symmetry $SU(2)_L \otimes U(1)_Y \otimes U(1)_{(B-L)}$ is broken down to the electromagnetic symmetry $U(1)_e$, and the neutral and charged gauge bosons acquire the nonzero masses as

$$\begin{aligned}
m_{\mathrm{Z}}^2 &= \frac{1}{4}(g_1^2 + g_2^2)\upsilon_{\mathrm{EW}}^2,\\
m_{\mathrm{W}}^2 &= \frac{1}{4} g_2^2 \upsilon_{\mathrm{EW}}^2,\\
m_{Z_{BL}}^2 &= g_{BL}^2(\upsilon_N^2 + \upsilon_{\mathrm{EW}}^2 - \upsilon_{\mathrm{SM}}^2),
\end{aligned} \tag{10}$$

where $\upsilon_{\rm SM}^2 = \upsilon_u^2 + \upsilon_d^2$, $\upsilon_{\rm EW}^2 = \upsilon_u^2 + \upsilon_d^2 + \sum_{\alpha=1}^3 \upsilon_{L_\alpha}^2$, $\upsilon_N^2 = \sum_{\alpha=1}^3 \upsilon_{N_\alpha}^2$, and g_2, g_1, g_{BL} denote the gauge couplings of $SU(2)_L, U(1)_Y$ and $U(1)_{(B-L)}$, respectively.

To satisfy present electroweak precision observations we assume the mass of neutral $U(1)_{(B-L)}$ gauge boson $m_{Z_{BL}} > 1$ TeV which implies $\upsilon_N > 1$ TeV when $g_{BL} < 1$, then we derive $\max((Y_N)_{ij}) \leq 10^{-6}$ and $\max(\upsilon_{L_I}) \leq 10^{-3}$ GeV [36] to explain experimental data on neutrino oscillation. Considering the minimization conditions at one-loop level, we formulate the 3×3 mass-squared matrix for right-handed sneutrinos as

$$m^2_{\tilde{N}^c} \simeq \begin{pmatrix} \Lambda^2_{\tilde{N}^c_1} - \Lambda^2_{BL}, & 0, & -\frac{\upsilon_{N_1}}{\upsilon_{N_3}}\Lambda^2_{\tilde{N}^c_1} \\ 0, & \Lambda^2_{\tilde{N}^c_2} - \Lambda^2_{BL}, & -\frac{\upsilon_{N_2}}{\upsilon_{N_3}}\Lambda^2_{\tilde{N}^c_2} \\ -\frac{\upsilon_{N_1}}{\upsilon_{N_3}}\Lambda^2_{\tilde{N}^c_1}, & -\frac{\upsilon_{N_2}}{\upsilon_{N_3}}\Lambda^2_{\tilde{N}^c_2}, & \frac{\upsilon^2_{N_1}\Lambda^2_{\tilde{N}^c_1} + \upsilon^2_{N_2}\Lambda^2_{\tilde{N}^c_2}}{\upsilon^2_{N_3}} - \Lambda^2_{BL} \end{pmatrix} \tag{11}$$

with $\Lambda^2_{BL} = m^2_{Z_{BL}}/2 + \Delta T_{\tilde{N}}$. Where $\Delta T_{\tilde{N}}$ denotes one-loop radiative corrections to the right-handed sneutrinos from top, bottom, tau, and their supersymmetric partners [39].

III. EFFECTIVE HAMILTON FOR $b \to s\gamma$

The transition $b \to s\gamma$ is attributed to the effective Hamilton at hadronic scale

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts}\Big[C_1\mathcal{O}^c_1 + C_2\mathcal{O}^c_2 + \sum_{i=3}^{6} C_i\mathcal{O}_i + \sum_{i=7}^{8}(C_i\mathcal{O}_i + C'_i\mathcal{O}'_i)\Big], \tag{12}$$

where $\mathcal{O}_i (i = 1, 2, \cdots, 8)$ and $\mathcal{O}'_i (i = 7, 8)$ are defined as [41],

$$\mathcal{O}^c_1 = (\bar{s}_L\gamma_\mu T^a c_L)(\bar{c}_L\gamma^\mu T^a b_L), \qquad \mathcal{O}^c_2 = (\bar{s}_L\gamma_\mu c_L)(\bar{c}_L\gamma^\mu b_L), \qquad \mathcal{O}_3 = (\bar{s}_L\gamma_\mu b_L)\sum_q(\bar{q}\gamma^\mu q),$$
$$\mathcal{O}_4 = (\bar{s}_L\gamma_\mu T^a b_L)\sum_q(\bar{q}\gamma^\mu T^a q), \qquad \mathcal{O}_5 = (\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\rho b_L)\sum_q(\bar{q}\gamma^\mu\gamma^\nu\gamma^\rho q), \qquad \mathcal{O}_6 = (\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\rho T^a b_L)\sum_q(\bar{q}\gamma^\mu\gamma^\nu\gamma^\rho T^a q),$$
$$\mathcal{O}_7 = \frac{e}{g_s^2} m_b(\bar{s}_L\sigma_{\mu\nu} b_R)F^{\mu\nu}, \qquad \mathcal{O}'_7 = \frac{e}{g_s^2} m_b(\bar{s}_R\sigma_{\mu\nu} b_L)F^{\mu\nu}, \qquad \mathcal{O}_8 = \frac{1}{g_s} m_b(\bar{s}_L\sigma_{\mu\nu} T^a b_R)G^{a,\mu\nu},$$
$$\mathcal{O}'_8 = \frac{1}{g_s} m_b(\bar{s}_R\sigma_{\mu\nu} T^a b_L)G^{a,\mu\nu}, \tag{13}$$

and the second term is doubly Cabibbo-suppressed and relevant for the observables sensitive to complex phases in the effective Hamilton Eq. (12).

In supersymmetric extensions of the SM with minimal flavor violation where the only source of flavor violation at the electroweak scale is that of the SM, encoded in the Cabibbo-Kobayashi-Maskawa (CKM) matrix, there is no difference between the corrections to $b \to s\gamma$ transition in the MSSM with and without local $B - L$ gauge symmetry. Therefore the corrections to $b \to s\gamma$ transition only originating from the stop eigenstates through chargino-mediated loop, meanwhile all other squarks, gluino, neutralinos, and $B - L$ gaugino are decoupled at the electroweak scale [11]. In the MSSM with local $B - L$ symmetry and generic flavor structure, flavor-violating scalar mass terms and trilinear terms induce flavor nondiagonal vertices gluino-quark-squark, neutralino-quark-squark, $B - L$ gaugino-quark-squark. The contributions to quark-flavor transitions from those pieces should be constrained by rare B-decay, especially by the $b \to s\gamma$ decay [42].

Applying mass insertion approximation, we present the Wilson coefficients from the new physics beyond SM at matching scale as

$$\begin{aligned} C_{7,NP}(\mu_{\rm EW}) &= C_{7,H^\pm}(\mu_{\rm EW}) + C_{7,\chi^\pm}(\mu_{\rm EW}) + C_{7,\chi^0}(\mu_{\rm EW}) + C_{7,\tilde{g}}(\mu_{\rm EW}) + C_{7,\tilde{Z}_{BL}}(\mu_{\rm EW}), \\ C'_{7,NP}(\mu_{\rm EW}) &= C'_{7,\chi^\pm}(\mu_{\rm EW}) + C'_{7,\chi^0}(\mu_{\rm EW}) + C'_{7,\tilde{g}}(\mu_{\rm EW}) + C'_{7,\tilde{Z}_{BL}}(\mu_{\rm EW}), \\ C_{8,NP}(\mu_{\rm EW}) &= C_{8,H^\pm}(\mu_{\rm EW}) + C_{8,\chi^\pm}(\mu_{\rm EW}) + C_{8,\chi^0}(\mu_{\rm EW}) + C_{8,\tilde{g}}(\mu_{\rm EW}) + C_{8,\tilde{Z}_{BL}}(\mu_{\rm EW}), \\ C'_{8,NP}(\mu_{\rm EW}) &= C'_{8,\chi^\pm}(\mu_{\rm EW}) + C'_{8,\chi^0}(\mu_{\rm EW}) + C'_{8,\tilde{g}}(\mu_{\rm EW}) + C'_{8,\tilde{Z}_{BL}}(\mu_{\rm EW}), \end{aligned} \tag{14}$$

where the concrete are presented in Eq. (B1). In above equations, the pieces $C_{7,H^\pm}, C_{8,H^\pm}$ represent corrections to the Wilson coefficients from charged Higgs-top quark sector, the pieces $C^{(\prime)}_{7,\chi^\pm}, C^{(\prime)}_{8,\chi^\pm}$ represent corrections to the Wilson coefficients from chargino-up type squark sector, the pieces $C^{(\prime)}_{7,\chi^0}, C^{(\prime)}_{8,\chi^0}$ represent corrections to the Wilson coefficients from neutralino-down type squark sector, the pieces $C^{(\prime)}_{7,\tilde{g}}, C^{(\prime)}_{8,\tilde{g}}$ represent corrections to the Wilson coefficients from gluino-down type squark sector, and the pieces $C^{(\prime)}_{7,\tilde{Z}_{BL}}, C^{(\prime)}_{8,\tilde{Z}_{BL}}$ represent corrections to the Wilson coefficients from $B-L$ gaugino-down type squark sector, respectively.

The Wilson coefficients in Eq. (12) are calculated at the matching scale $\mu_{\rm EW}$, then evolved down to hadronic scale $\mu \sim m_b$ by the renormalization group equations. In order to obtain hadronic matrix elements conveniently, we define effective coefficients [41]

$$C_7^{\rm eff} = \frac{4\pi}{\alpha_s} C_7 - \frac{1}{3} C_3 - \frac{4}{9} C_4 - \frac{20}{3} C_5 - \frac{80}{9} C_6,$$
$$C_8^{\rm eff} = \frac{4\pi}{\alpha_s} C_8 + C_3 - \frac{1}{6} C_4 + 20 C_5 - \frac{10}{3} C_6. \tag{15}$$

In our numerical analyses, we evaluate the Wilson coefficients from the SM to next-to-next-to-leading logarithmic (NNLL) accuracy at hadronic energy scale:

$$C_7^{\rm eff}(m_b) = -0.304,$$
$$C_8^{\rm eff}(m_b) = -0.167. \tag{16}$$

On the other hand, the corrections to the Wilson coefficients from new physics only included leading logarithmic (LL) corrections:

$$\vec{C}_{\rm NP}(\mu) = \hat{U}(\mu,\mu_0)\vec{C}_{\rm NP}(\mu_0),$$
$$\vec{C}'_{\rm NP}(\mu) = \hat{U}'(\mu,\mu_0)\vec{C}'_{\rm NP}(\mu_0) \tag{17}$$

with

$$\vec{C}^T_{\rm NP} = (C_{1,\rm NP}, \cdots, C_{6,\rm NP}, C^{\rm eff}_{7,\rm NP}, C^{\rm eff}_{8,\rm NP}),$$
$$\vec{C}'^{,T}_{\rm NP} = (C'^{,\rm eff}_{7,\rm NP}, C'^{,\rm eff}_{8,\rm NP}). \tag{18}$$

Correspondingly the evolving matrices are approached as

$$\hat{U}(\mu,\mu_0) \simeq 1 - \left[\frac{1}{2\beta_0}\ln\frac{\alpha_s(\mu)}{\alpha_s(\mu_0)}\right]\hat{\gamma}^{(0)T},$$
$$\hat{U}'(\mu,\mu_0) \simeq 1 - \left[\frac{1}{2\beta_0}\ln\frac{\alpha_s(\mu)}{\alpha_s(\mu_0)}\right]\hat{\gamma}'^{(0)T}, \tag{19}$$

where the anomalous dimension matrices can be read from Ref. [43] as

$$\hat{\gamma}^{(0)} = \begin{pmatrix} -4 & \frac{8}{3} & 0 & -\frac{2}{9} & 0 & 0 & -\frac{208}{243} & \frac{173}{162} \\ 12 & 0 & 0 & \frac{4}{3} & 0 & 0 & \frac{416}{81} & \frac{70}{27} \\ 0 & 0 & 0 & -\frac{52}{3} & 0 & 2 & -\frac{176}{81} & \frac{14}{27} \\ 0 & 0 & -\frac{40}{9} & -\frac{100}{9} & \frac{4}{9} & \frac{5}{6} & -\frac{152}{243} & -\frac{587}{162} \\ 0 & 0 & 0 & -\frac{256}{3} & 0 & 20 & -\frac{6272}{81} & \frac{6596}{27} \\ 0 & 0 & -\frac{256}{9} & \frac{56}{9} & \frac{40}{9} & -\frac{2}{3} & \frac{4624}{243} & \frac{4772}{81} \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{32}{3} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\frac{32}{9} & \frac{28}{3} \end{pmatrix},$$
$$\hat{\gamma}'^{(0)} = \begin{pmatrix} \frac{32}{3} & 0 \\ -\frac{32}{9} & \frac{28}{3} \end{pmatrix}. \tag{20}$$

IV. OBSERVABLES IN $b \to s\gamma$

The precise experimental measurement of the $\bar{B} \to X_s\gamma$ provides a very stringent constraint on the nonstandard corrections to electric- and chromomagnetic-dipole operators $\mathcal{O}_{7,8}, \mathcal{O}'_{7,8}$. In our numerical analysis we adopt the expression for the branching ratio in Ref. [44] which new physics contributions is included to one-loop accuracy:

$$BR(\bar{B} \to X_s\gamma)_{NP} = 10^{-4} \times \Bigg[(3.15 \pm 0.23) + \frac{16\pi^2 a_{77}}{\alpha_S^2(\mu_b)}(|C_{7,NP}(\mu_{\rm EW})|^2 + |C'_{7,NP}(\mu_{\rm EW})|^2) + \frac{16\pi^2 a_{88}}{\alpha_S^2(\mu_b)}(|C_{8,NP}(\mu_{\rm EW})|^2 + |C'_{8,NP}(\mu_{\rm EW})|^2) + \frac{4\pi}{\alpha_S(\mu_b)}{\rm Re}\Big(a_7 C_{7,NP}(\mu_{\rm EW}) + a_8 C_{8,NP}(\mu_{\rm EW}) + \frac{4\pi a_{78}}{\alpha_S(\mu_b)}[C_{7,NP}(\mu_{\rm EW})C_{8,NP}(\mu_{\rm EW}) + C'_{7,NP}(\mu_{\rm EW})C'_{8,NP}(\mu_{\rm EW})]\Big)\Bigg], \tag{21}$$

where numerical values for the coefficients $a_{7,8,77,88,78}$ at the electroweak scale are also presented in Table I [44].

TABLE I. Numerical values for the coefficients $a_{7,8,77,88,78}$ at the electroweak scale.

a_7	a_8	a_{77}	a_{88}	a_{78}
$-7.184+0.612i$	$-2.225-0.557i$	4.743	0.789	$2.454-0.884i$

The direct CP-violation in $\bar{B} \to X_s\gamma$ is defined by [45]

$$A^{CP}_{\bar{B}\to X_s\gamma} = \frac{\Gamma(\bar{B}\to X_s\gamma)-\Gamma(B\to X_{\bar{s}}\gamma)}{\Gamma(\bar{B}\to X_s\gamma)+\Gamma(B\to X_{\bar{s}}\gamma)}\Big|_{E_\gamma>(1-\delta)E_\gamma^{\max}}$$
$$\simeq \frac{10^{-2}}{|C_7(\mu_b)|^2}[1.23\Im(C_2(\mu_b)C_7^*(\mu_b)) - 9.52\Im(C_8(\mu_b)C_7^*(\mu_b)) + 0.01\Im(C_2(\mu_b)C_8^*(\mu_b))], \quad (22)$$

where we take the fraction of the spectrum above the minimal photon energy cut as $\delta = 0.3$ in the second line in Eq. (22). Within framework of the SM, $A^{CP}_{\bar{B}\to X_s\gamma} \sim 0.5\%$, and the current world average value of this observable is given as $A^{CP}_{\bar{B}\to X_s\gamma} = -0.012 \pm 0.028$ [46].

Additionally the time-dependent CP-asymmetry $S_{K^*\gamma}$ is another interesting observable in the exclusive $B \to K^*\gamma$ decay. At LO level the expression for $S_{K^*\gamma}$ is approached by

$$S_{K^*\gamma} \simeq \frac{2\mathrm{Im}(e^{-i\phi_d}C_7(\mu_b)C_7'(\mu_b))}{|C_7(\mu_b)|^2+|C_7'(\mu_b)|^2}, \quad (23)$$

with ϕ_d denoting the phase of the B_d mixing amplitude. Using directly the experimental values, we give $\sin\phi_d = 0.67 \pm 0.02$ [1]. As a consequence, SM corrections to $S_{K^*\gamma}$ are suppressed by m_s/m_b [47]

$$S^{\mathrm{SM}}_{K^*\gamma} \simeq (-2.3 \pm 1.6)\%. \quad (24)$$

Meanwhile the experimental measurement on this CP-asymmetry is [48]

$$S_{K^*\gamma} = -0.15 \pm 0.22. \quad (25)$$

For the observable considered here, the relevant SM inputs are collected in Table II. The supersymmetric parameters involved here are soft breaking masses of the 2nd and 3rd generation squarks, $m^2_{\tilde{Q}_{2,3}}, m^2_{\tilde{U}_{2,3}}, m^2_{\tilde{D}_{2,3}}$, neutralino and chargino masses $m_{\chi^0_\alpha}, m_{\chi^\pm_\beta}, (\alpha = 1,\cdots,4, \beta = 1,2)$, and their mixing matrices. Additionally the free parameters also include $B-L$ gaugino/right-handed neutrino masses and mixing which are mainly determined from the nonzero VEVs of right-handed sneutrinos, the local $B-L$ gauge coupling g_{BL} and the soft gaugino mass m_{BL}. The flavor conservation mixing between left- and right-handed squarks $(\delta_u^{LR})_{33} = m^2_{\tilde{t}_X}/\Lambda^2_{NP}, (\delta_d^{LR})_{33} = m^2_{\tilde{b}_X}/\Lambda^2_{NP}$ are chosen to give the lightest Higgs mass in the range 124–126 GeV, where Λ_{NP} represents the energy scale of supersymmetry and the concrete expressions of $m^2_{\tilde{t}_X}, m^2_{\tilde{b}_X}$ are presented in Appendix A. The $b \to s$ transitions are mediated by those flavor changing insertions $(\delta^{LL}_{U,D})_{23} = (\delta m^2_{\tilde{U},\tilde{D}})^{LL}_{23}/\Lambda^2_{NP}$, $(\delta^{LR}_{U,D})_{23} = (\delta m^2_{\tilde{U},\tilde{D}})^{LR}_{23}/\Lambda^2_{NP}$, $(\delta^{RR}_{U,D})_{23} = (\delta m^2_{\tilde{U},\tilde{D}})^{RR}_{23}/\Lambda^2_{NP}$, which are originated from flavor-violating scalar mass terms and trilinear scalar couplings in soft breaking terms.

TABLE II. Input parameters [48] used in the numerical analysis.

Input	Input
$m_B = 5.280$ GeV	$m_{K^*} = 0.896$ GeV
$m_{B_s} = 5.367$ GeV	$m_\mu = 0.106$ GeV
$m_{\mathrm{W}} = 80.40$ GeV	$m_{\mathrm{Z}} = 91.19$ GeV
$\tau_B = 2.307 \times 10^{12}$ GeV	$f_B = 0.190 \pm 0.004$
$\alpha_{\mathrm{S}}(m_{\mathrm{Z}}) = 0.118 \pm 0.002$	$\alpha_{\mathrm{S}}(m_{\mathrm{Z}}) = 1/128.9$
$m_c(m_c) = 1.27 \pm 0.11$ GeV	$m_b(m_b) = 4.18 \pm 0.17$ GeV
$m_t^{\mathrm{pole}} = 173.1 \pm 1.3$ GeV	
$\lambda_{CKM} = 0.225 \pm 0.001$	$A_{CKM} = 0.811 \pm 0.022$
$\bar{\rho} = 0.131 \pm 0.026$	$\bar{\eta} = 0.345 \pm 0.014$

To coincide with updated experimental data on supersymmetric particle searching from LHC etc. [48], we choose $m_{\tilde{Q}_2} = m_{\tilde{Q}_3} = m_{\tilde{U}_2} = m_{\tilde{D}_2} = m_{\tilde{D}_3} = 2$ TeV, $m_{\tilde{U}_3} = 1$ TeV, $A_t = A_b = 0.8$ TeV. For those parameters in Higgsino and gaugino sectors of the MSSM, we set $m_1 = 300$ GeV, $m_2 = 600$ GeV, $m_{\tilde{g}} = 2$ TeV, $\mu = 800$ GeV. For the gauge coupling of local $B-L$ symmetry and relevant gaugino mass, we take $g_{BL} = 0.7$, $m_{BL} = 1$ TeV, $\upsilon_N = (0,0,3)$ TeV here. Similar to scenarios of the MSSM the $b \to s$ transitions can be evoked by the insertions $(\delta_U^{LL})_{23}, (\delta_U^{LR})_{23}, (\delta_U^{RR})_{23}$ through the one loop diagrams composed by virtual charginos and up-type scalar quarks, which are extensively discussed in literature before. In order to simplify our analyses here, we choose $(\delta_U^{LL})_{23} = (\delta_U^{LR})_{23} = (\delta_U^{RR})_{23} = 0$ in our numerical discussion. Actually the numerical results depend on $\tan\beta$ mildly with this choice on the parameter space. Because of the reason above, we set $\tan\beta = 20$ and mass of the lightest CP-odd Higgs as $m_{A^0} = 1$ TeV. With those assumptions on parameters of the model considered here, one obtains theoretical prediction on the lightest CP-even Higgs mass as 125.7 GeV which is consistent with the experimental data from LHC.

Through scanning the parameter space, we find that theoretical predictions on the branching ratio of $\bar{B} \to X_s\gamma$ and CP-asymmetries depend on the insertions $(\delta_D^{LL})_{23}, (\delta_D^{RR})_{23}$ weakly. Not losing generality, we always assume $(\delta_D^{LL})_{23} = (\delta_D^{RR})_{23} = 0$ in our numerical analyses.

Under our assumptions on the relevant parameter space, the supersymmetric corrections to the $b \to s$ transition are

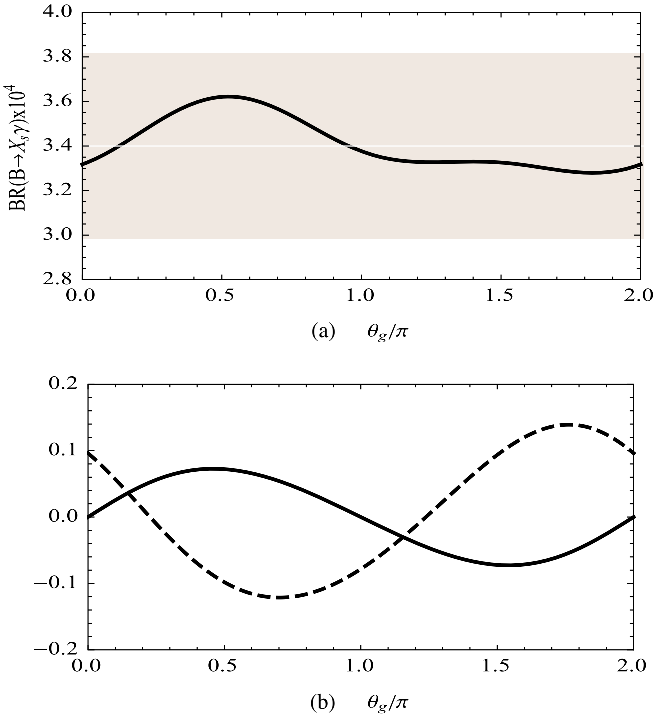

FIG. 1 (color online). Taking $(\delta_D^{LR})_{23} = 0.1, \theta_{BL} = 0$, we plot the branching ratio of $BR(\bar{B} \to X_s\gamma)$ varying with the CP phase θ_g in (a), and $A^{CP}_{\bar{B}\to X_s\gamma}$ (solid line) as well as $S_{K^*\gamma}$ (dashed line) varying with the CP phase θ_g in (b), respectively.

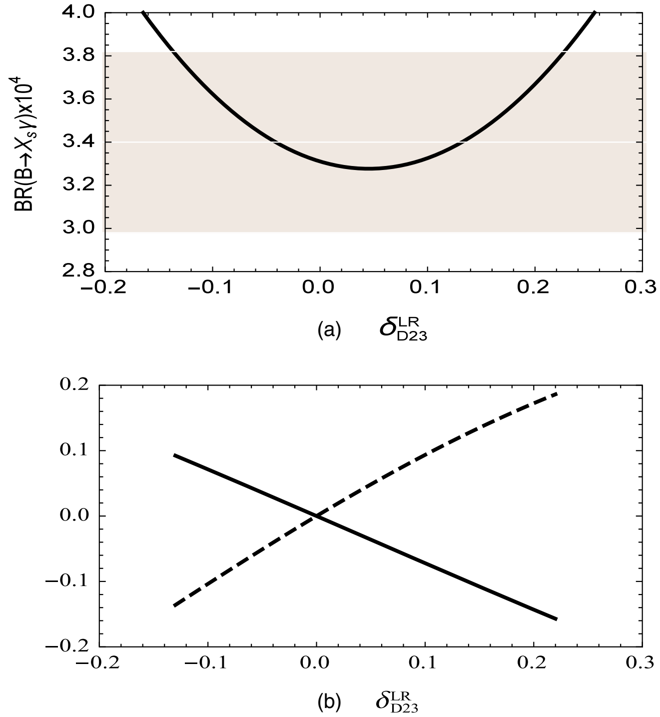

FIG. 2 (color online). Taking $\theta_g = 3\pi/2, \theta_{BL} = 0$, we plot the branching ratio of $BR(\bar{B} \to X_s\gamma)$ varying with the insertion $(\delta_D^{LR})_{23}$ in (a), and $A^{CP}_{\bar{B}\to X_s\gamma}$ (solid line) as well as $S_{K^*\gamma}$ (dashed line) varying with the insertion $(\delta_D^{LR})_{23}$ in (b), respectively.

mainly originated from $U(1)_{B-L}$ gaugino and gluino sectors. Correspondingly the CP phases of $U(1)_{B-L}$ gaugino and gluino also affect those theoretical evaluations strongly. Taking $(\delta_D^{LR})_{23} = 0.1$, we plot the branching ratio of $BR(\bar{B} \to X_s\gamma)$ varying with the CP phase θ_g in Fig. 1(a), and $A^{CP}_{\bar{B}\to X_s\gamma}$ (solid line) as well as $S_{K^*\gamma}$ (dashed line) varying with the CP phase θ_g in Fig. 1(b), respectively. In Fig. 1(a) the gray region represents the experimental data on $BR(\bar{B} \to X_s\gamma)$ within two standard deviations. Adopting our assumptions on relevant parameter space, one finds that those theoretical evaluations on $BR(\bar{B} \to X_s\gamma)$, $A^{CP}_{\bar{B}\to X_s\gamma}$, and $S_{K^*\gamma}$ are consistent with the experimental data within 3 standard deviations. Furthermore, the absolute values on theoretical evaluations on $A^{CP}_{\bar{B}\to X_s\gamma}$ and $S_{K^*\gamma}$ of the considered model are larger than that of the SM much more as $\theta_g = \pi/2, 3\pi/2$, which can be detected in experiments of the near future.

In order to investigate the trends of $BR(\bar{B} \to X_s\gamma)$, $A^{CP}_{\bar{B}\to X_s\gamma}$ and $S_{K^*\gamma}$ varying with $(\delta_D^{LR})_{23}$, we assume that $\theta_g = 3\pi/2$ and other parameters are same as above in Fig. 2. As $-0.15 \le (\delta_D^{LR})_{23} \le 0.22$ the theoretical evaluation on $BR(\bar{B} \to X_s\gamma)$ coincides with experimental data within two standard deviations. Meanwhile the theoretical evaluation on $A^{CP}_{\bar{B}\to X_s\gamma}$ (solid line) diminishes steeply with increasing of $(\delta_D^{LR})_{23}$, and the theoretical evaluation on

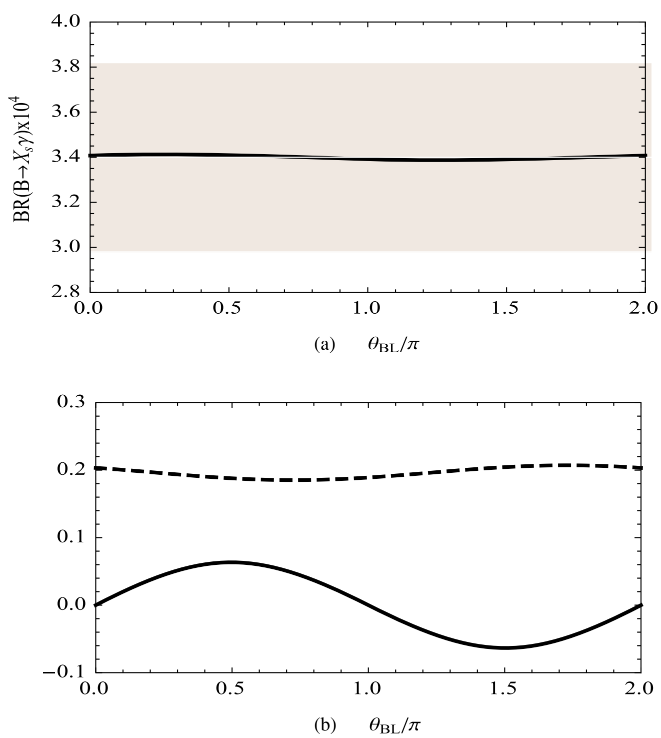

FIG. 3 (color online). Taking $(\delta_D^{LR})_{23} = 0.1, \theta_g = 0$, we plot the branching ratio of $BR(\bar{B} \to X_s\gamma)$ varying with the CP phase θ_{BL} in (a), and $10 \times A^{CP}_{\bar{B}\to X_s\gamma}$ (solid line) as well as $S_{K^*\gamma}$ varying with the CP phase θ_{BL} in (b), respectively.

$S_{K^*\gamma}$ (dashed line) raises quickly with increasing of $(\delta_D^{LR})_{23}$, respectively. The numerical results indicate $A^{CP}_{\bar{B}\to X_s\gamma} \simeq 10\%$, $S_{K^*\gamma} \simeq -14\%$ as $(\delta_D^{LR})_{23} \simeq -0.15$, and $A^{CP}_{\bar{B}\to X_s\gamma} \simeq -16\%$, $S_{K^*\gamma} \simeq 18\%$ as $(\delta_D^{LR})_{23} \simeq 0.22$, which all differ from the theoretical evaluations of the SM obviously.

Taking $(\delta_D^{LR})_{23} = 0.1$, we plot the branching ratio of $BR(\bar{B} \to X_s\gamma)$ varying with the CP phase θ_{BL} in Fig. 3(a), and $A^{CP}_{\bar{B}\to X_s\gamma}$ (solid line) as well as $S_{K^*\gamma}$ (dashed line) varying with the CP phase θ_{BL} in Fig. 3(b), respectively. Those theoretical evaluations on $BR(\bar{B} \to X_s\gamma)$, $A^{CP}_{\bar{B}\to X_s\gamma}$ and $S_{K^*\gamma}$ vary with the CP phase θ_{BL} mildly because we assume $g_{BL} \ll g_s$ at electroweak energy scale. Additionally the theoretical evaluations on $BR(\bar{B} \to X_s\gamma)$ and $A^{CP}_{\bar{B}\to X_s\gamma}$ of the considered model do not deviate from that of the SM obviously, however the theoretical evaluations on $S_{K^*\gamma}$ deviate from that of the SM obviously because this quantity reflects the interference between $\mathcal{O}_7$ and $\mathcal{O}'_7$ at hadronic scala.

Assuming $\theta_{BL} = 3\pi/2$ we plot $BR(\bar{B} \to X_s\gamma)$, $A^{CP}_{\bar{B}\to X_s\gamma}$ and $S_{K^*\gamma}$ varying with $(\delta_D^{LR})_{23}$ in Fig. 4. As $-0.25 \leq (\delta_D^{LR})_{23} \leq 0.4$ the theoretical evaluation on $BR(\bar{B} \to X_s\gamma)$ coincides with experimental data within two standard deviations. Meanwhile the theoretical evaluation on $A^{CP}_{\bar{B}\to X_s\gamma}$ (solid line) diminishes mildly with increasing $(\delta_D^{LR})_{23}$, and the theoretical evaluation on $S_{K^*\gamma}$ (dashed line) raises quickly with increasing $(\delta_D^{LR})_{23}$, respectively. The numerical results indicate $A^{CP}_{\bar{B}\to X_s\gamma} \simeq 1\%$, $S_{K^*\gamma} \simeq -22\%$ as $(\delta_D^{LR})_{23} \simeq -0.25$, and $A^{CP}_{\bar{B}\to X_s\gamma} \simeq -2\%$, $S_{K^*\gamma} \simeq 40\%$ as $(\delta_D^{LR})_{23} \simeq 0.4$, respectively.

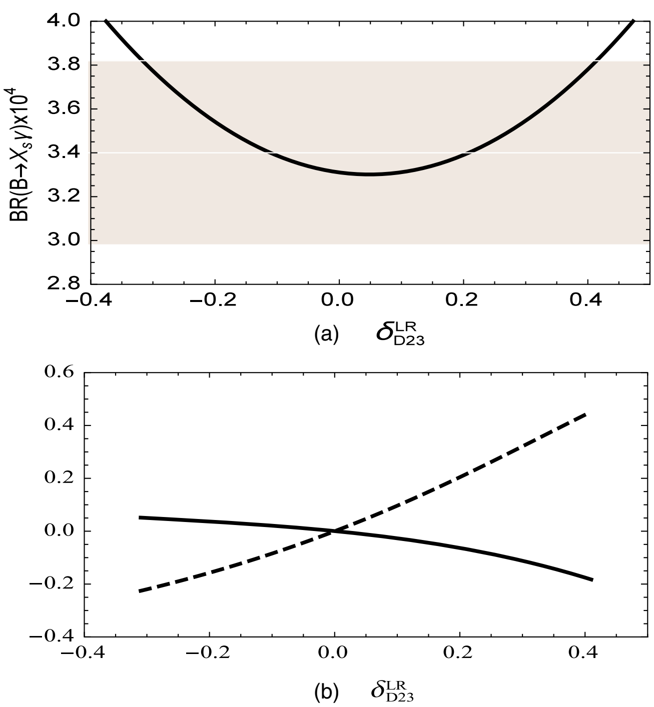

FIG. 4 (color online). Taking $\theta_{BL} = 3\pi/2, \theta_g = 0$, we plot the branching ratio of $BR(\bar{B} \to X_s\gamma)$ varying with the insertion $(\delta_D^{LR})_{23}$ in (a), and $10 \times A^{CP}_{\bar{B}\to X_s\gamma}$ (solid line) as well as $S_{K^*\gamma}$ (dashed line) varying with the insertion $(\delta_D^{LR})_{23}$ in (b), respectively.

V. SUMMARY

Rare B-meson decays are very sensitive to new physics beyond the SM since the theoretical evaluations on corresponding physical quantities are not seriously affected by the uncertainties originating from unperturbative QCD effects. Considering the constraint from the observed Higgs signal at the LHC, we study the supersymmetric corrections to the branching ratio $BR(\bar{B} \to X_s\gamma)$ and the CP asymmetries $A^{CP}_{\bar{B}\to X_s\gamma}$, $S_{K^*\gamma}$ in the MSSM with local $U(1)_{B-L}$ symmetry [33–36] with nonuniversal soft breaking terms. After obtaining the Wilson coefficients at matching scale, we evolve the Wilson coefficients from the SM down to the hadronic scale at NNLL accuracy, and evolve that from new physics down to hadronic scale at LL accuracy, respectively. The lightest neutral Higgs with mass around 125 GeV constrains the correlation between $\tan\beta$ and the soft Yukawa coupling A_t strongly, nevertheless constrains neutral flavor changing mass insertions weakly. Under our assumptions on parameters of the considered model, the numerical analyses indicate that the insertion $(\delta_D^{LR})_{23}$ affects the theoretical predictions on $BR(\bar{B} \to X_s\gamma)$, $A^{CP}_{\bar{B}\to X_s\gamma}$, and $S_{K^*\gamma}$ strongly. In addition, the CP phases θ_g, θ_{BL} also affect the numerical results acutely when the neutral gauginos $m_{\tilde{g}} \sim m_{BL} \geq 1$ TeV and the squarks acquire the masses around several TeVs.

ACKNOWLEDGMENTS

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APPENDIX A: THE MASS SQUARED MATRICES FOR SQUARKS

With the minimal flavor violation assumption, the 2×2 mass squared matrix for scalar tops is given as

$$\mathcal{Z}_t^\dagger \begin{pmatrix} m^2_{\tilde{t}_L} & m^2_{\tilde{t}_X} \\ m^2_{\tilde{t}_X} & m^2_{\tilde{t}_R} \end{pmatrix} \mathcal{Z}_t = \mathrm{diag}(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}), \qquad \text{(A1)}$$

with

$$m^2_{\tilde{t}_L} = \frac{(g_1^2+g_2^2)\upsilon^2_{\rm EW}}{24}(1-2\cos^2\beta)(1-4c^2_{\rm W}) + \frac{g^2_{BL}}{6}(\upsilon^2_N - \upsilon^2_{\rm EW} + \upsilon^2_{\rm SM}) + m_t^2 + m^2_{\tilde{Q}_3},$$
$$m^2_{\tilde{t}_R} = -\frac{g_1^2\upsilon^2_{\rm EW}}{6}(1-2\cos^2\beta) - \frac{g^2_{BL}}{6}(\upsilon^2_N - \upsilon^2_{\rm EW} + \upsilon^2_{\rm SM}) + m_t^2 + m^2_{\tilde{U}_3}, \qquad m^2_{\tilde{t}_X} = -\frac{\upsilon_u}{\sqrt{2}}A_tY_t + \frac{\mu\upsilon_d}{\sqrt{2}}Y_t. \tag{A2}$$

Here Y_t, A_t denote Yukawa coupling and trilinear soft-breaking parameters in the top quark sector, respectively. In a similar way, the mass-squared matrix for scalar bottoms is

$$\mathcal{Z}_b^\dagger \begin{pmatrix} m^2_{\tilde{b}_L} & m^2_{\tilde{b}_X} \\ m^2_{\tilde{b}_X} & m^2_{\tilde{b}_R} \end{pmatrix} \mathcal{Z}_b = {\rm diag}(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}), \tag{A3}$$

with

$$m^2_{\tilde{b}_L} = \frac{(g_1^2+g_2^2)\upsilon^2_{\rm EW}}{24}(1-2\cos^2\beta)(1+2c^2_{\rm W}) + \frac{g^2_{BL}}{6}(\upsilon^2_N - \upsilon^2_{\rm EW} + \upsilon^2_{\rm SM}) + m_b^2 + m^2_{\tilde{Q}_3},$$
$$m^2_{\tilde{b}_R} = \frac{g_1^2\upsilon^2_{\rm EW}}{12}(1-2\cos^2\beta) - \frac{g^2_{BL}}{6}(\upsilon^2_N - \upsilon^2_{\rm EW} + \upsilon^2_{\rm SM}) + m_b^2 + m^2_{\tilde{D}_3}, \qquad m^2_{\tilde{b}_X} = \frac{\upsilon_d}{\sqrt{2}}A_bY_b - \frac{\mu\upsilon_u}{\sqrt{2}}Y_b, \tag{A4}$$

here Y_b, A_b denote Yukawa couplings and trilinear soft-breaking parameters in the b quark sector, respectively.

APPENDIX B: THE WILSON COEFFICIENTS AT ELECTROWEAK SCALE

$$C_{7,H^\pm}(\mu_{\rm EW}) = \frac{\alpha_s(\mu_{\rm EW})}{4\pi}\frac{x_tc_\beta^2}{s_\beta^2}\left\{-\frac{5}{216}\frac{\partial^3\varrho_{3,1}}{\partial x^3_{H^\pm}} + \frac{1}{8}\frac{\partial^2\varrho_{2,1}}{\partial x^2_{H^\pm}} - \frac{1}{9}\frac{\partial\varrho_{1,1}}{\partial x_{H^\pm}} + \frac{2}{9}\frac{\partial\varrho_{1,1}}{\partial x_t}\right\}(x_t, x_{H^\pm})$$
$$- \frac{\alpha_s(\mu_{\rm EW})}{4\pi}x_t\left\{-\frac{1}{12}\frac{\partial^2\varrho_{2,1}}{\partial x^2_{H^\pm}} + \frac{1}{6}\frac{\partial\varrho_{1,1}}{\partial x_{H^\pm}} + \frac{1}{3}\frac{\partial\varrho_{1,1}}{\partial x_t}\right\}(x_t, x_{H^\pm}),$$

$$C_{7,\chi^\pm}(\mu_{\rm EW}) = \frac{\alpha_s(\mu_{\rm EW})}{96\pi}(U_+)^*_{1i}(U_+)_{1i}\frac{(\delta^2m^{LL}_{\tilde{U}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{cs}}x_{\rm W}[(1+Q_u)T_3 - 3(2+Q_u)T_2 + 6T_1](x_{\chi_i^\pm}, x_{\tilde{t}_L}, x_{\tilde{c}_L})$$
$$+ \frac{\alpha_s(\mu_{\rm EW})m_sm_{\chi_i^\pm}}{8\pi m_{\rm W}m_bc_\beta}(U_-)_{2i}(U_+)_{1i}\frac{(\delta^2m^{LL}_{\tilde{U}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{cs}}x_{\rm W}\left[\left(1-\frac{Q_u}{2}\right)(T_2-2T_1) + 2\frac{\partial\varrho_{1,1}}{\partial x_{\chi_i^\pm}}\right](x_{\chi_i^\pm}, x_{\tilde{t}_L}, x_{\tilde{c}_L})$$
$$- \frac{\alpha_s(\mu_{\rm EW})m_t}{96\pi m_{\rm W}s_\beta}(U_+)^*_{1i}(U_+)_{2i}\frac{(\delta^2m^{LR}_{\tilde{U}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{cs}}x_{\rm W}[(1-Q_u)T_3 - 3(2-Q_u)T_2 + 6T_1](x_{\chi_i^\pm}, x_{\tilde{t}_R}, x_{\tilde{c}_L})$$
$$- \frac{\alpha_s(\mu_{\rm EW})m_tm_sm_{\chi_i^\pm}}{8\pi m^2_{\rm W}m_bs_\beta c_\beta}(U_-)_{2i}(U_+)_{2i}\frac{(\delta^2m^{LR}_{\tilde{U}})_{23}x_{\rm W}}{\Lambda^2_{NP}V_{tb}V^*_{cs}}\left[\left(1+\frac{Q_u}{2}\right)(T_2-2T_1) + 2\frac{\partial\varrho_{1,1}}{\partial x_{\chi_i^\pm}}\right](x_{\chi_i^\pm}, x_{\tilde{t}_R}, x_{\tilde{c}_L})$$
$$- \frac{\alpha_s(\mu_{\rm EW})}{96\pi}(U_+)^*_{1i}(U_+)_{1i}\frac{(\delta^2m^{LR}_{\tilde{U}})_{23}(\delta^2m^{LR}_{\tilde{U}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[(1+Q_u)D_3 - 3(2+Q_u)D_2 + 6D_1](x_{\chi_i^\pm}, x_{\tilde{t}_L}, x_{\tilde{t}_R}, x_{\tilde{c}_L})$$
$$- \frac{\alpha_s(\mu_{\rm EW})m_sm_{\chi_i^\pm}}{8\pi m_{\rm W}m_bc_\beta}(U_-)_{2i}(U_+)_{1i}\frac{(\delta^2m^{LR}_{\tilde{U}})_{23}(\delta^2m^{LR}_{\tilde{U}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times\left[\left(1-\frac{Q_u}{2}\right)(D_2-2D_1) + 2\frac{\partial\varrho_{1,1}}{\partial x_{\chi_i^\pm}}\right]$$
$$\times(x_{\chi_i^\pm}, x_{\tilde{t}_L}, x_{\tilde{t}_R}, x_{\tilde{c}_L}) + \frac{\alpha_s(\mu_{\rm EW})m_t}{96\pi m_{\rm W}s_\beta}(U_+)^*_{1i}(U_+)_{2i}\frac{(\delta^2m^{LL}_{\tilde{U}})_{23}(\delta^2m^{LR}_{\tilde{U}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[(1-Q_u)D_3 - 3(2-Q_u)D_2$$
$$+ 6D_1](x_{\chi_i^\pm}, x_{\tilde{t}_R}, x_{\tilde{t}_L}, x_{\tilde{c}_L}) + \frac{\alpha_s(\mu_{\rm EW})m_tm_sm_{\chi_i^\pm}}{8\pi m^2_{\rm W}m_bs_\beta c_\beta}(U_-)_{2i}(U_+)_{2i}\frac{(\delta^2m^{LL}_{\tilde{U}})_{23}(\delta^2m^{LR}_{\tilde{U}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}$$
$$\times\left[\left(1+\frac{Q_u}{2}\right)(D_2-2D_1) + 2\frac{\partial\varrho_{1,1}}{\partial x_{\chi_i^\pm}}\right](x_{\chi_i^\pm}, x_{\tilde{t}_R}, x_{\tilde{t}_L}, x_{\tilde{c}_L}),$$

$$
\begin{aligned}
C_{7,\chi^0}(\mu_{\rm EW}) =& \frac{Q_d\alpha_s(\mu_{\rm EW})}{96\pi c_{\rm W}^2}|\mathcal{N}^i_d|^2\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{s}_L})\\
&+\frac{Q_d\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m_{\rm W}m_b c_{\rm W}c_\beta}(U_N)_{3i}\mathcal{N}^i_d\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{s}_L})\\
&+\frac{Q_d\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m^2_{\rm W}c^2_\beta}(U_N)_{3i}(U_N)^*_{3i}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{s}_R})\\
&+\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)_{1i}(U_N)_{3i}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{s}_R})\\
&+\frac{Q_d\alpha_s(\mu_{\rm EW})m_b}{96\pi m_{\rm W}c_{\rm W}c_\beta}\mathcal{N}^{i*}_d(U_N)_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{s}_L})\\
&+\frac{Q_d\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m^2_{\rm W}c^2_\beta}(U_N)_{3i}(U_N)_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{s}_L})\\
&+\frac{Q_d\alpha_s(\mu_{\rm EW})m_s}{96\pi m_{\rm W}c_{\rm W}c_\beta}\mathcal{N}^i_d(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&+\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_b c^2_{\rm W}}(U_N)_{1i}\mathcal{N}^i_d\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})}{96\pi c^2_{\rm W}}|\mathcal{N}^i_d|^2\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m_{\rm W}m_b c_{\rm W}c_\beta}(U_N)_{3i}\mathcal{N}^i_d\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m^2_{\rm W}c^2_\beta}(U_N)_{3i}(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)_{1i}(U_N)_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_b}{96\pi m_{\rm W}c_{\rm W}c_\beta}\mathcal{N}^{i*}_d(U_N)_{3i}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}x_{\rm W}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m^2_{\rm W}c^2_\beta}(U_N)_{3i}(U_N)_{3i}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_s}{24\pi m_{\rm W}c_{\rm W}c_\beta}\mathcal{N}^i_d(U_N)^*_{3i}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_R})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_b c^2_{\rm W}}(U_N)_{1i}\mathcal{N}^i_d\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_R}),
\end{aligned}
$$

$$
\begin{aligned}
C_{7,\tilde{g}}(\mu_{\rm EW}) =& \frac{Q_d\alpha^2_s(\mu_{\rm EW})s^2_{\rm W}}{18\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\tilde{g}},x_{\tilde{b}_L},x_{\tilde{s}_L})\\
&+\frac{Q_d\alpha^2_s(\mu_{\rm EW})s^2_{\rm W}e^{-i\theta_g}}{3\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{g}}}{m_b}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\tilde{g}},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&-\frac{Q_d\alpha^2_s(\mu_{\rm EW})s^2_{\rm W}}{18\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[D_3-3D_2](x_{\tilde{g}},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_L})\\
&-\frac{Q_d\alpha^2_s(\mu_{\rm EW})s^2_{\rm W}e^{-i\theta_g}}{3\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{g}}}{m_b}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}[D_2-2D_1](x_{\tilde{g}},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_R}),
\end{aligned}
$$

$$C_{7,\tilde{Z}_{BL}}(\mu_{\rm EW}) = \frac{Q_d\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2}{216\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\tilde{Z}_{BL}},x_{\tilde{b}_L},x_{\tilde{s}_L})$$
$$+\frac{Q_d\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2 e^{-i\theta_{BL}}}{36\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{Z}_{BL}}}{m_b}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\tilde{Z}_{BL}},x_{\tilde{b}_L},x_{\tilde{s}_R})$$
$$-\frac{Q_d\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2}{216\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}[D_3-3D_2](x_{\tilde{Z}_{BL}},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_L})$$
$$-\frac{Q_d\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2 e^{-i\theta_{BL}}}{36\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{Z}_{BL}}}{m_b}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}[D_2-2D_1](x_{\tilde{Z}_{BL}},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_R}),$$

$$C'_{7,\chi^\pm}(\mu_{\rm EW}) = \frac{\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m_{\rm W}^2 c_\beta^2}(U_-)_{2i}(U_-)^*_{2i}\frac{(\delta^2 m^{LL}_{\tilde{U}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[(1+Q_u)T_3-2(3+Q_u)T_2+6T_1](x_{\chi_i^\pm},x_{\tilde{t}_L},x_{\tilde{c}_L})$$
$$+\frac{\alpha_s(\mu_{\rm EW})m_{\chi_i^\pm}}{8\pi m_{\rm W}c_\beta}(U_+)^*_{1i}(U_-)^*_{2i}\frac{(\delta^2 m^{LL}_{\tilde{U}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}\left[\left(1-\frac{Q_u}{2}\right)(T2-2T_1)+2\frac{\partial\varrho_{1,1}}{\partial x_{\chi_i^\pm}}\right](x_{\chi_i^\pm},x_{\tilde{t}_L},x_{\tilde{c}_L})$$
$$-\frac{\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m_{\rm W}^2 c_\beta^2}(U_-)_{2i}(U_-)^*_{2i}\frac{(\delta^2 m^{LR}_{\tilde{U}})_{23}(\delta^2 m^{LR}_{\tilde{U}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[(1+Q_u)D_3-3(2+Q_u)D_2+6D_1](x_{\chi_i^\pm},x_{\tilde{t}_L},x_{\tilde{t}_R},x_{\tilde{c}_L})$$
$$-\frac{\alpha_s(\mu_{\rm EW})m_{\chi_i^\pm}}{8\pi m_{\rm W}c_\beta}(U_+)^*_{1i}(U_-)^*_{2i}\frac{(\delta^2 m^{LR}_{\tilde{U}})_{23}(\delta^2 m^{LR}_{\tilde{U}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times\left[\left(1-\frac{Q_u}{2}\right)(D_2-2D_1)+2\frac{\partial\varrho_{1,1}}{\partial x_{\chi_i^\pm}}\right](x_{\chi_i^\pm},x_{\tilde{t}_L},x_{\tilde{t}_R},x_{\tilde{c}_L}),$$

$$C'_{7,\chi^0}(\mu_{\rm EW}) = \frac{Q_d\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m_{\rm W}^2 c_\beta^2}(U_N)^*_{3i}(U_N)_{3i}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi_i^0},x_{\tilde{b}_L},x_{\tilde{s}_L})$$
$$+\frac{Q_d\alpha_s(\mu_{\rm EW})m_{\chi_i^0}}{16\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)^*_{3i}\mathcal{N}_d^{i*}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi_i^0},x_{\tilde{b}_L},x_{\tilde{s}_L})$$
$$+\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}^2}{216\pi c_{\rm W}^2}(U_N)_{1i}(U_N)^*_{1i}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi_i^0},x_{\tilde{b}_R},x_{\tilde{s}_R})$$
$$+\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_s m_{\chi_i^0}}{24\pi m_{\rm W}m_b c_{\rm W}c_\beta}(U_N)^*_{1i}(U_N)^*_{3i}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi_i^0},x_{\tilde{b}_R},x_{\tilde{s}_R})$$
$$+\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_s}{144\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)^*_{1i}(U_N)_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi_i^0},x_{\tilde{b}_R},x_{\tilde{s}_L})$$
$$+\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi_i^0}}{24\pi m_b c_{\rm W}}(U_N)^*_{1i}\mathcal{N}_d^{i*}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi_i^0},x_{\tilde{b}_R},x_{\tilde{s}_L})$$
$$+\frac{Q_d\alpha_s(\mu_{\rm EW})m_b}{96\pi m_{\rm W}c_\beta}(U_N)_{1i}(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi_i^0},x_{\tilde{b}_L},x_{\tilde{s}_R})$$
$$+\frac{Q_d\alpha_s(\mu_{\rm EW})m_s m_{\chi_i^0}}{16\pi m_{\rm W}^2 c_\beta^2}(U_N)^*_{3i}(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi_i^0},x_{\tilde{b}_L},x_{\tilde{s}_R})$$

$$
\begin{aligned}
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_bm_s}{96\pi m_{\rm W}^2c_\beta^2}(U_N)^*_{3i}(U_N)_{3i}\frac{(\delta^2m^{LR}_{\tilde D})_{23}(\delta^2m^{LR}_{\tilde D})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde b_R},x_{\tilde s_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_{\chi^0_i}}{16\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)^*_{3i}\mathcal{N}^{i*}_d\frac{(\delta^2m^{LR}_{\tilde D})_{23}(\delta^2m^{LR}_{\tilde D})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde b_R},x_{\tilde s_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}^2}{216\pi c_{\rm W}^2}(U_N)_{1i}(U_N)^*_{1i}\frac{(\delta^2m^{LR}_{\tilde D})^*_{23}(\delta^2m^{LR}_{\tilde D})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde b_R},x_{\tilde b_L},x_{\tilde s_R})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_sm_{\chi^0_i}}{24\pi m_{\rm W}m_bc_{\rm W}c_\beta}(U_N)^*_{1i}(U_N)^*_{3i}\frac{(\delta^2m^{LR}_{\tilde D})^*_{23}(\delta^2m^{LR}_{\tilde D})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde b_R},x_{\tilde b_L},x_{\tilde s_R})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_s}{144\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)^*_{1i}(U_N)_{3i}\frac{(\delta^2m^{LL}_{\tilde D})_{23}(\delta^2m^{LR}_{\tilde D})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde b_R},x_{\tilde b_L},x_{\tilde s_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_bc_{\rm W}}(U_N)^*_{1i}\mathcal{N}^{i*}_d\frac{(\delta^2m^{LL}_{\tilde D})_{23}(\delta^2m^{LR}_{\tilde D})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde b_R},x_{\tilde b_L},x_{\tilde s_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_b}{24\pi m_{\rm W}c_\beta}(U_N)_{1i}(U_N)^*_{3i}\frac{(\delta^2m^{RR}_{\tilde D})_{23}(\delta^2m^{LR}_{\tilde D})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde b_R},x_{\tilde s_R})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_sm_{\chi^0_i}}{16\pi m_{\rm W}^2c_\beta^2}(U_N)^*_{3i}(U_N)^*_{3i}\frac{(\delta^2m^{RR}_{\tilde D})_{23}(\delta^2m^{LR}_{\tilde D})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde b_R},x_{\tilde s_R}),
\end{aligned}
$$

$$
\begin{aligned}
C'_{7,\tilde g}(\mu_{\rm EW})=&\frac{Q_d\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2}{18\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2m^{RR}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\tilde g},x_{\tilde b_R},x_{\tilde s_R})\\
&+\frac{Q_d\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2e^{i\theta_g}}{3\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde g}}{m_b}\frac{(\delta^2m^{LR}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\tilde g},x_{\tilde b_R},x_{\tilde s_L})\\
&-\frac{Q_d\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2}{18\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2m^{LR}_{\tilde D})^*_{23}(\delta^2m^{LR}_{\tilde D})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\tilde g},x_{\tilde b_R},x_{\tilde b_L},x_{\tilde s_R})\\
&-\frac{Q_d\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2e^{i\theta_g}}{3\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde g}}{m_b}\frac{(\delta^2m^{LL}_{\tilde D})_{23}(\delta^2m^{LR}_{\tilde D})_{33}x_{\rm W}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}\times[D_2-2D_1](x_{\tilde g},x_{\tilde b_R},x_{\tilde b_L},x_{\tilde s_L}),
\end{aligned}
$$

$$
\begin{aligned}
C'_{7,\tilde Z_{BL}}(\mu_{\rm EW})=&\frac{Q_d\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2}{216\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2m^{RR}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\tilde Z_{BL}},x_{\tilde b_R},x_{\tilde s_R})\\
&+\frac{Q_d\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2e^{i\theta_{BL}}}{36\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde Z_{BL}}}{m_b}\frac{(\delta^2m^{LR}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\tilde Z_{BL}},x_{\tilde b_R},x_{\tilde s_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2}{216\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2m^{LR}_{\tilde D})^*_{23}(\delta^2m^{LR}_{\tilde D})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\tilde Z_{BL}},x_{\tilde b_R},x_{\tilde b_L},x_{\tilde s_R})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2e^{i\theta_{BL}}}{36\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde Z_{BL}}}{m_b}\frac{(\delta^2m^{LL}_{\tilde D})_{23}(\delta^2m^{LR}_{\tilde D})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\tilde Z_{BL}},x_{\tilde b_R},x_{\tilde b_L},x_{\tilde s_L}),
\end{aligned}
$$

$$
\begin{aligned}
C_{8,H^\pm}(\mu_{\rm EW})=&\frac{\alpha_s(\mu_{\rm EW})}{4\pi}\frac{x_tc_\beta^2}{s_\beta^2}\left\{-\frac{1}{24}\frac{\partial^3\varrho_{3,1}}{\partial x^3_{H^\pm}}-\frac{1}{4}\frac{\partial^2\varrho_{2,1}}{\partial x^2_{H^\pm}}+\frac{1}{4}\frac{\partial\varrho_{1,1}}{\partial x_{H^\pm}}\right\}(x_t,x_{H^\pm})\\
&-\frac{\alpha_s(\mu_{\rm EW})}{4\pi}x_t\left\{\frac{1}{4}\frac{\partial^2\varrho_{2,1}}{\partial x^2_{H^\pm}}-\frac{1}{2}\frac{\partial\varrho_{1,1}}{\partial x_{H^\pm}}+\frac{1}{2}\frac{\partial\varrho_{1,1}}{\partial x_t}\right\}(x_t,x_{H^\pm}),
\end{aligned}
$$

$$\begin{aligned}
C_{8,\chi^\pm}(\mu_{\rm EW}) &= \frac{\alpha_s(\mu_{\rm EW})}{96\pi}(U_+)^*_{1i}(U_+)_{1i}\frac{(\delta^2 m^{LL}_{\tilde U})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{cs}}x_{\rm W}[T_3-3T_2](x_{\chi^\pm_i},x_{\tilde t_L},x_{\tilde c_L}) \\
&- \frac{\alpha_s(\mu_{\rm EW})m_s m_{\chi^\pm_i}}{32\pi m_{\rm W}m_b c_\beta}(U_-)_{2i}(U_+)_{1i}\frac{(\delta^2 m^{LL}_{\tilde U})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{cs}}x_{\rm W}[T_2-2T_1](x_{\chi^\pm_i},x_{\tilde t_L},x_{\tilde c_L}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})m_t}{96\pi m_{\rm W}s_\beta}(U_+)^*_{1i}(U_+)_{2i}\frac{(\delta^2 m^{LR}_{\tilde U})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{cs}}x_{\rm W}[T_3-3T_2](x_{\chi^\pm_i},x_{\tilde t_R},x_{\tilde c_L}) \\
&- \frac{\alpha_s(\mu_{\rm EW})m_t m_s m_{\chi^\pm_i}}{16\pi m^2_{\rm W}m_b s_\beta c_\beta}(U_+)^*_{1i}(U_+)_{2i}\frac{(\delta^2 m^{LR}_{\tilde U})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{cs}}x_{\rm W}[T_2-2T_1](x_{\chi^\pm_i},x_{\tilde t_R},x_{\tilde c_L}) \\
&- \frac{\alpha_s(\mu_{\rm EW})}{96\pi}(U_+)^*_{1i}(U_+)_{1i}\frac{(\delta^2 m^{LR}_{\tilde U})_{23}(\delta^2 m^{LR}_{\tilde U})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^\pm_i},x_{\tilde t_L},x_{\tilde t_R},x_{\tilde c_L}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})m_s m_{\chi^\pm_i}}{32\pi m_{\rm W}m_b c_\beta}(U_-)_{2i}(U_+)_{1i}\frac{(\delta^2 m^{LR}_{\tilde U})_{23}(\delta^2 m^{LR}_{\tilde U})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^\pm_i},x_{\tilde t_L},x_{\tilde t_R},x_{\tilde c_L}) \\
&- \frac{\alpha_s(\mu_{\rm EW})m_t}{96\pi m_{\rm W}s_\beta}(U_+)^*_{1i}(U_+)_{2i}\frac{(\delta^2 m^{LL}_{\tilde U})_{23}(\delta^2 m^{LR}_{\tilde U})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^\pm_i},x_{\tilde t_L},x_{\tilde t_R},x_{\tilde c_L}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})m_t m_s m_{\chi^\pm_i}}{16\pi m^2_{\rm W}m_b s_\beta c_\beta}(U_+)^*_{1i}(U_+)_{2i}\frac{(\delta^2 m^{LL}_{\tilde U})_{23}(\delta^2 m^{LR}_{\tilde U})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^\pm_i},x_{\tilde t_R},x_{\tilde t_L},x_{\tilde c_L}),
\end{aligned}$$

$$\begin{aligned}
C_{8,\chi^0}(\mu_{\rm EW}) &= \frac{\alpha_s(\mu_{\rm EW})}{96\pi c^2_{\rm W}}|\mathcal{N}^i_d|^2\frac{(\delta^2 m^{LL}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde s_L}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m_{\rm W}m_b c_{\rm W}c_\beta}(U_N)_{3i}\mathcal{N}^i_d\frac{(\delta^2 m^{LL}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde s_L}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m^2_{\rm W}c^2_\beta}(U_N)_{3i}(U_N)^*_{3i}\frac{(\delta^2 m^{RR}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde b_R},x_{\tilde s_R}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)_{1i}(U_N)_{3i}\frac{(\delta^2 m^{RR}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde b_R},x_{\tilde s_R}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})m_b}{96\pi m_{\rm W}c_{\rm W}c_\beta}\mathcal{N}^{i*}_d(U_N)_{3i}\frac{(\delta^2 m^{LR}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde b_R},x_{\tilde s_L}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m^2_{\rm W}c^2_\beta}(U_N)_{3i}(U_N)_{3i}\frac{(\delta^2 m^{LR}_{\tilde D})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde b_R},x_{\tilde s_L}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})m_s}{96\pi m_{\rm W}c_{\rm W}c_\beta}\mathcal{N}^i_d(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde D})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde s_R}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_b c^2_{\rm W}}(U_N)_{1i}\mathcal{N}^i_d\frac{(\delta^2 m^{LR}_{\tilde D})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde s_R}) \\
&- \frac{\alpha_s(\mu_{\rm EW})}{96\pi c^2_{\rm W}}|\mathcal{N}^i_d|^2\frac{(\delta^2 m^{LR}_{\tilde D})_{23}(\delta^2 m^{LR}_{\tilde D})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}[D_3-3D_2](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde b_R},x_{\tilde s_L}) \\
&- \frac{\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m_{\rm W}m_b c_{\rm W}c_\beta}(U_N)_{3i}\mathcal{N}^i_d\frac{(\delta^2 m^{LR}_{\tilde D})_{23}(\delta^2 m^{LR}_{\tilde D})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde b_L},x_{\tilde b_R},x_{\tilde s_L})
\end{aligned}$$

$$
\begin{aligned}
&-\frac{\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m_{\rm W}^2 c_\beta^2}(U_N)_{3i}(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&-\frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)_{1i}(U_N)_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&-\frac{\alpha_s(\mu_{\rm EW})m_b}{96\pi m_{\rm W}c_{\rm W}c_\beta}\mathcal{N}^{i*}_d(U_N)_{3i}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_L})\\
&-\frac{\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m_{\rm W}^2 c_\beta^2}(U_N)_{3i}(U_N)_{3i}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_L})\\
&-\frac{Q_d\alpha_s(\mu_{\rm EW})m_s}{96\pi m_{\rm W}c_{\rm W}c_\beta}\mathcal{N}^{i}_d(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&-\frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_b c_{\rm W}^2}(U_N)_{1i}\mathcal{N}^{i}_d\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_R}),
\end{aligned}
$$

$$
\begin{aligned}
C_{8,\tilde{g}}(\mu_{\rm EW})=&\frac{\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2}{576\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[23T_3-42T_2-54T_1](x_{\tilde{g}},x_{\tilde{b}_L},x_{\tilde{s}_L})\\
&+\frac{\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2 e^{-i\theta_g}}{96\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{g}}}{m_b}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}\left[23T_2-46T_1-9\frac{\partial\varrho_{1,1}}{\partial x_{\tilde{g}}}\right](x_{\tilde{g}},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&-\frac{\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2}{576\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[23D_3-42D_2-54D_1](x_{\tilde{g}},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_L})\\
&-\frac{\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2 e^{-i\theta_g}}{96\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{g}}}{m_b}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times\left[23D_2-46D_1-9\frac{\partial\varrho_{1,1}}{\partial x_{\tilde{g}}}\right](x_{\tilde{g}},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_R}),
\end{aligned}
$$

$$
\begin{aligned}
C_{8,\tilde{Z}_{BL}}(\mu_{\rm EW})=&\frac{\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2}{216\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\tilde{Z}_{BL}},x_{\tilde{b}_L},x_{\tilde{s}_L})\\
&+\frac{\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2 e^{-i\theta_{BL}}}{36\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{Z}_{BL}}}{m_b}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\tilde{Z}_{BL}},x_{\tilde{b}_L},x_{\tilde{s}_R})\\
&-\frac{\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2}{216\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}x_{\rm W}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}\times[D_3-3D_2](x_{\tilde{Z}_{BL}},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_L})\\
&-\frac{\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2 e^{-i\theta_{BL}}}{36\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{Z}_{BL}}}{m_b}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\tilde{Z}_{BL}},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_R}),
\end{aligned}
$$

$$
\begin{aligned}
C'_{8,\chi^\pm}(\mu_{\rm EW})=&\frac{\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m_{\rm W}^2 c_\beta^2}(U_-)_{2i}(U_-)^*_{2i}\frac{(\delta^2 m^{LL}_{\tilde{U}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^\pm_i},x_{\tilde{t}_L},x_{\tilde{c}_L})\\
&-\frac{\alpha_s(\mu_{\rm EW})m_{\chi^\pm_i}}{16\pi m_{\rm W}c_\beta}(U_-)^*_{2i}(U_+)^*_{1i}\frac{(\delta^2 m^{LL}_{\tilde{U}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^\pm_i},x_{\tilde{t}_L},x_{\tilde{c}_L})\\
&-\frac{\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m_{\rm W}^2 c_\beta^2}(U_-)_{2i}(U_-)^*_{2i}\frac{(\delta^2 m^{LR}_{\tilde{U}})_{23}(\delta^2 m^{LR}_{\tilde{U}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^\pm_i},x_{\tilde{t}_L},x_{\tilde{t}_R},x_{\tilde{c}_L})\\
&+\frac{\alpha_s(\mu_{\rm EW})m_{\chi^\pm_i}}{16\pi m_{\rm W}c_\beta}(U_-)^*_{2i}(U_+)^*_{1i}\frac{(\delta^2 m^{LR}_{\tilde{U}})_{23}(\delta^2 m^{LR}_{\tilde{U}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^\pm_i},x_{\tilde{t}_L},x_{\tilde{t}_R},x_{\tilde{c}_L}),
\end{aligned}
$$

$$
\begin{aligned}
C'_{8,\chi^0}(\mu_{\rm EW}) = {} & \frac{\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m_{\rm W}^2 c_\beta^2}(U_N)^*_{3i}(U_N)_{3i}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{s}_L}) \\
& + \frac{\alpha_s(\mu_{\rm EW})m_{\chi^0_i}}{16\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)^*_{3i}\mathcal{N}^{i*}_d\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{s}_L}) \\
& + \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}^2}{216\pi c_{\rm W}^2}(U_N)_{1i}(U_N)^*_{1i}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{s}_R}) \\
& + \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_s m_{\chi^0_i}}{24\pi m_{\rm W}m_b c_{\rm W}c_\beta}(U_N)^*_{1i}(U_N)^*_{3i}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{s}_R}) \\
& + \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_s}{144\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)^*_{1i}(U_N)_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{s}_L}) \\
& + \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_b c_{\rm W}}(U_N)^*_{1i}\mathcal{N}^{i*}_d\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{s}_L}) \\
& + \frac{\alpha_s(\mu_{\rm EW})m_b}{96\pi m_{\rm W}c_\beta}(U_N)_{1i}(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_3-3T_2](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{s}_R}) \\
& + \frac{\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m_{\rm W}^2 c_\beta^2}(U_N)^*_{3i}(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}}{\Lambda^2_{NP}V_{tb}V^*_{ts}}x_{\rm W}[T_2-2T_1](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{s}_R}) \\
& - \frac{\alpha_s(\mu_{\rm EW})m_b m_s}{96\pi m_{\rm W}^2 c_\beta^2}(U_N)^*_{3i}(U_N)_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_L}) \\
& - \frac{\alpha_s(\mu_{\rm EW})m_{\chi^0_i}}{16\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)^*_{3i}\mathcal{N}^{i*}_d\frac{(\delta^2 m^{LR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_L}) \\
& - \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}^2}{216\pi c_{\rm W}^2}(U_N)_{1i}(U_N)^*_{1i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_R}) \\
& - \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_s m_{\chi^0_i}}{24\pi m_{\rm W}m_b c_{\rm W}c_\beta}(U_N)^*_{1i}(U_N)^*_{3i}\frac{(\delta^2 m^{LR}_{\tilde{D}})^*_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_R}) \\
& - \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_s}{144\pi m_{\rm W}c_{\rm W}c_\beta}(U_N)^*_{1i}(U_N)_{3i}\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_3-3D_2](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_L}) \\
& - \frac{\alpha_s(\mu_{\rm EW})s_{\rm W}m_{\chi^0_i}}{24\pi m_b c_{\rm W}}(U_N)^*_{1i}\mathcal{N}^{i*}_d\frac{(\delta^2 m^{LL}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_R},x_{\tilde{b}_L},x_{\tilde{s}_L}) \\
& - \frac{\alpha_s(\mu_{\rm EW})m_b}{24\pi m_{\rm W}c_\beta}(U_N)_{1i}(U_N)^*_{3i}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times\{D_3-3D_2\}(x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_R}) \\
& - \frac{\alpha_s(\mu_{\rm EW})m_s m_{\chi^0_i}}{16\pi m_{\rm W}^2 c_\beta^2}(U_N)^*_{3i}(U_N)^*_{3i}\frac{(\delta^2 m^{RR}_{\tilde{D}})_{23}(\delta^2 m^{LR}_{\tilde{D}})^*_{33}}{\Lambda^4_{NP}V_{tb}V^*_{ts}}x_{\rm W}\times[D_2-2D_1](x_{\chi^0_i},x_{\tilde{b}_L},x_{\tilde{b}_R},x_{\tilde{s}_R}),
\end{aligned}
$$

$$\begin{aligned}
C'_{8,\tilde{g}}(\mu_{\rm EW}) &= \frac{\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2}{576\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m_{\tilde{D}}^{RR})_{23}}{\Lambda_{NP}^2 V_{tb}V_{ts}^*}x_{\rm W}[23T_3 - 42T_2 - 54T_1](x_{\tilde{g}}, x_{\tilde{b}_R}, x_{\tilde{s}_R}) \\
&+ \frac{\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2 e^{i\theta_g}}{96\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{g}}}{m_b}\frac{(\delta^2 m_{\tilde{D}}^{LR})_{23}}{\Lambda_{NP}^2 V_{tb}V_{ts}^*}x_{\rm W}\left[23T_2 - 46T_1 - 9\frac{\partial \varrho_{1,1}}{\partial x_{\tilde{g}}}\right](x_{\tilde{g}}, x_{\tilde{b}_R}, x_{\tilde{s}_L}) \\
&- \frac{\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2}{576\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m_{\tilde{D}}^{LR})_{23}^*(\delta^2 m_{\tilde{D}}^{LR})_{33}}{\Lambda_{NP}^4 V_{tb}V_{ts}^*}x_{\rm W}\times[23D_3 - 42D_2 - 54D_1](x_{\tilde{g}}, x_{\tilde{b}_R}, x_{\tilde{b}_L}, x_{\tilde{s}_R}) \\
&- \frac{\alpha_s^2(\mu_{\rm EW})s_{\rm W}^2 e^{i\theta_g}}{96\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{g}}}{m_b}\frac{(\delta^2 m_{\tilde{D}}^{LL})_{23}(\delta^2 m_{\tilde{D}}^{LR})_{33}^*}{\Lambda_{NP}^4 V_{tb}V_{ts}^*}x_{\rm W}\times\left[23D_2 - 46D_1 - 9\frac{\partial \varrho_{1,1}}{\partial x_{\tilde{g}}}\right](x_{\tilde{g}}, x_{\tilde{b}_L}, x_{\tilde{b}_R}, x_{\tilde{s}_L}),
\end{aligned}$$

$$\begin{aligned}
C'_{8,\tilde{Z}_{BL}}(\mu_{\rm EW}) &= \frac{\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2}{216\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m_{\tilde{D}}^{RR})_{23}}{\Lambda_{NP}^2 V_{tb}V_{ts}^*}x_{\rm W}[T_3 - 3T_2](x_{\tilde{Z}_{BL}}, x_{\tilde{b}_R}, x_{\tilde{s}_R}) \\
&+ \frac{\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2 e^{i\theta_{BL}}}{36\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{Z}_{BL}}}{m_b}\frac{(\delta^2 m_{\tilde{D}}^{LR})_{23}}{\Lambda_{NP}^2 V_{tb}V_{ts}^*}x_{\rm W}[T_2 - 2T_1](x_{\tilde{Z}_{BL}}, x_{\tilde{b}_R}, x_{\tilde{s}_L}) \\
&- \frac{\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2}{216\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{(\delta^2 m_{\tilde{D}}^{LR})_{23}^*(\delta^2 m_{\tilde{D}}^{LR})_{33}}{\Lambda_{NP}^4 V_{tb}V_{ts}^*}x_{\rm W}[D_3 - 3D_2](x_{\tilde{Z}_{BL}}, x_{\tilde{b}_R}, x_{\tilde{b}_L}, x_{\tilde{s}_R}) \\
&- \frac{\alpha_s(\mu_{\rm EW})\alpha_{BL}s_{\rm W}^2 e^{i\theta_{BL}}}{36\pi\alpha_{\rm EW}(\mu_{\rm EW})}\frac{m_{\tilde{Z}_{BL}}}{m_b}\frac{(\delta^2 m_{\tilde{D}}^{LL})_{23}(\delta^2 m_{\tilde{D}}^{LR})_{33}^*}{\Lambda_{NP}^4 V_{tb}V_{ts}^*}x_{\rm W}[D_2 - 2D_1](x_{\tilde{Z}_{BL}}, x_{\tilde{b}_L}, x_{\tilde{b}_R}, x_{\tilde{s}_L}), \qquad \text{(B1)}
\end{aligned}$$

where the couplings in the expression are

$$\begin{aligned}
&\mathcal{N}_d^i = \frac{1}{3}(U_N)_{1i}s_{\rm W} - (U_N)_{2i}c_{\rm W}, \qquad \mathcal{N}_l^i = (U_N)_{1i}s_{\rm W} + (U_N)_{2i}c_{\rm W}, \qquad \mathcal{C}_{ij}^L = 2(c_{\rm W}^2 - s_{\rm W}^2)\delta_{ij} + (U_-)_{1i}^*(U_-)_{1j}, \\
&\mathcal{C}_{ij}^R = 2(c_{\rm W}^2 - s_{\rm W}^2)\delta_{ij} + (U_+)_{1i}(U_+)_{1j}^*, \qquad B_H^k = \cos\beta(Z_H)_{1k} - \sin\beta(Z_H)_{2k}, \\
&(\zeta_{LL}^u)_k = \left(1 - \frac{4}{3}s_{\rm W}^2\right)B_H^k + \frac{2m_u^2 c_{\rm W}^2}{m_{\rm W}^2 s_\beta}(Z_H)_{1k}, \qquad (\zeta_{RR}^u)_k = B_H^k + \frac{3m_u^2 c_{\rm W}^2}{2m_{\rm W}^2 s_{\rm W}^2 s_\beta}(Z_H)_{1k}, \\
&(\zeta_{LL}^d)_k = \left(1 - \frac{2}{3}s_{\rm W}^2\right)B_H^k - \frac{2m_d^2 c_{\rm W}^2}{m_{\rm W}^2 c_\beta}(Z_H)_{2k}, \qquad (\zeta_{RR}^d)_k = B_H^k - \frac{3m_d^2 c_{\rm W}^2}{m_{\rm W}^2 s_{\rm W}^2 c_\beta}(Z_H)_{2k}, \\
&(\xi_k^{\chi^\pm})_{ij} = (Z_H)_{1k}(U_-)_{1i}(U_+)_{2j} + (Z_H)_{2k}(U_-)_{2i}(U_+)_{1j}, \\
&(\xi_k^{\chi^0})_{ij} = [(Z_H)_{1k}(U_N)_{3j} - (Z_H)_{2k}(U_N)_{4j}][(U_N)_{1i}s_{\rm W} - (U_N)_{2i}c_{\rm W}], \\
&(\eta_k^{\chi^\pm})_{ij} = (Z_{H^\pm})_{1k}(U_-)_{1i}(U_+)_{2j} + (Z_{H^\pm})_{2k}(U_-)_{2i}(U_+)_{1j}, \\
&(\eta_k^{\chi^0})_{ij} = [(Z_{H^\pm})_{1k}(U_N)_{3j} - (Z_{H^\pm})_{2k}(U_N)_{4j}][(U_N)_{1i}s_{\rm W} - (U_N)_{2i}c_{\rm W}], \\
&A_M^{ki} = (Z_H)_{1k}(Z_{H^\pm})_{1i} - (Z_H)_{2k}(Z_{H^\pm})_{2i}, \\
&A_{u\mu}^k = A_u(Z_H)_{1k} + \mu^*(Z_H)_{2k}, \qquad A_{d\mu}^k = A_d(Z_H)_{2k} + \mu^*(Z_H)_{1k}, \\
&P_{u\mu}^k = A_u(Z_{H^\pm})_{1k} - \mu^*(Z_{H^\pm})_{2k}, \qquad P_{d\mu}^k = A_d(Z_{H^\pm})_{2k} - \mu^*(Z_{H^\pm})_{1k}. \qquad \text{(B2)}
\end{aligned}$$

APPENDIX C: THE FUNCTIONS

The functions in the Wilson coefficients of $\gamma-$ and $g-$ penguin operators are

$$\begin{aligned} T_1(x,y,z) &= \left[\frac{\partial \varrho_{1,1}}{\partial y} + \frac{\partial \varrho_{1,1}}{\partial z}\right](x,y,z), \\ T_2(x,y,z) &= \left[\frac{\partial^2 \varrho_{2,1}}{\partial y^2} + 2\frac{\partial^2 \varrho_{2,1}}{\partial y \partial z} + \frac{\partial^2 \varrho_{2,1}}{\partial z^2}\right](x,y,z), \\ T_3(x,y,z) &= \left[\frac{\partial^3 \varrho_{3,1}}{\partial y^3} + 3\frac{\partial^3 \varrho_{3,1}}{\partial y^2 \partial z} + 3\frac{\partial^3 \varrho_{3,1}}{\partial y \partial z^2} + \frac{\partial^3 \varrho_{3,1}}{\partial z^3}\right](x,y,z), \end{aligned} \tag{C1}$$

and

$$\begin{aligned} D_1(x,y,z,u) &= \left[\frac{\partial \varrho_{1,1}}{\partial y} + \frac{\partial \varrho_{1,1}}{\partial z} + \frac{\partial \varrho_{1,1}}{\partial u}\right](x,y,z,u), \\ D_2(x,y,z,u) &= \left[\frac{\partial^2 \varrho_{2,1}}{\partial y^2} + 2\frac{\partial^2 \varrho_{2,1}}{\partial y \partial z} + 2\frac{\partial^2 \varrho_{2,1}}{\partial y \partial u} + \frac{\partial^2 \varrho_{2,1}}{\partial z^2} + 2\frac{\partial^2 \varrho_{2,1}}{\partial z \partial u} + \frac{\partial^2 \varrho_{2,1}}{\partial u^2}\right](x,y,z,u), \\ D_3(x,y,z,u) &= \left[\frac{\partial^3 \varrho_{3,1}}{\partial y^3} + 3\frac{\partial^3 \varrho_{3,1}}{\partial y^2 \partial z} + 3\frac{\partial^3 \varrho_{3,1}}{\partial y^2 \partial u} + 3\frac{\partial^3 \varrho_{3,1}}{\partial y \partial z^2} + 6\frac{\partial^3 \varrho_{3,1}}{\partial y \partial z \partial u} + 3\frac{\partial^3 \varrho_{3,1}}{\partial y \partial u^2} \right. \\ &\quad \left. + \frac{\partial^3 \varrho_{3,1}}{\partial z^3} + 3\frac{\partial^3 \varrho_{3,1}}{\partial z^2 \partial u} + 3\frac{\partial^3 \varrho_{3,1}}{\partial z \partial u^2} + \frac{\partial^3 \varrho_{3,1}}{\partial u^3}\right](x,y,z,u) \end{aligned} \tag{C2}$$

with

$$\varrho_{m,n}(x_1, x_2, \cdots, x_N) = \sum_{i=1}^{N} \frac{x_i^m \ln^n x_i}{\prod_{j\neq i}^{N}(x_i - x_j)}. \tag{C3}$$

[1] D. Asner et al. (Heavy Flavor Average Group Collaboration), arXiv:1010.1589.
[2] M. Misiak et al., Phys. Rev. Lett. **98**,022002 (2007).
[3] M. Misiak and M. Steinhauser, Nucl. Phys. **B764**, 62 (2007).
[4] C. Greub, T. Hurth, and D. Wyler, Phys. Rev. D **54**, 3350 (1996).
[5] C. Greub and P. Liniger, Phys. Lett. B **494**, 237 (2000); Phys. Rev. D **63**, 054025 (2001).
[6] A. Buras, M. Misiak, and J. Urban, Nucl. Phys. **B586**, 397 (2000).
[7] E. Gabrielli, A. Masiero, and L. Silvestrini, Phys. Lett. B **374**, 80 (1996).
[8] M. Ciuchini, G. Degrassi, P. Gambino, and G. F. Giudice, Nucl. Phys. **B527**, 21 (1998).
[9] P. Ciafaloni, A. Romanino, and A. Strumia, Nucl. Phys. **B524**, 361 (1998).
[10] F. Borzumati and C. Greub, Phys. Rev. D **58**, 074004 (1998).
[11] S. Bertolini, F. Borzumati, A. Masiero, and G. Ridolfi, Nucl. Phys. **B353**, 591 (1991).
[12] R. Barbieri and G. F. Giudice, Phys. Lett. B **309**, 86 (1993).
[13] F. Borzumati, C. Greub, T. Hurth, and D. Wyler, Phys. Rev. D **62**, 075005 (2000).
[14] M. Causse and J. Orloff, Eur. Phys. J. C **23**, 749 (2002).
[15] S. Prelovsek and D. Wyler, Phys. Lett. B **500**, 304 (2001).
[16] M. Ciuchini, G. Degrassi, P. Gambino, and G. F. Giudice, Nucl. Phys. **B534**, 3 (1998).
[17] S. Bertolini and J. Matias, Phys. Rev. D **57**, 4197 (1998).
[18] W. N. Cottingham, H. Mehrban, and I. B. Whittingham, Phys. Rev. D **60**, 114029 (1999).
[19] G. Barenboim and M. Raidal, Phys. Lett. B **457**, 109 (1999).
[20] J. L. Hewett and D. Wells, Phys. Rev. D **55**, 5549 (1997).
[21] A. Ali, P. Ball, L. T. Handoko, and G. Hiller, Phys. Rev. D **61**, 074024 (2000).
[22] A. Masiero and L. Silvestrini, arXiv:hep-ph/9709244; arXiv:hep-ph/9711401.
[23] M. Ciuchini et al., J. High Energy Phys. 10 (1998) 008.
[24] R. Contion and I. Scimemi, Eur. Phys. J. C **10**, 347 (1999).
[25] F. Krauss and G. Soff, Nucl. Phys. **B633**, 237 (2002).

[26] Tai-Fu Feng, Xue-Qian Li, Wen-Gan Ma, and Feng Zhang, Phys. Rev. D **63**, 015013 (2001).
[27] S. Chatrchyan *et al.* (CMS Collaboration), Phys. Lett. B **716**, 30 (2012).
[28] G. Aad *et al.* (ATLAS Collaboration), Phys. Lett. B **716**, 1 (2012).
[29] B. Adeva *et al.* (LHCb Collaboration), arXiv:0912.4179.
[30] T. Aushev *et al.*, arXiv:1002.5012.
[31] B. O'Leary *et al.* (SuperB Collaboration), arXiv:1008.1541.
[32] R. Barbier *et al.*, Phys. Rep. **420**, 1 (2005); C.-H. Chang and T.-F. Feng, Eur. Phys. J. C **12**, 137 (2000).
[33] P. Fileviez Perez and S. Spinner, Phys. Lett. B **673**, 251 (2009).
[34] V. Barger, P. Fileviez Perez, and S. Spinner, Phys. Rev. Lett. **102**, 181802 (2009).
[35] P. Fileviez Perez and S. Spinner, Phys. Rev. D **80**, 015004 (2009).
[36] P. Fileviez Perez and S. Spinner, J. High Energy Phys. 04 (2012) 118.
[37] V. Barger, P. Fileviez Perez, and S. Spinner, Phys. Lett. B **696**, 509 (2011).
[38] D. K. Ghosh, G. Senjanovic, and Y. Zhang, Phys. Lett. B **698**, 420 (2011).
[39] C.-H. Chang, T.-F. Feng, Y.-L. Yan, H.-B. Zhang, and S.-M. Zhao, Phys. Rev. D **90**, 035013 (2014).
[40] J. Hamann, S. Hannestad, G. Raffelt, I. Tamborra, and Y. Y. Y. Wong, Phys. Rev. Lett. **105**, 181301 (2010).
[41] W. Altmannshofer, P. Ball, A. Bharucha, A. J. Buras, D. M. Straub, and M. Wick, J. High Energy Phys. 01 (2009) 019.
[42] J. S. Hagelin, S. Kelley, and T. Tanaka, Nucl. Phys. **B415**, 293 (1994).
[43] P. Gambino, M. Gorbahn, and U. Haisch, Nucl. Phys. **B673**, 238 (2003).
[44] E. Lunghi and J. Matias, J. High Energy Phys. 04 (2007) 058.
[45] H. M. Asatrian and A. Ioannisian, Phys. Rev. D **54**, 5642 (1996); M. Ciuchini, E. Gabrielli, and G. F. Giudice, Phys. Lett. B **388**, 353 (1996); S. Baek and P. Ko, Phys. Rev. Lett. **83**, 488 (1999); A. L. Kagan and M. Neubert, Phys. Rev. D **58**, 094012 (1998); K. Kiers, A. Soni, and G. -H. Wu, Phys. Rev. D **62**, 116004 (2000).
[46] S. Nishida *et al.* (Belle Collaboration), Phys. Rev. Lett. **93**, 031803 (2004); B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **101**, 171804 (2008).
[47] P. Ball, G. W. Jones, and R. Zwicky, Phys. Rev. D **75**, 054004 (2007).
[48] K. A. Olive *et al.* (Particle Data Group), Chin. Phys. C **38**, 090001 (2014).